Technologies for Exploration and the Pursuit of Innovation: Three Essays on Strategic Knowledge Creation and Schumpeterian Competition

by

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Abstract

Schumpeter introduced a new perspective on the nature of competition in market economies–one dominated by innovation and the dynamics of ‘creative destruction’. In so doing, he opened up new perspectives on the nature of competition itself. At a more macro-level, the Schumpeterian perspective focuses on the role of innovation in transforming existing industries and markets and constructing new ones and shaping the competitive battles between firms. But perhaps even more importantly, where older models primarily focused on competition in product or factor markets, the Schumpeterian perspective forces consideration of the processes involved in invention, discovery, and capability creation; processes that underlie innovation and the dynamics of creative destruction. From this perspective, competition in markets is complemented by activities focused on knowledge creation and capability creation. For firms, knowledge creation becomes a strategic end unto itself; for scholars, the phenomena of knowledge creation comes center stage in the fields of strategy, entrepreneurship, and innovation.

The essays presented here are focused on a set of technologies for exploration and innovation that underwrite Schumpeterian competition. The first essay proposes a theory of strategic domain pioneering that seeks to explain how organizations can develop new domains of scientific, engineering, and/or technological knowledge for strategic ends. The second essay examines how management control systems influence the construction of new organizational capabilities by influencing the outputs of an organization’s dynamic capabilities. The third essay examines how management control systems influence the pursuit of exploration- and exploitation-related activities at the organizational level of analysis. The focus of all three is on the fundamental processes of knowledge creation that underwrite the process of innovation and capability creation at the core of Schumpeterian competition–processes at the very core of the fields of strategy, innovation, and entrepreneurship.

Keywords: strategic knowledge creation; technologies for exploration; innovation, Schumpeterian competition; dynamic capabilities; management control systems

Dedication

For Jade – for everything

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The dissertation is an intensely personal creation, and yet, at the same time, its shape and contours are influenced in so many ways by so many different people, events, and circumstances. How does one untangle all the specific debts owed in such a path dependent processes?

At the outset, I would like to especially thank Ian McCarthy, Tom Lawrence, and Elicia Maine for their insight, support, advice, enthusiasm, and patience as I pursued the various lines of research that ultimately culminated in this dissertation. Ian has written about linear, recursive, and chaotic new product development paradigms – my path in this project has exemplified the chaotic regime. Ian, Tom, and Elicia have each played an important role in the evolution of my thinking and in the direction of my research. While it may not always be immediately apparent, their fingerprints are all over the end result. And while I believe that it is a much better project as a result, I am the first to note that the faults herein are mine and mine alone.

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1. Introduction

The three essays presented here explore a set of themes centered on the dynamics of innovation and the pursuit of advantage. Collectively, they address several prominent areas of the strategic management literature, including strategic knowledge creation, dynamic capabilities, and the processes involved in managing exploration and exploitation processes at the organizational level. They are, however, connected by a single underlying preoccupation. In different ways, each essay is ultimately concerned with the logic and mechanics of competition via innovation.

The common starting point is Schumpeter's contention that competition in the capitalist system is driven by processes of creative destruction born of innovation. In an oft-cited passage, Schumpeter argues:

> The first thing to go is the traditional conception of the modus operandi of competition….in capitalist reality as distinguished from its textbook picture, it is not that kind of competition which counts but the competition from the new commodity, the new technology, the new source of supply, the new type of organization…competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of existing firms but at their foundations and their very lives. This kind of competition is as much more effective than the other as a bombardment is in comparison with forcing a door (1976: 84).

The work collected here, then, is primarily an investigation into the processes of invention and innovation that are at the core of the Schumpeterian conception of competition, where Schumpeterian competition is understood as competition that is driven by introduction of product, process, and/or technological innovation with the aim of transforming existing industries and markets or the pioneering of novel industries and markets The objective, though, is to move beyond the simple acknowledgment of the importance of innovation in determining competitive contests frequently encountered in the management and strategy literatures and to get on with the important work of explaining how this kind of competition actually works. The essays presented here seek to do just that by exploring aspects of strategic knowledge creation, the management of invention and discovery, and capability construction and reconfiguration that are central to the pursuit of innovation within a Schumpeterian perspective on competition. In that respect, the essays presented here are clearly just part of a much larger project of central importance to the field of strategy.

The first essay, *Strategic domain pioneering and nonlocal action*, introduces a model of strategic knowledge creation that explicates the processes involved in pioneering novel domains of scientific, engineering, and technological knowledge that underwrite innovation and which, in so doing, open up the possibilities for novel strategic action and the pursuit of competitive advantage.

Schumpeter (1976) stresses the importance of competition via the new commodity or the new technology that radically breaks with existing industry norms. These kinds of innovations do not arise fully formed – *ex nihilo* – out of nothing, however. When we start peeling back the layers of causality, I argue that we find a core set of knowledge creation processes in play. More specifically, the contention here is that innovative products and technologies are ultimately underwritten by scientific, engineering, and technological knowledge and that the processes of invention and knowledge creation are at the foundation of Schumpeterian modes of competition. Understanding how scientific, engineering, and technological knowledge creation works, then, is paramount for working out the mechanisms that underwrite Schumpeterian competition. This is what the theory of strategic knowledge creation introduced in this essay seeks to accomplish. As developed here, the theory of strategic domain pioneering focuses on explaining the processes that underwrite organizational efforts to develop new branches of proprietary scientific, engineering, and technical knowledge and expertise that extend the current frontiers of knowledge – in fields like advanced materials and nanotechnology, biotechnology, quantum computing, or artificial intelligence and robotics – and that enable firms to ultimately develop and deploy new products, services, and technologies in the pursuit of competitive advantage and the kinds of industry and market transformation at the heart of Schumpeterian modes of competition.

Schumpeterian competition implicitly stresses the importance of *nonlocal action* – of strategic moves that radical transform the existing competitive landscape that stem from innovations that create novel possibilities for strategic action. In the language of fitness landscapes (c.f., Gavetti, 2011), nonlocal action is understood as strategic moves that provide access to and/or (perhaps more accurately) create new positions in the competitive landscape that are distant from those accessible to rivals on the basis of their current stocks of knowledge and resource endowments. In the fitness landscape framework, the distance between any two points on the landscape is taken as reflection of an underlying similarity on some important dimension of interest.

As applied to the strategy literature (e.g., in Gavetti, 2011), the dimensions of interest are typically understood to include organizational design, knowledge, resource and capability, and strategic factors that capture the different choices about how firms can be designed and managed, how they are positioned strategically, what kinds of capabilities they deploy in their pursuit of advantage, what kind of business models they pursue, the knowledge and expertise they possess or have access to, etc. In this context, local action can be thought of incremental changes in a firm's current resource endowments, knowledge and expertise, capabilities, strategic positioning, or organizational design features. Nonlocal action, in an analogous fashion, is taken to mean more substantial changes across of these kinds of underlying features. In practical terms, this could mean a firm moving from a strategy focused on niche production of very high-end, highly differentiated products based on a strategy of developing pioneering new products to a strategy focused on serving the mass markets based on the pursuit of cost advantages through scale or a transition from a vertically integrated approach to production toward a model based on a focus on the establishment of a few core competences with the balance of activities outsourced to other market participants.

The second essay, *Leveraging dynamic capabilities: A contingent management control system approach*, introduces a framework illustrating how the four types of management control systems in Simons' (1994) typology can be used in conjunction with an organization's other dynamic capabilities (Teece, 2007; Augier and Teece, 2009) to orchestrate the development of new organizational capabilities in the pursuit of innovation.

Management control systems, as defined by Simons (1995), are the inter-related set of formal and informal organizational systems, routines, and procedures that management uses to define goals and objectives for individuals, teams and business units within the firm, define the bounds of acceptable activity, search out and establish consensus about opportunities and threats, and measure progress against goals (c.f., McCarthy and Gordon, 2011), They are the processes and systems which management uses to coordinate and direct activity throughout the organization.

As March (1991) points out, given limited resources, organizations must balance the normally conflicting imperatives of enhancing near-term performance in order to avoid imminent collapse with the need to invest in uncertain innovation if they are to survive – and perhaps even prosper – in the future. Limited resources, therefore, entails an inherent trade-off between allocating scarce 'orchestration processes' towards building incremental capabilities to enhance the organization's current position versus allocating the same resources towards creating novel organizational competencies in the pursuit of advantages that accrue to successful innovation. In March's terms, firms must balance the imperatives of exploitation and exploration, where exploitation entails activities centered on improving on, and adding to, the firm's current offerings, business models, knowledge stocks, and underlying resource and capability endowments whereas exploration entails a focus on developing new knowledge and areas of expertise, the pursuit of product, service, and process innovations, the pioneering of new capabilities and resource endowments, and the development of new markets and industries. In the most general terms, as defined by March:

> Exploitation refers to the utilization and refinement of what is known. It is reflected in efforts toward efficiency, standardization, accountability, and control. Exploration is the pursuit of what is not known. It is reflected in efforts to generate and experiment with deviant procedures and new possibilities (2010: 24).

Where exploitation entails building on existing organizational capabilities to enhance the firm's current positioning; exploration involves pioneering new sources of advantage through innovation. One way firms pursue exploration is via dynamic capabilities: organizational routines deployed to create new capabilities (Winter, 2003; Teece, 2007; Augier and Teece, 2009) that underwrite the firm's pursuit of novel positioning. Seen this way, dynamic capabilities constitute a technology for exploration and nonlocal action. More specifically, this essay argues that management can use belief and interactive control systems to orient capability orchestration processes towards more radical departures from current resource and capability configurations, while boundary and diagnostic control systems can be employed to orient the orchestration of more incremental reconfigurations of existing configurations of resources and capabilities. This framework, in effect, illustrates how the outputs of dynamic capabilities themselves can be dynamically tuned between more radical and more incremental ends in the pursuit of advantage through innovation. As such this framework represents a managerial technology for Schumpeterian competition that deeply complements the framework for strategic domain pioneering introduced in the first essay.

The third essay, *Achieving contextual ambidexterity in R&D organizations: A management control system approach*, introduces a framework for using management control systems to influence the kinds of R&D outputs that internal R&D groups generate.

Here again, we see the familiar dilemma between exploitation and exploration. On the one hand, R&D groups are asked to build on current knowledge positions to reinforce existing stocks of expertise and capability; on the other hand, breakthrough innovation depends on pioneering breakthrough knowledge, which requires exploration rather than exploitation. Balancing these conflicting demands on R&D effort and resources is typically regarded as problematic.

Building on the taxonomy of management control systems introduced by Simons (1994), the framework developed in this essay illustrates how the pursuit of breakthrough innovation can be driven by belief and interactive control systems at the same time that boundary and diagnostic control systems act to enhance the generation of incremental innovation within the same R&D group – establishing what has been termed *contextual ambidexterity*. In competition dominated by innovation, the ability to dynamically tune the balance of incremental versus radical R&D knowledge outputs constitutes an important and powerful strategic weapon. The R&D management processes outlined in this essay, then, comprise another core managerial technology for Schumpeterian competition.

Taken together, the three essays introduced here offer up a more comprehensive understanding of the nature of Schumpeterian competition while, at the same time, providing a powerful set of managerial technologies for driving Schumpeterian competition and the pursuit of advantage. As such, they constitute an important advance to theory in strategic management, innovation, and entrepreneurship.

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2. Strategic Domain Pioneering and Nonlocal Action

2.1. ABSTRACT

When rival firms adopt similar strategies, competition drives down returns and compresses variance. One important source of advantage arises from Schumpeterian innovation and the ability to undertake nonlocal action. The question arises, can nonlocal action be strategic? One prominent answer, typically associated with the evolutionary school of strategy, suggests no, asserting that innovation ultimately is driven by luck and serendipity. This paper suggests otherwise, arguing that nonlocal action can be strategic because firms can purposefully pioneer new domains of scientific, engineering, and technological knowledge in the pursuit of Schumpeterian innovation in products, technologies, and modes of production. To this end, a new theory of strategic domain pioneering is introduced. The idea of strategic domain pioneering as a 'technology for exploration and nonlocal action' and some implications for the theory of organizational and managerial control systems and the locus of knowledge are discussed in the final section. In orientation, the theory of strategic domain pioneering introduced here is congruent with the new behavioral theory of strategy forwarded by Gavetti (2011). By showing how knowledge creation processes can be actively managed for strategic ends, this paper expands upon and extends Gavetti's nascent framework in new directions.

2.2. INTRODUCTION

Where earlier work in strategic management sought out the sources of sustained competitive advantage (e.g., Porter, 1980, Barney, 1991, Peteraf, 1993), recent scholarship has tended toward the view that sustainable competitive advantage is, at best, exceedingly rare and that sources of advantage – when discovered, created, and effectively deployed – are typically fleeting and temporary (D'Aveni, Battista Dagnino, and Smith, 2010). Accordingly, attention has shifted from strategies for acquiring and maintaining the kinds of valuable, rare, non-imitable, and non-substitutable resources (Barney, 1991; see also Barney 1986a; Amit and Schoemaker, 1993) that the Resource-based View (RBV) identified as the foundation of durable sources of competitive advantage towards an interest in strategies and practices oriented around the continual creation of new sources of temporary advantage under conditions of near constant upheaval and innovation (e.g., Nickerson, Silverman, and Zenger, 2007; Teece, 2007; Augier and Teece, 2009) that are more responsive to the demands of dynamic environments where advantage must be continually sought, fought for, and renewed.

This conception of strategic action is rooted in the tradition of the Schumpeterian conception of competition characterized by creative destruction driven by the introduction of new technologies and new products, the pioneering of new markets and industries, and the introduction of new modes of organization and production (Schumpeter, 1976). Advantage, in the Schumpeterian analysis of competition, arises when a firm is able to introduce novel technologies or products that overturn existing markets and industries and/or create novel markets and industries that are difficult for rivals to emulate over the near- to intermediate-term.

The Schumpeterian conception of competition stresses the importance of innovation for competitive advantage. In particular, the focus is on radical, or revolutionary, innovations that enable a firm to compete in ways that rivals cannot because they lack the requisite knowledge. Advantage tends to be ephemeral when new products, processes, or technologies can be quickly replicated or countered by a firm's rivals. The underlying premise is that when innovations build on knowledge closely related to prior knowledge, they are more easily replicated or countered by rival firms as they are 'easier to reach' from the existing stocks of knowledge at the disposal of (or available to) rival firms. In the language of fitness landscapes (c.f., Gavetti, 2011), the strategic imperative is the pursuit of what can be termed *nonlocal action* – strategic moves that provide access to and/or create new positions in the competitive landscape that are distant from those accessible to rivals on the basis of their current stocks of knowledge and resource endowments.

While the strategic imperative of nonlocal action – drawing, as it does, on long-established conceptions of radical/revolutionary innovation, Schumpeterian competition, and competitive landscapes in the strategy literature – is well defined conceptually and established in managerial practice (as suggested by the popularity of works like *Blue Ocean Strategy* (Kim and Mauborgne, 2005), the processes of knowledge creation involved in the kinds of invention and discovery that underwrite the development of new products, services, and technologies at the heart of the Schumpeterian mode of competition remain opaque. More specifically, neither the dominant paradigm of knowledge creation in the management literature, exemplified by the seminal works of Cohen and Levinathal (1990), Nonaka (1994), and Nickerson and Zenger (2004), nor the main alternatives to the dominant theories of knowledge creation presented to date (see for example Cook and Brown, 1999; Gourlay, 2006), have had an explicit focus on the fundamental knowledge creation processes at work in pioneering new domains of scientific, engineering, and technological knowledge that underwrite Schumpeterian competition and nonlocal action. This presents both a challenge and an opportunity for theory; one that I address in this paper.

More specifically, this paper seeks to address this theoretical gap by proposing a theory of scientific, engineering, and technological knowledge creation that firm's can deploy in the pursuit of Schumpeterian competition and nonlocal action. In the framework introduced here, novel products, services, and technologies introduced into the marketplace are understood as the end stage of a series of processes involved in knowledge creation, incubation, and deployment (c.f., Hamel and Prahalad, 1994; Nickerson, Silverman, and Zenger, 2007; Maine, 2008; Gavetti, 2011). The focus of the theory of strategic knowledge creation forwarded here is on the 'front-end' of this stream of inter-related activities, i.e, the processes involved in creating new pools of knowledge and expertise in novel domains of science, engineering, and technology that form the foundation from which the firm's new products, services, and technologies are ultimately derived. The theory of *strategic domain pioneering* introduced in this paper is concerned with the processes that underwrite organizational efforts to develop new branches of proprietary scientific, engineering, and technical knowledge and expertise that extend the current frontiers of knowledge – in fields like advanced materials and nanotechnology, biotechnology, quantum computing, or artificial intelligence and robotics – and which ultimately enable these firms to develop and deploy new products, services, and technologies in the pursuit of competitive advantage and the kinds of industry and market transformation at the heart of Schumpeterian modes of competition.

A particularly audacious example of strategic domain pioneering in practice can be found in the pioneering work on synthetic biology undertaken by the J. Craig Venter Institute (JCVI) and the closely associated Synthetic Genomics, Inc., a firm that Venter created to commercialize the basic science research conducted at the JCVI (Hylton, 2012). As Hylton notes, together, JCVI and Synthetic Genomics comprise approximately 500 scientists, with backgrounds in many different disciplines, focused on developing the emerging field of synthetic biology and harnessing this knowledge across a wide range of industrial applications – from energy and food production to novel therapeutics for medicine. One of the main goals of synthetic biology projects like those represented by Venter's JCVI and Synthetic Genomics, Inc. is to generate the knowledge, expertise, and capabilities required to design and build bespoke organisms – i.e., organisms engineered by scientists as opposed to having been evolved in nature – whose properties have been engineered to work in desired ways, e.g., working as micro-factories producing hydrocarbons or vaccines (Hylton, 2012). The potential markets for these applications are vast, but success is far from certain given the current state of scientific knowledge. Success, here, depends – at least in part – on the ability of JCVI and Synthetic Genomics to develop novel scientific, technological, and engineering knowledge and expertise – on strategic domain pioneering. The primary objective of this paper is to explain how these kinds of strategic domain pioneering knowledge creation processes operate.

2.3. THEORETICAL BACKGROUND

As a general rule, when rival firms adopt similar strategies, business models, capabilities, and technologies, and when they try address similar markets with relatively homogenous products and technologies, competition drives down returns and compresses performance variance. Advantage depends on differentiation – in business models, organizational capabilities strategy, technology, and/or products and services. Advantage depends, in other words, on the ability of the firm to undertake lines of action that are qualitatively, and fundamentally, different from those of its peers. In the fitness landscape metaphor, firm characteristics, like strategies, business models, capabilities, technologies, and product market offerings, are mapped to locations in an abstract space (Gavetti, 2011). From this perspective, similarity is understood in terms of distance: when rivals are highly similar, they 'sit' adjacent to one another in the fitness landscape. Advantage, then, arises, in part (i.e., it is necessary, but not sufficient), from the ability to 'do differently' from one's rivals, to occupy non-adjacent places on the fitness landscape. Following Gavetti, this can be thought of as the 'imperative of nonlocal action'.

Competitive advantage, though, is relatively rare and often fleeting (Porter, 1991). Rivals are constantly alert to, and on the lookout for, opportunities (Kirzner, 1999) and are quick to emulate successful models when they discover them. Innovative competitors transform existing markets and industries and/or create new markets and industries that make incumbent firms less relevant (Schumpeter, 1976; Abernathy and Clark, 1985; Utterback, 1994; Christensen, 1997). In the absence of isolating mechanisms (Barney, 1991; Mahoney and Pandian, 1992: 371-373), valuable sources of differentiation are often quickly and mercilessly eroded away by the entrepreneurial actions (Klein, 2008) of existing rivals and/or new entrants. At the same time, *new* sources of differentiation are notoriously difficult to discover, imagine, and/or create (Tripsas and Gavetti, 2000; Gavetti, 2011). As Tripsas and Gavetti note, differentiation and innovation at the firm level is often stymied by the inertia of core capabilities and the shadow they cast on firm action (see also, Penrose, 1959; Leonard-Barton, 1995; Kogut and Zander, 1996; Denrell, Fang, and Winter, 2003; Gilbert, 2005) as well as the bounded cognition of organizational members (see too, Gavetti and Levinthal, 2000; Gavetti, 2011) that curtails the ability to envision and effectutate (Sarasvathy, 2001; Wiltbank, Dew, Read, and Sarasvathy, 2006; Klein, 2008) new courses of entrepreneurial action and Schumpeterian innovation.

Sustained advantage depends not only on achieving advantage at a point in time, what Porter (1991) called the 'cross-sectional problem', but the ability to continuously create *new* sources of differentiation and advantage (see too, Nickerson, Silverman, and Zenger, 2007). Put in terms of the fitness landscape metaphor laid out by Gavetti (2011), this is the challenge of nonlocal action. But, it is just this sort of thing that Gavetti (2011) has argued is so frequently problematic.

The fitness landscape metaphor encourages us to think about a firm's current configuration of strategies, capabilities, business models, technologies, products, knowledge, networks, alliances, etc. in terms of a literal position in a highly abstract space. By definition, *any* kind of differentiation, innovation, development, or other change in any of these variables is represented by a different point in the same abstract configuration space. And again, by definition, the points in this kind of abstract configuration space are understood to be ordered by similarity such that the closer together two points are from one another, the more similar the underlying features. From this perspective, any kind of change, development, differentiation, or innovation a firm undertakes can be thought of as a *move* from one point in this space to another. When the move represents an incremental change in some characteristic or feature (or set of features), the move can be described as *local*; when the move represents are more significant change in position, along a single characteristic or across some combination of underlying features, the move can be described as *nonlocal*.

A strategy of nonlocal action entails a strategy for moving from one point in this configuration space to a non-adjacent location; undertaking any such a move is what we can term a *nonlocal action*. (In this highly idealized model, we abstract from the practicalities of what it actually means to *move* from one space to another, e.g., on whether or not it is ever possible to change firm characteristics discontinuously, and we ignore the processes involved in actually enacting/effectuating these kinds of organizational change in order to focus attention on the effects of relative magnitude of change – or movement – on likely performance outcomes and similar variables).

The imperative of nonlocal action is clear. The question is whether or not a firm can deliberately pursue a strategy of nonlocal action in the sense of an *intended* line of action (see Mintzberg, Ahlstrand, and Lampel, 1998). As Gavetti argues, "something can be important to performance in theory but have no agency implications if it is not controllable" (2011: 2).

One influential line of argument, originating in evolutionary and behavioral approaches to strategy, suggests that, in fact, firms cannot deliberately pursue a strategy of nonlocal action. Here, nonlocal action is ultimately understood as the *consequence* of processes involving serendipity and luck (e.g., Ahuja and Lampert, 2001; Denrell, Fang, and Winter, 2003; Cattani, 2006; see too Gavetti, 2011). As Denrell, Fang, and Winter put it, “the character of the strategic opportunity implies that the process is likely to have been *serendipitous*, in the strict sense of the word. That is, success is a consequence of effort and luck joined by alertness and flexibility” (Denrell, Fang, and Winter, 2003: 985, emphasis in original). Such processes often are quite prosaic, even quotidian. As Denrell et al. argue:

> This does not imply…that it would necessarily take a *heroic effort* to identify such opportunities….in contrast to financial markets where blatant arbitrage opportunities are rare, we submit that the discovery of strategic opportunities is a normal occurrence in the product markets (2003: 985, emphasis in original).

This framework offers a rather pessimistic stance regarding the possibility of genuine strategic agency. Here, the prospects for *strategic nonlocal action* – i.e., deliberate, or intended, action oriented toward enabling the firm to significantly change its position in the competitive landscape by establishing new markets or competing in existing markets via the introduction of fundamentally new kinds of products, technologies, modes of production, etc. (Schumpeter, 1976; Kirzner, 1999) that is initiated by management with the objective of realizing some set of higher order organizational goals or objectives – are limited and highly constrained at best. In this framework, innovation – i.e., sources of variation (see Nelson, 2006) underwriting the possibility of nonlocal action – is understood to arise from what are essentially stochastic knowledge creation processes (Campbell, 1960) not amenable to standard forms of organizational control (Ouchi, 1979; McCarthy and Gordon, 2011). In this context, the literature on exploration (March, 1991, 2006, 2010; Ahuja and Lampert, 2001), absorptive capacity (Cohen and Levinthal, 1990; Zahra and George, 2002; Volberda, Foss, Lyles, 2010); organizational knowledge creation (Nonaka, 1994; Cook and Brown, 1999; Hargadon and Fanelli, 2002; Gourlay, 2006; Nonaka, von Krogh, and Voelpel, 2006; Nonaka and von Krogh, 2009, Tsoukas, 2009), organizational ambidexterity (Cao, Gedajlovic, and Zhang, 2009; Raisch, Birkenshaw, Probst, and Tushman, 2009, McCarthy and Gordon, 2011), and the processes mediating, and conditions moderating, organizational creativity (e.g., Nahapiet and Ghoshal, 1998; Carlile, 2004; Un and Cuervo-Cazurra, 2004; Hargadon and Bechky, 2006) can be understood, at least in part, as seeking answers regarding the possibility of engineering organizations to enable, make possible, or otherwise encourage emergent nonlocal action by enhancing the capacity to generate innovations.

What passes for strategy in this discourse, then, is something closer to what Mintzberg, Ahlstrand, and Lampel (1998) describe as *emergent strategy*: a primarily retrospective sensemaking (Weick, Sutcliffe, and Obstfeld, 2005) kind of process where a (relatively coherent) pattern of action is understood, ex post, to have arisen in the organization's ongoing activities without pre-planning or intention – or even in contradistinction to the organization's ex ante formal strategic plans. In this context, the prospects for nonlocal action arise haphazardly and depend critically on alertness (Buchanan and Vanberg, 1991; Kirzner, 1999), serendipity and luck (Denrell, Fang, and Winter, 2003), and management's ability to marshal and construct the requisite resources and capabilities required (Teece, 2007; Augier and Teece, 2009; Gavetti, 2011) for their realization. It is a logic of strategic and entrepreneurial action that stresses the priority of effectual processes (Sarasvathy, 2001; Wiltbank, Dew, Read, and Sarasvathy, 2006) over deliberate planning and positioning (Gavetti, 2011).

This paper argues, in contrast to views prioritizing serendipity, emergence, and luck, that nonlocal action, in fact, can be strategic in the sense suggested by Mintzberg, Ahlstrand, and Lampel's (1998) notion of *intended strategy*. The central proposition of this paper is that the processes of scientific and technological knowledge creation underwriting Schumpeterian modes of competition (Barney, 1986b) can be strategic because, contra Ouchi (1979), these processes can be oriented towards particular (nonlocal) ends – i.e., the establishment of specific domains (Kim, 2002) of novel scientific and technological knowledge – thereby opening up new spaces for future competition (c.f., Hamel and Prahalad, 1994; Kirzner, 1999). The aim of this paper is to sketch out a framework for understanding the nature of the knowledge creation processes at the core of these *strategic domain pioneering* activities which, following March (1991, 2006, 2010), can be considered a *technology for exploration*, or which, in line with Gavetti (2011), could be termed *a technology for strategic nonlocal action*. That is to say, this paper articulates a framework for understanding the processes of knowledge creation that management can strategically deploy in the pursuit of innovation and competitive advantage in the context of a Schumpeterian conception of strategic action focused on transforming existing industries and markets and/or the creation of new industries and markets – processes that themselves can be considered as kind of management technology in their own right (c.f., Birkinshaw, Hamel, and Mol, 2008).

2.4. THE STANDARD ACCOUNT OF KNOWLEDGE CREATION

A standard account of knowledge creation involves three main elements: a theory of knowledge, an explication of the machinery of knowledge creation, and the articulation of a explanatory program. These are not always explicitly developed. While most theoretical work on knowledge creation explicitly defends a theory, or typology, of knowledge (c.f., Faulkner, 1994) and a model of knowledge creation processes and mechanisms, the overarching explanatory program is often left implicit. This is problematic. A theory of knowledge creation that is explanatorily adequate and pragmatically useful in some contexts may prove wholly inadequate when employed in explanations of other organizational phenomena or is taken as the basis for pragmatic action by organization's seeking to leverage knowledge creation for specific purposes.

The theory of strategic domain pioneering outlined here differs from the standard account of organizational knowledge creation that has arisen within the strategy and management literature along all three of these dimensions. This is, in some sense, unsurprising given that the theory of strategic domain pioneering addresses a rather different set of concerns, or problem situations (c.f., Popper, 1979; Rescher, 2000) than earlier theories of organizational knowledge creation. It can, however, at times lead to a bit of confusion if one is not careful. While the problem situations are meaningfully different, there is a good deal of overlap. Much has been written about knowledge creation and innovation. Much of this work, however, ultimately concerns different set of issues than is the focus here. Moreover, this work is, for the most part, complementary to the theory of strategic domain pioneering presented here. Making these distinctions explicit can help us sidestep some potential land mines and constructively move forward.

Knowledge and knowledge creation have become central themes in the strategy, innovation, and management literatures over the past several decades. Rightly so, organizational knowledge and knowledge creation processes play an important role in a wide range of fundamental strategic and organizational phenomena, including:

- Explanations of firm heterogeneity (e.g., Kogut and Zander, 1992, 1996; Conner and Prahalad, 1996; Nahapiet and Ghoshal, 1998; Nonaka, Toyama, and Nagata, 2000);
- Strategic decision making (e.g., Walsh, 1995; Kaplan, 2011);
- Organizational capabilities (e.g., Penrose, 1959; Nelson and Winter, 1982; Levitt and March, 1988; Pentland and Rueter, 1994; Spender, 1996; Felin and Foss, 2009);
- Dynamic capabilities (e.g., Teece, 2007; Augier and Teece, 2009);
- Innovation and technological change (e.g., Dosi, 1982; Cohen and Levinthal, 1990; Faulkner, 1994; Howells, 1995; Leonard-Barton, 1995; Hargadon and Sutton, 1997; Nightingale, 1998; Carlisle, 2002, 2004; Hargadon and Fanelli, 2002; Fleming and Sorenson, 2004; Nickerson and Zenger, 2004; Hargadon and Bechky, 2006; Arthur, 2007; Nickerson, Silverman, and Zenger, 2007; Kaplan and Tripsas, 2008; Volberda, Foss, and Lyles, 2010);
- New product development (e.g., McCarthy, Tsinopoulos, Allen, and Rose-Anderssen, 2006);
- Sensemaking and organizational identity (e.g., March, 1994; Kogut and Zander, 1996; Weick, Sutcliffe, and Obstfeld, 2005; King, Felin, and Whetten, 2009);
- Institutional theory and social agency (e.g., March, 1994; DiMaggio, 1997; Lawrence, 1999; Lawrence and Suddaby, 2006; Czarniawska, 2009; Fligstein and McAdam, 2011);
- Management and organizational control systems theory (e.g., Ouchi, 1979; Eisenhardt, 1985; Simons, 1995; Chiesa, Frattini, Lamberti, and Noci, 2009; McCarthy and Gordon, 2011);
- The nature of entrepreneurial action (e.g., Buchanan and Vanberg, 1991; Kirzner, 1999; Sarasvathy, 2001; Denrell, Fang, and Winter, 2003; Sarasvathy, Dew, Read, and Wiltbank, 2008; Chiles, Bluedorn, and Gupta, 2007; Klein, 2008; Felin and Zenger, 2009; Gavetti, 2011; Foss and Klein, 2012).

A theory of knowledge creation contributes to these literatures in two ways. First, it posits a theory regarding what, exactly, *knowledge* is – that is, it outlines a knowledge ontology (c.f., Kogut and Zander, 1992; Faulkner, 1994; Nonaka, 1994; Spender, 1996; Cook and Brown, 1999; Gourlay, 2006; Nonaka, von Krogh, and Voelpel, 2006). Second, it explicates what processes, mechanisms, and other factors are involved in the production of new knowledge (c.f., Cohen and Levinthal, 1990; Kogut and Zander, 1992; Nonaka, 1994; Nahapiet and Ghoshal, 1998; Carlile, 2002, 2004; Hargadon and Fanelli, 2002; Gourlay, 2006; Hargadon and Bechky, 2006; Nonaka, von Krogh, and Voelpel, 2006; Håkanson, 2007; Nonaka and von Krogh, 2009; Tsoukas, 2009). The meta-objective of these theory building exercises is a comprehensive knowledge framework that both underwrites and informs explanations invoking knowledge and knowledge creation in the strategy and management literature.

The standard account of knowledge creation – which stems directly from the seminal contributions of Cohen and Levinthal (1990), Kogut and Zander (1992), and Nonaka (1994) – that has emerged over the past two decades is relatively straightforward. It can be articulated in a few simple propositions.

The first proposition is a claim about the basic elements of knowledge. Drawing on Ryle's (1949) distinction between 'knowing that' and 'knowing how' and Polanyi's (1962, 1966a, 1966b) constructs of explicit and tacit knowledge, the standard account posits that all knowledge can ultimately be reduced to two elemental kinds – *declarative knowledge* and *procedural knowledge* (c.f., Kogut and Zander, 1992; Nonaka, 1994; Gourlay, 2006). In positing this fundamental knowledge ontology of declarative and procedural representations, Kogut and Zander (1992), Nonaka (1994), and Cohen and Levinthal (1990) each explicitly and straightforwardly borrow from the cognitive sciences where these constructs are a central element of the information processing paradigm (c.f., Whetten, Felin, and King, 2009 on theory borrowing in organizational theory). In this knowledge ontology, declarative knowledge representations encode knowledge of facts, or propositions about the world while procedural knowledge representations encode the knowledge involved in skillful action and categorical perception – neither of which can be reduced to the other. These two basic knowledge kinds are the material out of which the higher-order knowledge structures like mental models, frames, dominant logics, etc. (Walsh, 1995; Kaplan, 2011), which underpin practice, are built (Cohen and Levinthal, 1990; Kogut and Zander, 1992; Nonaka, 1994; c.f, Newell and Simon, 1976; Newell, 1982; and Anderson, 1996 for a more detailed description of the underlying cognitive architecture that underlies the standard account of knowledge creation).

The second proposition is a claim about the fundamental processes of knowledge creation – what Gourlay (2006) calls the 'engine' of knowledge creation. In the standard account, knowledge creation occurs via *combinative processes* that build new stocks of declarative and procedural knowledge out of existing stores of knowledge (and ongoing perceptual experience) and that associate together existing bits of knowledge into higher-order assemblages that underwrite organizational capabilities and competencies (c.f., Cohen and Levinthal, 1990; Kogut and Zander, 1992, 1996; Nonaka, 1994; see also Cook and Brown, 1999; Gourlay, 2006; Nonaka, von Krogh, and Voelpel, 2006; Nonaka and von Krogh, 2009; Tsoukas, 2009) and the processes of invention, innovation, and creativity (c.f., Cohen and Levinthal, 1990; Kogut and Zander, 1992; 1996; Fleming and Sorenson, 2004; Nickerson and Zenger, 2004).

Drawing on prior research in the cognitive sciences, Cohen and Levinthal, for example, contend that organizational problem solving, invention, and creativity depend on the same basic associative (i.e, combinative) processes that underlie learning: “we argue that problem solving and learning capabilities are so similar that there is little reason to differentiate their modes of development….the psychology literature suggests that creative capacity and what we call absorptive capacity are quite similar” (1990: 130-131). In a similar vein, Nickerson and Zenger posit that “following previous work, we assume that solutions to complex problems represent unique combinations or syntheses of existing knowledge” (2004: 618; see too Kogut and Zander, 1992; Nerkar, 2003; Fleming and Sorenson, 2004). In Nonaka’s (1994) model of organizational knowledge creation, new organizational competencies and capabilities depend on the complex, inter-related stocks of declarative and procedural knowledge that arise at the individual level via combinative processes (what Nonaka termed the knowledge conversion spiral) and subsequently are shared – and built upon – across the relevant communities of practice (see too Spender, 1996’ Cook and Brown, 1999; Tsoukas, 2009). Here too, though, the fundamental process of knowledge creation involves combinative processes. Nonaka, for example, explicitly draws his model of ‘knowledge conversion’ from Anderson’s ACT model of cognition (Nonaka, 1994: 18).

The third, and final, proposition defining the standard account of knowledge creation concerns the broad explanatory project. The overarching research program of the standard account is to explain the production of new stocks of knowledge because it is out of the accumulated stocks of declarative and procedural knowledge that competency and skilled action arise in the cognitive architectures that have been adopted by researchers interested in knowledge creation (Newell, 1982; Anderson, 1996). In these kinds of architectures, skilled action (e.g., Spender, 1996; Cook and Brown, 1999; Weick, Sutcliffe, and Obstfeld, 2005) and creative problem solving (Campbell, 1960; Cohen and Levinthal, 1990; Fleming and Sorenson, 2004; Nickerson and Zenger, 2004) reflect rather straightforwardly the accumulation of prior knowledge. Anderson notes:

> Simon wrote ‘an ant, viewed as a behaving system, is quite simple. The apparent complexity of its behavior over time is largely a reflection of the complexity of the environment in which it finds itself’ (64). Simon argued that human cognition is much the same–a few relatively simple mechanisms responding to the complexity of the knowledge that is stored in the mind (1996: 364).

The objective, then, is to explain how new knowledge – i.e., novel combinations of stocks of existing knowledge and ongoing perceptual experience – is generated by identifying the antecedents and moderators that affect the flows and stocks of knowledge accumulation (e.g., Cohen and Levinthal, 1990; Nonaka, 1994; Nahapiet and Ghoshal, 1998; Carlile, 2002, 2004; Hargadon and Fanelli, 2002; Hargadon and Bechky, 2006; Håkanson, 2007; Tsoukas, 2009; Volberda, Foss, and Lyles, 2010). Research on knowledge creation reduces to a question of identifying what factors contribute to – or otherwise affect – the accumulation of novel stocks of declarative and procedural knowledge.

2.5. PROBLEMS WITH THE STANDARD ACCOUNT

When we turn our attention to scientific, engineering, and technological knowledge creation, several problems with the standard account quickly emerge.

The first involves the problem of incommensurability that arises in the development of new scientific, engineering, and technological frameworks (Kuhn, 1970; Bird, 2000). Combinative process theories of knowledge creation postulate a deep continuity between existing stocks of knowledge and new knowledge. Invention and creative activity in the standard account are understood to reflect the combination of existing elements of knowledge in novel combinations (Campbell, 1960). New concepts, then, have a lineage that rather directly derives from the current frontier of knowledge. Kuhn (1970), however, showed that science does not always advance so continuously (c.f., Dosi, 1982 for an analogous exploration of the advance of engineering and technological knowledge). Periods of steady advance, or normal science, are punctuated by periods of crisis, or revolutionary science, where radically new conceptual frameworks and associated world-views displace the existing disciplinary matrix (Bird, 2000). These new frameworks that emerge are not continuous with the old. Kuhn argues:

> To make the transition to Einstein's universe, the whole conceptual web whose strands are space, time, matter, force and so on, had to be shifted and laid down down again on nature whole….In a sense I am unable to explicate further, the proponents of competing paradigms practice their trades in different worlds (Kuhn, cited in Bird, 2000: 46).

More generally, the standard account of knowledge creation has difficulties accounting for the large-scale structure of inquiry/progress in scientific, engineering, and technological domains. Knowledge creation in these arenas does not proceed linearly and accumulatively (Kuhn, 1970; Dosi, 1982; Bird, 2000; Rescher, 2000; Feyerabend, 2010). What Kuhn labeled 'normal science' – or the engineering and technological analogs (c.f., Dosi, 1921) – dominated by well-established paradigms is always confronted with 'revolutionary' paradigms (Feyerabend, 2010) and the emergence of new domains of inquiry and exploration (Hofstadter, 1999; Bird, 2000). At the same time, as Rescher notes, the progress of inquiry *within* a given framework itself proceeds in a highly non-linear fashion, where we find "in the course of cognitive progress the state of questioning changes no less drastically than the state of knowledge" (2000: 59). Neither of these patterns of inquiry, however, can be explained – in any straightforward manner, at least – within the standard account of knowledge creation where all cognitive progress is reduced to the mere accumulation of incremental stocks of declarative and procedural knowledge.

The origin of creative ideas is also problematic for the standard account, where all new ideas are said to be generated by combinative processes. The problem here is that the notion of combinative processes at the core of the standard account has proven insufficient to account for scientific knowledge creation and, mutatis mutandis, for engineering and technological knowledge creation (Horgan and Tienson, 1994). As Horgan and Tienson note, “Classicism has made very little progress in understanding *central* processes,” which is problematic because “belief fixation – the generation of new beliefs on the basis of current input together with other beliefs both occurrent and nonoccurrent – is a paradigmatic example“ (1994: 312) of these kinds of processes.

While the standard account explains knowledge creation in terms of the combination of discrete, atomic knowledge element precursors into more molecular composites, Fodor argues that knowledge creation in science proceeds very differently: “it is (in Fodor’s terminology) *isotropic* and *Quineian*” (Horgan and Tienson, 1994: 312). Quoting Fodor again:

> By saying that confirmation is isotropic, I mean ….crudely: everything that the scientist knows is, in principle, relevant to determining what else he ought to believe….
>
> By saying that scientific confirmation is Quineian, I mean…the shape of our whole science bears on the epistemic status of each scientific hypothesis….
>
> The problem in both cases is to get the structure of the entire belief system to bear on individual occasions of belief fixation. We have, to put it bluntly, no computational formalisms that show us how to do this, and we have no idea how such formalisms might be developed….In this respect, cognitive science hasn’t even *started*; we are literally no farther advanced than we were in the darkest days of behaviorism (Fodor, cited in Horgan and Tienson, 1994: 312-314).

This problem, obviously, is particularly severe in the context of a theory of scientific, engineering, and technological knowledge creation.

Finally, the knowledge ontology at the core of the standard account fails to provide an adequate space for the kinds of *model representations* that have risen to prominence in recent discussions of scientific cognition and practice within the philosophy of science over the past several years (Giere, 2006; Godfrey-Smith, 2006a, 2006b, 2009; Frigg and Hartmann, 2009; Frigg, 2010) and epistemology (Floridi, 2011)[1]. For Giere (2004; 2006), models and model-based cognition are the ineliminable core of theorizing and scientific practice – not adjuncts (c.f. Cartwright, 1997, 2010). "For Giere," Godfrey-Smith notes "models are idealized structures that we use to represent the world via resemblance relations between the model and real-world target systems" (2006a: 725-726). Scientific practice, then, from this perspective, is understood in terms of building and using models to represent, study, and investigate some part of the

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[1] While the term 'model' has numerous disparate connotations in the natural and social sciences and philosophy, the construct of a model representation as a precise technical term within the philosophy of science reflects recent work on the foundations of scientific cognition (c.f., Godfrey-Smith, 2006a) that should not be conflated with other, similar constructs. At the same time, as Frigg and Hartmann (2009) note, within the philosophy of science the construct is itself still evolving as inquiry into model-based conceptions of scientific practice evolves. A fairly broad conception of model-based representations is posited in this paper, including, for example, both the highly abstract, idealized models that Godfrey-Smith (2006a) takes as paradigmatic members of this class as well as the kinds of direct representations that Godfrey-Smith considers somewhat different. While not dismissing the important differences between these two kinds of representations, the position taken here is that they are best understood as different kinds of the super-ordinate construct. By the same token, I take it as relatively unproblematic and straightforward to extend the construct of model-based representations to areas of applied science, engineering, and technological representations too. Following Rescher (2012), I take erotetic (i.e., explanatory), predictive, and pragmatic cognition to be fundamentally of one kind (c.f., Popper, 1979; Klemke, Hollinger, Wÿss Rudge (1998). Like Godfrey-Smith's abstract, highly idealized and direct representation models, then, I class applied science, engineering, and technological model-based representations under the same super-ordinate construct of model representations.

(natural or social) world while engineering and technological practice is understood in terms of using models to create new technologies, systems, or artifacts.

Importantly, model representations are not reducible to declarative or procedural knowledge structures (Giere, 2006; Frigg and Hartmann, 2009; Floridi, 2011). Ontologically, they are an autonomous kind of knowledge in the same way that declarative and procedural knowledge are autonomous from one another (and from model representations). That models are distinct from declarative representations can be seen when we consider that any single model can have many different descriptions (Giere, 2006; Frigg and Hartmann, 2009). There is, in other words, a many-to-one mapping from declarative knowledge representations to model representations. And while building and using models frequently involves physical actions, model-based cognition is fundamentally an epistemic, rather than pragmatic activity (Kirsh and Maglio, 1994).

The upshot is that while the standard account supposes all cognition is mediated by declarative and procedural knowledge structures, recent work in the philosophy of science and epistemology indicate that a distinct, and ontologically autonomous, kind of knowledge – model representations – are, in fact the central representational vehicle in scientific, engineering, and technological cognition. In these contexts, declarative and procedural knowledge are subservient. We *talk about* models and *work with* models in the course of scientific, engineering, and technological activity (c.f., Hargadon and Sutton, 1997; Bucciarelli, 2002; Carlile, 2002, 2004; Hargadon and Fanelli, 2002; Hutchins, 2005; Håkanson, 2007; Menary, 2007; Clark, 2008; Nersessian, 2009), but these are ancillaries – the main epistemic load is carried by the model representations (Giere, 2004, 2006).

2.6. A THEORY OF STRATEGIC DOMAIN PIONEERING

There are two main questions that need to be answered when we look at a theory of knowledge creation. The first asks what is the theory of knowledge that is being postulated. This question seeks to understand what it is that is being created when new knowledge is being created. The second asks how the processes of knowledge creation should be understood within the theory. This question seeks to understand what sort of processes are involved in the creation of new knowledge. At the same time, the theory of strategic domain pioneering suggests that scientific, engineering, and technological knowledge creation can be strategic – i.e., that these kinds of knowledge creation activities can be 'tuned' toward organizational objectives. This raises additional questions regarding how, contra Ouchi (1979), scientific, engineering, and technological knowledge creation processes can be effectively managed.

When we turn to theory of strategic domain pioneering, the answers to these questions are relatively straightforward. In simplest terms, the theory of strategic domain pioneering can be encapsulated in the following sets of propositions:

(P1) *The epistemic core of scientific, engineering, and technological cognition is best understood in terms of the capacity to construct, explore, and reason with model representations within a specific domain of scientific, engineering, or technological activity.*

(P2) *The capacity to engage in these kinds of scientific, engineering, and technological activities is made possible – and constituted – by epistemic actions within an amalgamated system of extended cognitive resources where external representational vehicles are used as Galilean thought tools.*

(P3) *Scientific, engineering, and technological knowledge creation is best understood as the construction of the capacity to engage in these kinds of scientific, engineering, and technological model-based cognition in novel domains of scientific, engineering, or technological activity*. *This is termed domain pioneering.*

(P4) *Domain pioneering, in turn, is made possible – and constituted – by epistemic action within an amalgamated system of extended cognitive resources that serves to (i) frame new research programs, (ii) seed new model systems, and (iii) actively drive the ongoing trajectory, or flow, of thought.*

(P5) *Domain pioneering becomes strategic when it is oriented toward achieving specific higher-level, strategic organizational goals and objectives through Schumpeterian innovation in products, technologies, and modes of production. That is,* *when pioneering novel domains of scientific, engineering, or technological activity is undertaken to support nonlocal action.*

Drawing on the model-based conception of scientific, engineering, and technological cognition in the philosophy of science (e.g., Giere, 2004, 2006; Godfrey-Smith, 2006a, 2006b; Frigg and Hartmann, 2009) and the extended cognition paradigm in the cognitive sciences (Clark, 1997, 2008; Clark and Chalmers, 1998; Menary, 2010; Rowlands, 2010; Theiner, 2011), the theory of strategic domain pioneering builds on a very different set of conceptual foundations than does the standard account. It also seeks to answer a somewhat different set of problems. Not surprisingly, then, the theory of strategic domain pioneering differs from the standard account on a point by point basis across all three basic elements that (jointly) define the space occupied by a theory of knowledge creation: knowledge ontology, fundamental knowledge creation processes, and underlying explanatory project. The following sections provide a brief overview of the central elements of the theory of strategic domain pioneering.

2.6.1. Rethinking the nature of knowledge

In the standard account, knowledge is understood in terms of stocks of declarative and procedural representations. Cook and Brown (1999) described this conceptualization of knowledge as the ‘epistemology of possession’. The basic idea is that knowledge is an object. Agents with the right stocks of knowledge can perform a particular set of actions or talk about some set of facts about the world because they have access to the relevant stores of declarative and procedural knowledge; agents who do not possess the right stores of knowledge, conversely, do not.

In the theory of strategic domain pioneering, scientific, engineering, and technological knowledge is understood as the *capacity* to engage in fluid model-based cognition within a particular domain (Giere, 2006). This conception of scientific, engineering, and technological cognition is ultimately very different from that posited in the standard account.

Giere notes that conception of theories as propositional entities (i.e., made up of a fixed stock of declaratives) “is deeply entrenched, particularly in philosophy and philosophy of science” (2006: 60).[2] Scientific, engineering, and technological practice, however, sits uncomfortably with the standard account of knowledge. Analyzing actual scientific practice, Giere (2004, 2006), Ohlsson (1993), and Ohlsson and Lehtinen (1997) argue that the idea of a *theory* as some sort of thing, or an object, is a mistake. In this framework, theorizing is understood in terms of the capacity to build, explore, learn from, and reason with models (c.f., Ohlsson and Lehtinen, 1997; Cartwright, 2009), not the possession of some set of facts or propositions. From this perspective, there is, in fact, no *theory* per se. Rather, what there *is* is a fluency in constructing models in some domain out of more abstract building blocks which are capable of being fleshed out in a more concrete fashion for particular purposes (Ohlsson and Lehtinen, 1997; Giere, 2006; Cartwright, 2009).

The standard account is even more problematic when we turn to the design processes at the core of engineering and technological cognition where sketching and modeling play a central role (Alexander, 1964; Goel, 1995; Graham, 2004). Designing is a process of iteratively, and often recursively, evolving forms to meet a desired function by working out models (Alexander, 1964; Goel, 1995; Graham, 2004; c.f., Howells, 1995; Arthur, 2007). But models are not discursive structures (Giere, 2006; Frigg and Hartmann, 2009) and modeling and sketching processes involving the construction of novel forms are not well explained by cognitive architectures predicated on motor programs based on production system cognitive architectures (c.f., Simon, 1999) like those posited to underwrite procedural knowledge (Collins and Kusch, 1998; Sennett, 2008).

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[2] The same, mutatis mutandis, is held to be true in engineering and design, where, even though designers frequently employ diagrams or other, similar, kinds of representations, the prevailing assumption has been that these are informationally equivalent to propositional representations and that cognition *ultimately* depends on ‘translating’ between the non-discursive representations and the language of thought (c.f., Goel, 1995).

Following Ryle (1949), what is required is an account of performances; a specification of *what it is* that underwrites an agent's abilities in some task environment. The objective here, according to Dennett, Ryle's student, is to specify "how could any system (with features A, B, C, …) possibly accomplish X?" where X stands for some aspect of cognition (Dennett, 1978: 111). As Dennett says, "this is an *engineering* question" (1978: 111, emphasis in original). The answer lies in the specification of a system that can do X, not in the discovery and articulation of laws that show how X is nomically expected in some context (Cummins, 2000; Kim, 2002, 2005; Bechtel and Abrahamsen, 2005). This is a very different conceptualization of knowledge than the one seen in the standard account.

The central insight of the cognitive revolution is that cognition can be explained by reference to cognitive architectures specifying what Horgan and Tienson term the 'rules and representations' that underwrite some performance (1996, 1999; c.f., Marr, 1982). Within this framework, *representations* – rather straightforwardly – refers to the representational vehicles that encode an agent's knowledge, while *rules* refers to the (computational, logical, dynamic, etc.) processes underlying cognition. Taken together, a set of rules and representations constitutes a cognitive architecture. To explain a specific performative ability, then, entails specifying a cognitive architecture composed of some specific set of rules and representations that enables an agent to perform the task in question. In the context of the theory of strategic domain pioneering, this general imperative involves specifying the architecture involved in scientific, engineering, and technological knowledge creation for strategic purposes.

Traditionally, the strong assumption underwriting the cognitive sciences is that the idea that cognition is something that occurs in the brain. Clark calls this the 'BRAINBOUND' model of cognition – the idea that "all human cognition depends directly on neural activity alone" (2008: xxvii). In this paradigm, the rules and representations that constitute the cognitive architecture are realized in the brain's neural machinery in some way or another.[3]

Functionalism in the theory of mind, however, asserts that the rules and representations that constitute a cognitive architecture are defined by their function – or the roles they play – within the overall cognitive system, not the physical stuff they are made out of (Clark, 2008; Rowlands, 2010; c.f. Lowe, 2000). In contradistinction to the BRAINBOUND assumption of traditional cognitive science, then, the extended cognition paradigm (Clark, 1997; 2008; Clark and Chalmers, 1998; Menary, 2010; Rowlands, 2010; Theiner, 2011), asserts that machinery of cognition, in certain conditions, is seated in "hybrid ensembles of neural, bodily, and environmental elements" (Clark, 2008: xxviii). These amalgamated systems (Rowlands, 2010) comprise extended functional cognitive systems where the rules and representations that constitute cognition are realized in representational vehicles and processes that involve neural and non-neural elements. As Clark describes it:

> the actual local operations that realize certain forms of human cognizing include inextricable tangles of feedback, feed-forward, and feed-around loops: loops that promiscuously criss-cross the boundaries of brain, body, and world. The local mechanisms of mind…are not all in the head. Cognition leaks out into the body and world (2008: xxviii).

Cognition is extended in two different senses in this framework. Rather straightforwardly, the extended cognition paradigm asserts that the machinery of cognition can, in certain circumstances, extend beyond the central nervous system in important, non-trivial, ways – the very machinery of cognition is understood to be (potentially) spatially and physically extended. But, there is a more important way in which cognition can be understood to be extended. In a literal sense, extended cognitive systems can have capabilities that exceed those of 'naked' agents who must rely solely on their innate neural resources (Clark, 1997, 2008; Sterelny, 2004; Hutchins,

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[3] That is, in some sort of classical or nonclassical cognitive architecture (Horgan and Tienson, 1994).

2005; De Cruz and De Smedt, 2010; Theiner, 2011; see to Crosby, 1997). This notion is captured by Dahlboom, who argues that “just as you cannot do very much carpentry with your bare hands, there is not much thinking you can do with your bare brain” (cited in Theiner, 2011: vii). Here, it is the notion that it is the cognitive capabilities of the agent that are extended that is being stressed. And it is this second notion of extension that is by far the most important for the theory of strategic domain pioneering because it turns out that the cognitive architecture that underwrites scientific, engineering, and technological cognition and knowledge creation fundamentally depends on the affordances provided by these kinds of amalgamated cognitive systems.

The theory of strategic domain pioneering highlights the fundamental, irreducible, role played by model representations in scientific, engineering, and technological cognition and knowledge creation. These model representations are a central element of the knowledge ontology posited by the theory. From a functional perspective, Godfrey-Smith states that:

> a rough definition of the relevant sense of ‘model’ can be given as follows: a model is an imagined or hypothetical structure that we describe and investigate in the hope of using it to understand some more complex, real-world ‘target’ system or domain (2006b: 7).

The scope of these models quickly tends to exceed the limited cognitive resources of the naked brain (Clark, 1997, 2008; Sterelny, 2004; Hutchins, 2005). Consequently, the representational vehicles that constitute all but the most simple models intrinsically depends on the incorporation and use of non-neural resources. Hutchins (2005) described this as a process where external vehicles serve to ‘stabilize’ and concretize the representation, which is best understood as hybrid of internal and external representational elements whose parts compliment one another from a functional perspective (c.f., Sterelny, 2004; Clark 2008). The non-neural component(s) can include elements like physical models, equations, diagrams, computer simulations, or verbal descriptions (Godfrey-Smith, 2006a; Frigg and Hartmann, 2009).

These physical bits are not the model itself, however. Giere stresses that the actual model is itself an abstract object (2006). Rather, these external resources serve as scaffolds for constructing, exploring, and/or interacting with aspects of the (abstract) model system for some particular purpose (Giere, 2004; 2006). These representational vehicles are the means through which agents can contemplate particular aspects of complex, abstract model systems that would be cognitively inaccessible to agents forced to rely solely on their innate neural resources (Popper, 1979; c.f, Menary, 2007; Clark, 2008; De Cruz and De Smedt, 2010).

The equations, diagrams, physical models, and descriptions employed in modeling are used as a means of positing (Frigg, 2010; c.f., Godfrey-Smith, 2006b), exploring (Godfrey-Smith, 2006a, 2006b; Cartwright, 2009), and/or thinking about (Godfrey-Smith, 2006b; Cartwright, 2009; De Cruz and De Smedt, 2010) some aspect of the abstract model system. In this sense, following Cartwright (2009), they are *Galilean thought tools (GLTs)* in that they are used to conceptualize specific properties of the abstract model in isolation. Postulating entities with certain, specific properties and a set of relations between the various postulated entities, the modeler is able to explore the emergent properties of the model system in order to learn about a particular target system (Godfrey-Smith, 2006a, 2006b; Cartwright, 2009; De Cruz and De Smedt, 2010) or explore potential design alternatives (Alexander, 1964; Goel, 1995; Graham, 2004). In this way, these Galilean thought tools enable the scientist, engineer, or designer to contemplate and/or work on models that would otherwise be inaccessible if they were forced to rely solely on the affordances of their innate neural resources (De Cruz and De Smedt, 2010).

Building, exploring, and thinking *with* abstract models in scientific, engineering, and technological domains proceeds by picking out external resources and using the affordances that these resources make available to build up partial, perspectival (Giere, 2006) representations of model systems and to reason about such systems (Godfrey-Smith, 2006a, 2006b; Cartwright, 2009; De Cruz and De Smedt, 2010). In these contexts, the agent’s physical actions comprise an irreducible element of the cognitive processes that underlie the agent’s higher-level cognitive capacities (Clark, 2008; Rowlands, 2010; Theiner, 2011).

Kirsch and Maglio (1994) introduced the construct of *epistemic action* to highlight these kinds of physical actions that agents perform to augment cognition (c.f., Clark, 2008; De Cruz and De Smedt, 2010; Theiner, forthcoming). Where pragmatic action involves modifying some part of the world to achieve a physical goal, epistemic action involves modifying some part of the world for cognitive gain. Clark (2008) argues that thinking, learning, and reasoning, in these contexts, is constituted by the epistemic actions which loop out from the agent to the world and back again (see also Rowlands, 2010; Theiner, 2011). These epistemic actions, in other words, are functionally part of the cognitive processes that comprise scientific, engineering, and technological cognition. The most important of these higher-level cognitive processes for scientific, engineering, and technological practice include the abilities to capture and structure observations (Crosby, 1997; Giere, 2006), build up representations of phenomena (Woodward, 1989; Kim, 2005; Giere, 2006), construct abstract model systems (Ohlsson and Lehtinen, 1997; Giere, 2006; Godfrey-Smith, 2006a, 2006b; Cartwright, 2009), and reason in cognitively opaque domains (De Cruz and De Smedt, 2010) – all of which fundamentally depend on epistemic action involving Galilean thought tools.

This argument can be summarized in two claims. The first is that scientific, engineering, and technological knowledge, from the perspective of the theory of strategic domain pioneering, is best understood in terms of the capacity to build, explore, and reason with models. The second is that the theory of strategic domain pioneering asserts that the capacity to engage in these kinds of activities is made possible, and constituted, by epistemic action on Galilean thought tools.

2.6.2. The explanatory project of the theory of strategic domain pioneering

As noted, the explanatory project of the standard account is the explication of the factors involved in the production of new stocks of declarative and procedural knowledge. Underlying this is a Humean perspective of science that holds that the sole objective of science is the elucidation of lawful empirical relationships (Bhaskar, 2008; c.f., Cummins, 2000; Bechtel and Abrahamsen, 2005). In the case of the standard account, this norm has been operationalized as the search for variance and process accounts (Van de Ven and Engleman, 2004) of the factors involved in knowledge creation.

The theory of knowledge underlying the theory of strategic domain pioneering holds to a very different explanatory project. Instead of seeking to identify the processes and factors responsible for generating new stocks of declarative and procedural representations, the theory of strategic domain pioneering seeks to understand how the capacity to engage in scientific, engineering, and technological cognition within novel domains – or fields – of scientific, engineering, and technological activity is made possible and how these kinds of strategic knowledge creation activities can be managed for strategic gain.

2.6.3. A model of strategic domain pioneering

In mature domains of scientific, engineering, and technology, there are a wide array of what Sterelny (2004) termed common-use cognitive resources that can be drawn upon, most of which are well established in the relevant epistemic community (Kuhn, 1970; Bird, 2000; Giere, 2006). Kuhn argued that these field-level cognitive resources form the disciplinary matrix within which ‘normal science’ progressed (Bird, 2000). At the same time, mature domains are typically oriented toward a number of well established projects or research programs. In scientific domains, these projects engender a sequence of inter-related questions that drive inquiry along well defined trajectories (Popper, 1979; Rescher, 2000). It has frequently been argued in the technology innovation literature that analogous trajectories emerge in the sequence of product and technology development for similar reasons (Dosi, 1982; Clark, 1985).

Domain pioneering involves establishing novel research programs in new fields of scientific, engineering, and technological activity where these kinds of field-level research programs and epistemic resources do not exist.[4] An account of strategic domain pioneering, then, must explain how novel research programs – often requiring

[4] In spite of intuitions which may suggest otherwise, in actual fact domain pioneering is a fairly commonplace occurrence in scientific practice (Hofstadter, 1999; Bird, 2000; Feyerabend, 2010). The large literature on ‘radical’ innovation would suggest that similar features are seen in the large scale structure of engineering and technological innovation too.

significant conceptual innovation – can be established outside of the frontiers of established scientific practice.

The theory of strategic domain pioneering asserts that there are three primary kinds of processes involved in establishing novel research programs in new domains of scientific, engineering, and technological activity: (i) top-down processes involved in framing new problems situations and research programs, (ii) bottom-up processes involved in seeding new model systems, and (iii) concurrent processes used to actively drive the ongoing trajectory of flow of thought of scientists, engineers, technologists, and designers working in novel domains. Moreover, the theory of strategic domain pioneering posited here asserts that all three of these domain pioneering processes depend on, and are constituted by, epistemic action on Galilean thought tools.

Rescher (2000) argues that the large scale structure of the path of inquiry (or design) is set along a particular trajectory by the initial framing of the research problem (c.f., Popper, 1979; Goel, 1995). Problem framing is the top-down process of problem-space structuring that transforms ill-structured problems into well structured problems (Goel, 1995). Framing drives the trajectory of inquiry, because as Paul Souriau noted, “a question well posed is half answered” (cited in Campbell, 1960: 385). In the context of scientific, engineering, and technological domain pioneering, these top-down framing processes involve working out a stylized description of the problematic (Woodward, 1989; Howells, 1995; Kim, 2002, 2005; Arthur, 2007; Helfat, 2007) which orients subsequent cognitive activities toward the solution of particular problems. In scientific domains, the questions revolve around how to explain some aspect of a phenomena (Kim, 2002, 2005), while in technological and engineering domains the questions typically revolve around finding a design that generates an adequate solution to the design brief (Howells, 1995; Arthur, 2007).

These top-down problem space structuring processes are complemented by bottom-up processes that posit new ‘props’ that underwrite the construction of new, and often innovative, conceptual frameworks (Frigg, 2009) for some domain of science, engineering, or technology. Where top-down framing processes structure a domain’s explananda, these bottom-up prop-positing processes seed explanantia for building models upon which highly elaborated models can be constructed in conceptual integration networks (Fauconnier and Turner, 2002). Many of the properties of the different parts of the resultant models, then, are implicitly defined by their context of use within these models and conceptual novelty emerges as both old and new elements of models are ‘worked out’ and ‘stretched’ to fit new circumstances (Van Dyck, 2005; Clark, 2008; De Cruz and De Smedt, 2010).

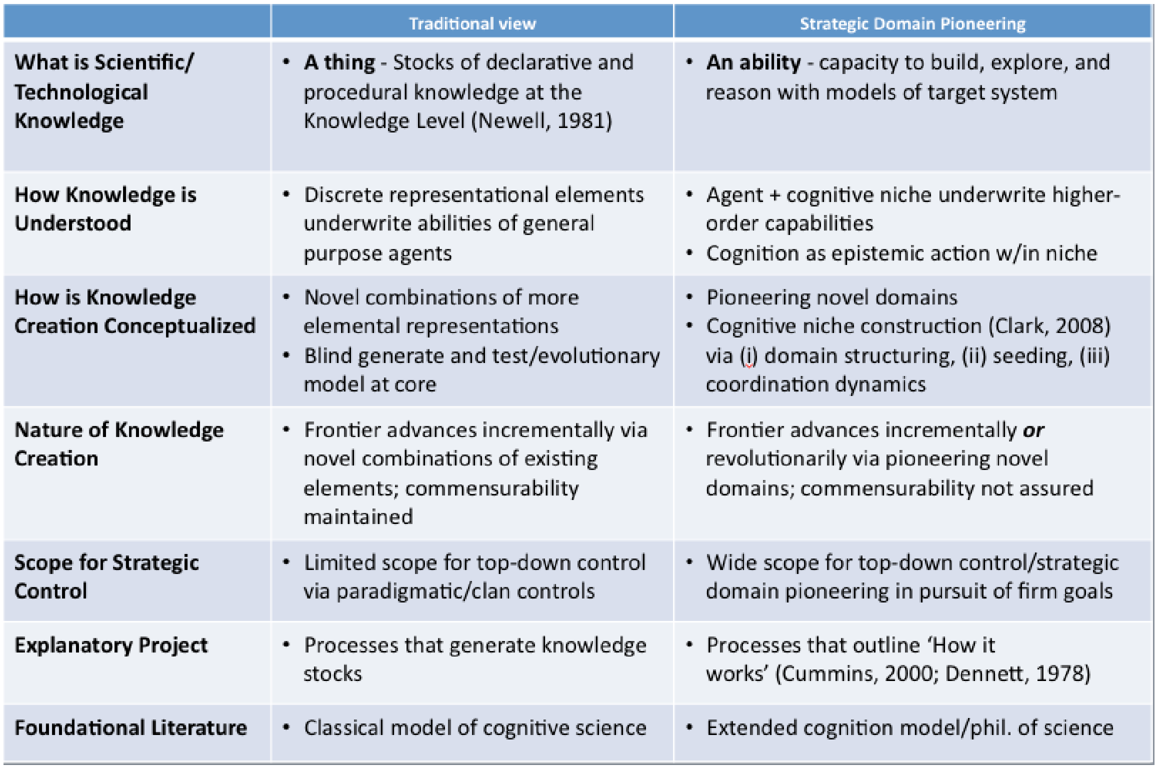
These top-down and bottom-up domain pioneering processes operate on and define the large-scale structure of inquiry and design within specific domains of science, engineering, and technology. Epistemic action on Galilean thought tools, however, can also be deployed to influence and direct the occurrent flow and trajectory of thought. Heuristics, check lists, directions, and other, similar kinds of tools are often deployed by novices in the development of expertise and by experts to augment performance in real-time (Clark, 2008). Clark (2008) argues that language, too, can serve as an important class of extended cognitive resources. He argues that “on the artifact model [of language],…words and sentences remain potent real-world structures encountered and used by a basically (though this is obviously too crude) pattern-completing brain” (Clark, 2008: 56). Such structures can be used to reliably drive the trajectory of thought, Clark argues: “words and sentences act as artificial input signals, often (as in self-directed speech) entirely self-generated, that nudge fluid natural systems of encoding and representations along reliable and useful trajectories” (2008: 54).

Domain pioneering becomes strategic when knowledge creation is oriented toward specific fields in the pursuit of Schumpeterian innovation and nonlocal action. Here, domain pioneering activities are analogous to what Mintzberg, Ahlstrand, and Lampel (1998) termed ‘intended strategy’. Just as realized strategy reflects the flow of emerging events and ongoing decision making on the intended course of action, the course of knowledge creation is also inevitably affected by the contingencies that arise out of the pursuit of knowledge itself. The notion of an intended direction, nonetheless, remains valid in both cases.

2.7. DISCUSSION

The model presented in the previous section articulates a framework for understanding how the capacity to engage in new domains of scientific, engineering, and technological activity can be actively constructed by organizations. To get here, it was necessary to rethink the foundations of the theories of knowledge and knowledge creation that have dominated discussions in the management and strategy literature to date. In the processes, it was necessary to reconsider the nature of the explanatory project itself. The construct of knowledge was transformed from one of ‘stocks’ of declarative and procedural knowledge elements to a more dynamic notion of a capacity to engage in certain kinds of key activities – the most important of these being the ability to construct, explore, and reason with models. Accordingly, we see now that the explanandum of a theory of knowledge creation is better understood in terms of the capacity to generate and engage in these kinds of model-based cognitive capabilities than something like the project of explicating the processes involved in the generation of stocks of flows of knowledge elements that has been the primary focus of much prior research. Identifying the antecedents and moderators of knowledge creation remains an important task, but the underlying understanding of what it is that is being created when we create new knowledge in organizations looks very different in the framework forwarded here.

Figure 1 summarizes the key differences in perspective between the theory of strategic domain pioneering introduced in this paper and the traditional view of knowledge creation in the management literature across a number of fundamental dimensions.



	Traditional view	Strategic Domain Pioneering
What is Scientific/ Technological Knowledge	- **A thing** - Stocks of declarative and procedural knowledge at the Knowledge Level (Newell, 1981)	- **An ability** - capacity to build, explore, and reason with models of target system
How Knowledge is Understood	- Discrete representational elements underwrite abilities of general purpose agents	- Agent + cognitive niche underwrite higher-order capabilities - Cognition as epistemic action w/in niche
How is Knowledge Creation Conceptualized	- Novel combinations of more elemental representations - Blind generate and test/evolutionary model at core	- Pioneering novel domains - Cognitive niche construction (Clark, 2008) via (i) domain structuring, (ii) seeding, (iii) coordination dynamics
Nature of Knowledge Creation	- Frontier advances incrementally via novel combinations of existing elements; commensurability maintained	- Frontier advances incrementally ***or*** revolutionarily via pioneering novel domains; commensurability not assured
Scope for Strategic Control	- Limited scope for top-down control via paradigmatic/clan controls	- Wide scope for top-down control/strategic domain pioneering in pursuit of firm goals
Explanatory Project	- Processes that generate knowledge stocks	- Processes that outline 'How it works' (Cummins, 2000; Dennett, 1978)
Foundational Literature	- Classical model of cognitive science	- Extended cognition model/phil. of science

Figure 1. Rethinking the Nature of Knowledge Creation

This change in perspective suggested by the introduction of the theory of strategic domain pioneering is important. Some concluding thoughts regarding the implications of these conceptual moves are appropriate here.

The first set of implications concerns the notion of strategic knowledge creation processes as a technology of exploration and a technology of nonlocal action.[5] At the outset of this paper, I suggested that the framework for strategic domain pioneering

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[5] Importantly, the two are different. That is, while strategic knowledge creation processes can be, simultaneously, a technology of exploration and a technology of nonlocal action, as a general rule, not all technologies of exploration need be a technology of nonlocal action too, and vice versa.

developed in this paper can, and should, be understood as a technology of exploration (March, 1991, 1994, 2006, 2010) and technology of nonlocal action (Gavetti, 2011). We can now understand what this means more clearly. Strategic domain pioneering involves organizing knowledge creation activities towards achieving a capacity, or capability, to engage in construction, exploration, and reasoning processes involving models (as this construct has been developed in this paper) in some particular domain of science, engineering, or technology. These capacities make possible the kinds of Schumpeterian innovation in products, technologies, and productive capabilities (i.e., Winter's (2003) zero-level capabilities) that can have the capacity – under the right conditions – to transform industries and markets. The processes underlying strategic domain pioneering, therefore, represent a means of generating novelty and innovation; they are what March would call a technology of exploration (March, 1991, 2011). And as such, they open up the scope for nonlocal action through which firms have the opportunity to evade, however temporarily, the full brunt of competition that dominates performance when firms compete in similar parts of the competitive landscape (Gavetti, 2011). In so doing, they are a *technology for nonlocal action* – a means for pioneering new possibilities for positioning in the competitive landscape.

The most distinctive feature of strategic domain pioneering as a technology of exploration is that it is purposive. It involves a kind of intended knowledge creation that is analogous to Mintzberg, Ahlstrand, and Lampel's (1998: 12) construct of *intended strategy*. Just as the construct of intended strategy describes an organizational-level commitment to undertaking some highly specific set of integrated actions in pursuit of some set of more general organizational goals, strategic domain pioneering entails the development of highly specialized kinds of knowledge-related capacities – involving the capacity to operate in some specific, novel domain of science, engineering, or technology – in the pursuit of new strategic positions, opportunities, and sources of advantage (Kirzner, 1999; Klein, 2008).

Evolutionary models of strategy, by contrast, view innovation as essentially serendipitous: "economic agents may stumble upon distant opportunities, but they lack the intelligence needed to search for and act on them reliably" (Gavetti, 2011: 2). The technologies of exploration highlighted in this tradition are non-purposive; the analog, here, is something closer to Mintzberg et al.'s construct of *emergent strategy*. The guiding idea seems to be that investment in innovation is more like a lottery than a plan. Firms can take steps to build absorptive capacity to enhance their ability to recognize and adapt knowledge developed outside of the organization (Cohen and Levinthal, 1990; Volberda, Foss, and Lyles, 2010), create 'protected harbors' within the organization where ideas can grow free[6] from the more immediate constraints imposed by the logic of exploitation that characterizes the rest of the organization (Raisch, Birkenshaw, Probst, and Tushman, 2009; March, 2010), or encourage investment in R&D focused on novel, emerging, and pioneering technologies over familiar, mature, and propinquitous technologies in order to enhance the probability of making 'breakthrough inventions' (Ahuja and Lampert, 2001), but the knowledge outputs gained from these endeavors can not be specified or anticipated in advance, much less pursued purposefully – they are strategies for endogenizing luck by investing in serendipity.

Emergent and intended strategy are complementary (Mintzberg, Ahlstrand, and Lampel, 1998). So too are purposive technologies for exploration, like strategic domain pioneering, and non-purposive technologies of exploration, like those highlighted in the prior paragraph. They are different means to similar ends. The objective of purposive and non-purposive technologies for exploration alike is to enable innovation. Their are significant differences, though. Perhaps the most important difference is that purposive technologies for exploration, like strategic domain pioneering, enable the deliberate pursuit of nonlocal action in ways that non-purposive technologies for exploration do not.

Strategic domain pioneering involves pioneering specific kinds of novel technologies or pushing specific new fields of scientific research and discovery forward at the organizational-level. When undertaken with an eye to the construction of specific opportunities (Kirzner, 1999; Klein, 2008; Sarasvathy, Dew, Read, and Wiltbank, 2008) via Schumpeterian innovation in products, technologies, and the means of production, such idiosyncratic knowledge resources can be a powerful source of competitive advantage (Barney, 1986b; Barney, 1991; Hamel and Prahalad, 1994, Nonaka, Toyama, and Nagata, 2000; Nickerson and Zenger, 2004). This is especially true when strategic

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[6] Or, at least, freer than they would be, otherwise.

domain pioneering is undertaken in the context of an overarching set of plans about how the firm will compete in the market and differentiate itself from its rivals on the basis of the new knowledge so developed (c.f., Chiles, Bluedorn, and Gupta, 2007; Klein, 2008) and when it involves the construction of new, complex, and highly idiosyncratic organizational capabilities (Teece, 2007; Augier and Teece, 2009) that enable the firm to compete in ways that rivals find difficult to replicate or otherwise respond too.

Whereas strategic domain pioneering processes are undertaken in the context of – and oriented towards – a firm's intended strategy, the whole point of non-purposive technologies for exploration is to encourage discovery and invention outside of the current range of firm activities and strategies. They exist to generate novelty (March, 2010). But novelty, in and of itself, is far from sufficient to underwrite the pursuit of nonlocal action in the absence of an overarching drive toward the creation of new opportunities and capabilities (Klein, 2008; Teece, 2007; Augier and Teece, 2009). Non-purposive technologies for exploration create something like real options (McGrath, 1999; Adner and Levinthal, 2004). In order to become strategically valuable, these options have to be further developed and incorporated into the organization's plans and primary strategic thrusts.

At the same time, non-purposive technologies for exploration are agnostic, for the most part, about the magnitude of novelty that is generated as measured by ability of the firm to underwrite nonlocal moves on the competitive landscape on the basis of the knowledge so generated. In the first place, radical discoveries in the laboratory do not necessarily always lead to disruptive effects on competitive positioning. But perhaps more importantly, there is nothing like a 'magnitude of novelty' parameter setting for non-purposive technologies for exploration that management can adjust to suit its needs. Non-purposive technologies for exploration remain something of a black box of innovation where the outputs generated are rather ambiguously related to inputs (i.e., time, money, effort) invested and where the magnitude of discovery and invention is seemingly randomly distributed, largely outside the control of management intervention or control (c.f., Ouchi, 1979).

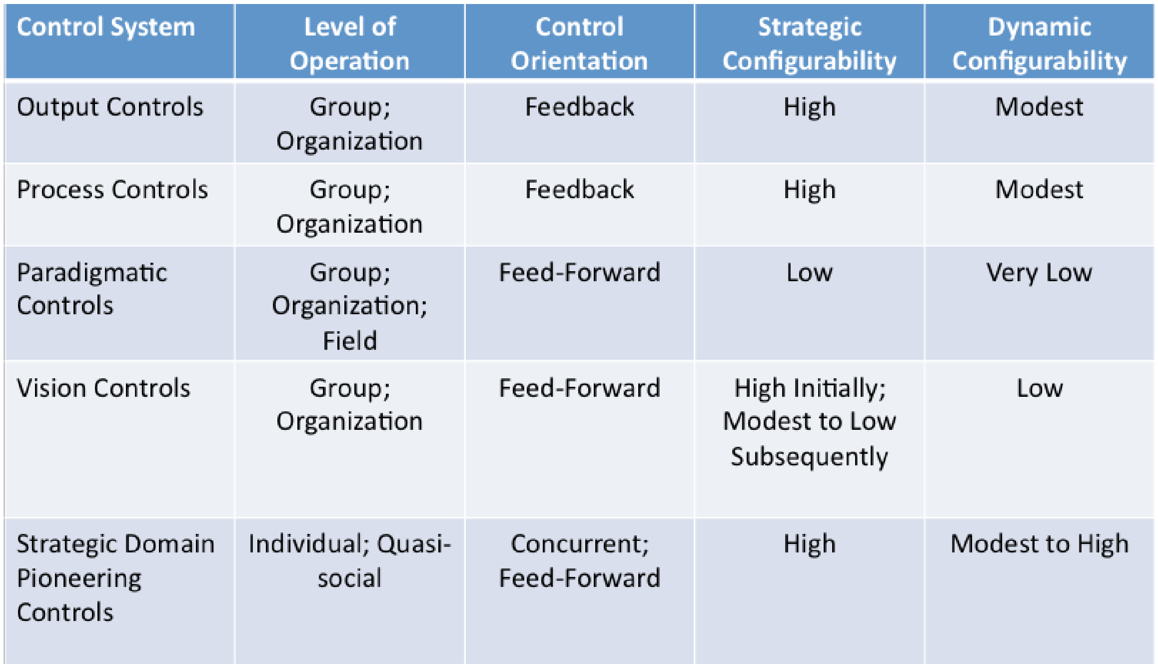
A second set of implications concerns the theory of organizational and managerial control systems. The literature on control systems has identified four primary kinds of control systems: (i) *output controls*, which operate by pre-specifying desired results and measuring organizational outputs to determine if outputs are aligned with objectives (Ouchi, 1979; Eisenhardt, 1985; Simons, 1995); (ii) *process controls*, which operate by pre-specifying the procedures or algorithms to be employed in a particular production process and monitoring organizational processes and routines to ensure that the correct procedures are, in fact, being followed (Ouchi, 1979; Eisenhardt, 1985; Simons, 1995); (iii) *paradigmatic controls*, which operate by instilling a set of common norms, values, beliefs, identities, role-structures, and conceptual frameworks in a group via in-depth socialization processes which act to both guide and constrain group member actions and decisions (Berger and Luckmann, 1966; Kuhn, 1970; Lakatos and Musgrave, 1970 Ouchi, 1979; DiMaggio and Powell, 1983; March, 1994; Simons, 1995; Kogut and Zander, 1996; Bird, 2000; Weick, Sutcliffe, and Obstfeld, 2005; Emirbayer and Johnson, 2008); and (iv) vision controls, which operate by specifying higher-order (organizational) goals, strategic intent, and aspirations that enable individuals and groups to orient myriads of diverse current activities towards an overarching, commonly held, long-term ideal that defines the organization’s mission and organizing purpose (Weick, 1979; Hamel and Prahalad, 1993, 1994; March, 1994; Simons, 1995; Nonaka and Toyama, 2005). Collectively, these four modes of control offer a wide scope of different mechanisms for driving behavior towards desired ends. At the same time, one can reasonably ask whether or not these four modes of control represent a comprehensive typology of control that spans the space of possibilities. The answer I would like to suggest is that they do not.

The theory of strategic knowledge creation outlined in this paper explains how, in principle, organizations have the capacity – to some extent at least – to shape the trajectory of scientific, technological, and engineering knowledge creation and knowledge outputs over time. It illustrates, in other words, how knowledge creation processes can be purposefully directed toward particular ends in accord with the organization’s overarching strategic goals (c.f., Hamel and Prahalad, 1994; Kirzner, 1999). More specifically, the model of strategic domain pioneering introduced here outlines a number of important mechanisms and processes that have the capacity to shape the large-scale structure of inquiry by way of structuring novel research programs and positing novel conceptual frameworks and the capacity to influence the fine-structure of inquiry by influencing the ongoing trajectory of cognitive activity by means of coordination dynamics and heuristic prompts.

In practice, the three main processes of strategic domain pioneering used to pioneer novel domains of scientific, engineering, and technological knowledge and expertise – domain structuring processes, element seeding processes, and coordination dynamics – can be recognized in many instances of actual scientific and engineering practice. Domain structuring processes, for example, can be found in David Marr's (1982) exposition of the levels of analysis framework for the cognitive sciences, Andy Clark's seminal work on extended cognition (e.g., Clark, 1997) or Anthony Chermero's work on embodied cognition (e.g., Chermero, 2009), each of which, in different ways, seeks to recast the basic explanatory project in the cognitive sciences. By the same token, one can find many rich examples of element seeding processes in the history of science, like Marvin Minsky's (1985) elaboration of the society of mind framework for cognitive modeling or Newell and Simon's (e.g., 1976) characterization of the physical symbol system hypothesis, both of which provided the conceptual raw materials for generations of subsequent scientific model building exercises. Finally, one can see examples of coordination dynamics in play in Hargadon and Bechky's (2006) explication of the processes at work in the genesis and maintenance of creative collectives and the examination of the central role 'boundary objects' play in engineering design and new product development seen in the work of Bucciarelli (2002) and Carlile (2002, 2004).

Once understood, these processes are easy to recognize and identify. The fundamental role that these processes play in knowledge creation, though, has been obscured, however, by the theoretical lens provided by the standard accounts of knowledge creation in the management and strategy literatures. The theory of strategic domain pioneering presented here, by contrast, explains the central role that these processes play in scientific, engineering, and technological knowledge creation and points towards an understanding of how firms could wield these knowledge creation processes towards strategic ends by simply deploying them in proprietary organizational settings.

This ability to shape the products of scientific, technological, and engineering knowledge creation processes towards specific strategic ends entails that strategic domain pioneering processes constitutes a kind of organizational or managerial control system. The mechanisms and processes involved in strategic domain pioneering, however, operate via very different kinds of principles than do the four modes of organizational and managerial control highlighted in the literature on control systems introduced above. This suggests, in turn, that these four modes of control represent, at best, an incomplete typology of control systems. By introducing a set of principles for the strategic control of scientific, technological, and engineering knowledge creation, the model of strategic domain pioneering introduced here opens up the possibility of new forms of organizational and managerial control (c.f., Rescher, 2012: 9). Figure 2 provides what I suggest can be considered an expanded typology of strategic control systems that highlights the unique characteristics of these strategic domain pioneering systems relative to the kinds of output, process, paradigmatic, and vision modes of control that have dominated prior discussions of management and organizational control systems across a number of fundamental dimensions.



Control System	Level of Operation	Control Orientation	Strategic Configurability	Dynamic Configurability
Output Controls	Group; Organization	Feedback	High	Modest
Process Controls	Group; Organization	Feedback	High	Modest
Paradigmatic Controls	Group; Organization; Field	Feed-Forward	Low	Very Low
Vision Controls	Group; Organization	Feed-Forward	High Initially; Modest to Low Subsequently	Low
Strategic Domain Pioneering Controls	Individual; Quasi-social	Concurrent; Feed-Forward	High	Modest to High

Figure 2. A Typology of Strategic Control Systems

A third set of implications concerns issues revolving around the proper locus of analysis (Felin and Hesterly, 2007; see also Felin and Foss, 2005, 2006) for work on knowledge and knowledge creation in organizational contexts entailed by the theory of strategic domain pioneering outlined here. Historically, this has been a contentious issue (Felin and Hesterly, 2007). As Felin and Hesterly note, the debate has been dominated by two positions: *methodological individualism*, which asserts, categorically, in Simon's terms, that "all learning takes place inside individual human heads" (Simon, 1991: 125), and *methodological collectivism*, which asserts, on the contrary, that "knowledge is fundamentally a social phenomenon that is different from the aggregation of individuals" (Felin and Hesterly, 2007: 197) and that "technical 'knowledge' is an attribute of the firm as a whole, as an organized entity, and is not reducible to what any single individual knows" (Nelson and Winter, 1982: 63, cited in Felin and Hesterly, 2007: 197). This dichotomy, in turn, reflects deep methodological, epistemological, and ontological commitments regarding the proper natural kinds study for the study human action and the interrelations between these different levels of analysis (Dansereau, Yammarino, and Kohles, 1999; Felin and Foss, 2005, 2006; Hitt, Beamish, Jackson, and Mathieu, 2007).

The theory of strategic domain pioneering outlined here, however, gives pause to the naturalness of the levels of analysis staked out by the different sides of this debate. In short, it is neither strictly individualistic nor necessarily collectivist in its basic parameters. In the place of the traditional decomposition of social phenomena into a nested hierarchy of (potentially interacting) units of analysis that ranges over individuals, groups, organizations, networks, and environmental (e.g., cultural) levels, the theory of strategic domain pioneering outlined here is built around the emerging paradigm of extended cognition (Clark, 2008; Menary, 2010; Rowlands, 2010; Theiner, 2011, forthcoming) where the naturalness of traditional individual and supra-individual categories begins to break down and where the analytical locus is shifted to more complex kinds of amalgamated systems (Rowlands, 2010) of material and extra-individual resources that defy decomposition into the more traditional units of analysis that have been postulated within the social sciences.

So what does the theory of strategic domain pioneering forwarded here have to say about the proper level of analysis for a theory of knowledge and knowledge creation? Strategic domain pioneering involves constructing the capacity to build, explore, and reason with models in novel domains of scientific, engineering, and technological activity. As outlined in the model presented here, both the capacity to engage in these kinds of model-based cognitive activities, which are constitutive of scientific, engineering, and technological competency, and the processes involved in pioneering new domains of scientific, engineering, and technological competency are made possible – and constituted – by epistemic actions on external resources that comprise integral components of amalgamated systems of neural and extra-neural cognitive resources that have been assembled and/or constructed specifically for these purposes.

In contradistinction to traditional individualistic or collectivist theories of knowledge and knowledge creation, the theory of strategic domain pioneering outlined here asserts that these *amalgamated systems* (Rowlands, 2010) – and not individuals or groups as they have normally been conceived in discussions of methodological individualism or methodological collectivism (Felin and Foss, 2005, 2006) – are, in fact, the proper locus of scientific, engineering, and technological knowledge and knowledge creation. That is to say, they are the natural kinds that are the proper objects of a theory of scientific, engineering, and technological knowledge and knowledge creation. In this regard, the theory of strategic domain pioneering forwarded here is congruent with the new conception regarding the proper natural kinds for the cognitive sciences outlined by Clark (2008), Rowlands (2010), and Theiner (2011) – what Rowlands has called 'the new science of mind': "*new* because it is underwritten by a novel conception of what sort of thing the mind is" (2010: 1, emphasis in original). As Rowlands argues, this new, non-Cartesian, paradigm for the cognitive sciences is predicated on the idea that:

> Some cognitive processes are composed, in part, of structures and processes that are located outside the brain of the cognizing subject. Cognitive process are an *amalgam* of neural structures and processes, bodily structures and processes, and environmental structures and processes….the idea of mental process as amalgamations (2010: 83).

As argued here, scientific, engineering, and technological cognition and knowledge creation involves amalgamated systems that are constructed around biological individuals. These special-purpose cognitive systems are centered around the biological individuals of methodological individualism, but it is the system as a whole that is the proper unit of analysis (Clark, 2008, 2010). Here, the machinery of cognition spills out beyond the biological individual to include material resources (e.g., Clark, 2008; Rowlands, 2010; Thiener, 2011) and, in certain contexts, other cognizing individuals (Theiner, forthcoming; c.f., Hargadon and Sutton, 1997; Hargadon and Bechky, 2006) as proper parts of the larger functioning cognitive system engaged in scientific, engineering, and technological cognition and knowledge creation.

The theory of strategic domain pioneering, then, entails something more than a simple individualism because fundamental components of the cognitive systems involved in scientific, engineering, and technological cognition extend beyond the boundaries of individual cognizers to include the epistemic niche these cognizer construct to augment their basic cognitive capacities (Clark, 2008). Absent these extended resources – whether material extraneural resources or , under the proper circumstances, the participation of other connected cognizers – the system's performance is quite different than what it would be otherwise; perhaps radically so. From a functionalist perspective (e.g., Clark, 2010; Rowlands, 2010) these external resources are proper parts of the relevant cognitive systems. The cognitive processes involved in scientific, engineering, and technological cognition are literally distributed across the parts of the physical and social environment in which the focal cognizer is situated.

The boundaries of these extended cognitive systems are fluid and porous. What counts as a part of any given extended cognitive system at any given time depends on the particularities of the causal couplings between the different external components that are generated by the actions of the focal cognizer (Clark, 2008; 2010). And while some external material components are assembled from common-use artifacts that are widely available to a given group (Sterelny, 2004; Hutchins, 2005), many are bespoke constructions created for the ad hoc purposes at hand (Goel, 1995; Clark, 2008) or are best seen as temporary scaffolding used to generate future knowledge and cognitive capabilities (Clark, 2008; Stotz, 2010).

At the same time, under the right circumstances, active elements (c.f., Clark, 2008 on active externalisms) of one cognizer's extended cognitive system can come to be incorporated into the extended cognitive systems of additional cognizers who are focused on similar cognitive tasks and who are working in common-use (physical or even virtual) spaces. Nersessian (2009) calls these shared external elements *hubs*. These hubs form intrinsic components of multiple extended cognitive systems, although the various cognitive role(s) these hubs play in the extended cognitive systems of different cognizer's need not be identical. In some circumstances, these hubs may be used concurrently, but this is not a necessary feature. Often, as Nersessian (2009) has noted, they used asynchronously. What matters is that they sit in the intersection, or overlap, of different extended cognitive systems oriented toward some set of shared (though not necessarily identical) epistemic goals.

The theory of strategic domain pioneering, however, is less than fully social as the term is commonly understood in the context of methodological collectivism. From the perspective of a theory of knowledge and knowledge creation, Felin and Hesterly (2007) argue that the debate between methodological individualism and methodological collectivism ultimately revolves around issues involving the locus of knowledge, i.e., at what level of analysis are the explanadum and explanans of the theory properly understood to reside. As Felin and Heterly (2007) note, methodological collectivists argue that groups or organizations have knowledge and/or cognitive capabilities that are not reducible to those of the individuals, or aggregates thereof, that comprise the higher-level units of analysis. Methodological individualists, by contrast, disagree; arguing instead that all knowledge and/or cognitive capabilities of higher-level units must ultimately be understood to reside in the knowledge and cognitive capabilities of specific (heterogenous) individuals (Felin and Hesterly, 2007) and that knowledge or capability ascriptions to higher-level units of analysis are epiphenomenal.

Felin and Hesterly (2007) suggest the key criteria for ascribing knowledge or cognitive capacities to higher-order, social levels of analysis rests on the preservation of competency in the face of cleavage. If the higher-order unit of analysis's aggregate effective knowledge and/or cognitive capacities are approximately the same before and after the removal of an individual, then the higher-order unit can be properly be said to be the locus of knowledge. If the higher-level unit's capabilities are degraded, on the other hand, than logically one must conclude that the locus of knowledge is not at that level.

Is scientific, engineering, and technological competency robust to cleavage? The evidence suggests, on the contrary, that organizational performance is, in fact, highly sensitive to the contributions of individual scientists, engineers, inventors, and technologists (e.g., Zucker and Darby, 1999), so clearly, the empirical evidence would seem to suggest that this does not seem to be the case. At the same time, there are strong theoretical reasons to doubt that competency would be robust to cleavage. The theory of strategic domain pioneering outlined here asserts that the kinds of extended cognitive systems that are at the core of scientific, engineering, and technological competency are organized/constructed by specific individuals and that the competencies involved in building, exploring, and reasoning with models, which is at the core of scientific, engineering, and technological competency, is a capacity that inheres to these very local extended cognitive systems. While the full competency surely resides at the level of the extended cognitive system, the system itself is an actively constructed and maintained extension of an individual cognizer (c.f., Popper, 1979). And unlike organizational routines (Levitt and March, 1988; Winter, 2003; Felin and Foss, 2009), or culture and identity (March, 1991; Kogut and Zander, 1996; King, Felin, and Whetten, 2009), if the focal cognizer is removed, the competency is degraded, perhaps even eliminated (the question here depends on the degree to which the particularities of the competency in question are redundant within the larger unit; redundancy, however, is not the same as supra-individual competency). Though the extended cognitive systems of individual cognizers can include common-source resources (Sterelny, 2004), hubs (Nersessian, 2009), and even other cognizers (c.f., Hargadon and Sutton, 1997; Hargadon and Bechky, 2006; Theiner, forthcoming) under special circumstances, the locus of these cognitive systems remains centered on the individual cognizers at the center of such extended systems in whom the capacity to build, explore, and reason with models is ultimately rooted.

It would seem, then, that the theory of strategic domain pioneering fits poorly into the mold of either methodological individualism or methodological collectivism. Scientific, engineering, and technological cognition and knowledge creation depend intimately on supra-individual amalgamations of material and social resources. Yet, at the same time, scientific, engineering, and technological competency remains stubbornly granular and decidedly non-organizational in its basic nature. Extended cognitive systems can be – and frequently are – hosted in larger organizational forms, but they are not intrinsically social as the construct is traditionally understood. They are something else, something different (c.f., Rowlands, 2010; Theiner, 2011).

What, then, is the alternative? It would seem that the model of strategic domain pioneering introduced here points towards what can be thought of as a *quasi-social* level of analysis as the locus of knowledge. As developed here, this quasi-social locus of knowledge and knowledge creation has three main features. Like frameworks based on methodological individualism, the theory of strategic domain pioneering outlined here asserts that scientific, engineering, and technological cognition and knowledge creation is centered on individual cognizers and acknowledges the sharp degradation of the capacities of higher-level units following cleavage. At the same time, congruent with frameworks based on methodological collectivism, the theory of strategic domain pioneering acknowledges that, under the right circumstances, the cognitive capacities of individual cognizers can depend on the establishment of amalgamated systems that have other cognizers as proper parts (c.f., Theiner, forthcoming; see also Hutchins, 1995b) and it asserts that knowledge creation often (though not necessarily always) fundamentally depends on the contributions of other cognizers acting synchronously (Hargadon and Sutton, 1997; Hargadon and Bechky, 2006) or asynchronously (Bucciarelli, 2002; Carlile, 2002, 2004; Nersessian, 2009). Finally, in line with Donald (2001) and Sterleny (2004), the theory of strategic domain pioneering highlights the central role of common-use epistemic resources in higher-level reasoning and, in congruence with Popper (1979), it focuses attention on the central role prior theories and stylized facts (c.f., Helfat, 2007), construals of problem situations, and lines of critical argument play in structuring future knowledge creation processes.

The postulation of a novel level of analysis may seem like a rather radical move at first glance. It certainly contradicts the widely held intuition that there is a definite hierarchy of ‘natural’ levels to the world (Kim, 2002). Kim argues that this concern is misplaced: “I think that attempts to construct an overarching levels ontology for the whole of the natural world in which every object has its ‘appropriate’ place are rather pointless if not hopeless” (2002: 16). In place of a fixed hierarchy or levels, Kim argues for a more pragmatic where the demands of the inquiry determine the appropriate locus for theory:

> The thing to note here is that this is a kind of top-down approach: we first select a kind of interest to us, say biological organisms or a selected group of biological species, and ask how their properties and behaviors can be explained in terms of their microstructure. What microentities and microproperties are to be invoked in such explanations is not fixed in advance; their choice is entirely opportunistic (2002: 18).

In the context of strategic domain pioneering, inquiry is focused on knowledge creation in new domains of scientific, engineering, and technological activity that is purposefully oriented toward Schumpeterian modes of competition – i.e., competition via new products or services, new technologies, the construction of new kinds of markets and new modes of production, etc. Trying to understand how these strategic knowledge processes work, however, has been problematic. As seen, the standard account of cognition and knowledge creation in the management literature – exemplified by the seminal work of Cohen and Levinthal (1990), Kogut and Zander (1992), and Nonaka (1994) – does a poor job explaining these phenomena.

Accordingly, in this paper, I point toward an alternative framework for understanding these kinds of strategic knowledge creation processes. It is an account grounded in the idea that conceptual, or Galilean, models are at the core of scientific, engineering, and technological cognitive representations and that scientific, engineering, and technological cognition and knowledge creation depends on, and is, in fact, constituted, by epistemic action on extraneural cognitive resources that are best understood as Galilean thought tools. And it is an account where the locus of knowledge is best understood in terms of (quasi-social) amalgamated systems that do not fit neatly into the traditional categories forwarded by methodological individualism or methodological collectivism. The warrant for this move, I would argue, ultimately needs to be assessed in terms of the epistemic gain this theory of strategic domain pioneering offers to scholars interested in strategic knowledge creation and the pragmatic leverage it provides organizations seeking insight into the management of scientific, engineering, and technological knowledge creation.

One final point merits consideration. Strategic domain pioneering seems to to entail a paradox. The theory asserts that scientific, engineering, and technological knowledge creation – in analogy to the construct of *intended strategy* (Mintzberg, Ahlstrand, and Lampel, 1998) – can be directed toward specific ends, congruent with the organization's overarching goals. But, as Rescher notes, prima facie, this seems deeply problematic: "knowledge about the future poses drastic problems. And the issue of knowing the future of knowledge itself is particularly challenging. No-one can possibly predict the details of tomorrow's discoveries today" (2012:1). The problems become even more pressing when we consider the idea of predicting scientific, engineering, and technological knowledge creation. Again, Rescher argues "that aspect of the future which is most evidently unknowable is the future of invention, of discovery, of innovation–particularly in the case of science itself" (2012:2). The problem seems to be that if the future of knowledge is inherently opaque and inscrutable, how is it possible to effectively navigate to particular ends ? How can these two divergent claims be reconciled?

My answer is to this challenge is that setting off on a particular knowledge creation trajectory need not require precognition of the fine grain details of discovery, invention, and innovation in order for the activity to be strategic. *Realized strategy*, Mintzberg, Ahlstrand, and Lampel (1998) argue, is the resultant, or culmination, of *intended* and *emergent* streams of action. The same, I would argue, is true for strategic knowledge creation. The theory of strategic domain pioneering is a theory of *intended strategy*, not a theory of *realized strategy*. And it certainly does not preclude the emergent component. Again, as Rescher notes:

> It is a key fact of life that ongoing progress in scientific inquiry is a process of *conceptual* innovation that always places certain developments outside the cognitive horizons of earlier workers because the very concepts operative in their characterization become available only in the course of scientific discovery itself (2012: 3).

The apparent paradox, then, resolves when strategic domain pioneering is put in the proper perspective. Strategic knowledge creation involves establishing a conceptual framework and disciplinary matrix (Bird, 2000) with which it is possible to pioneer a novel domain of scientific, engineering, or technological knowledge in the expectation of being able to use the knowledge gained for future strategic gain. In the end, it is nothing like predicting a set of knowledge outcomes. Rather, it is about constructing the means for generating them. Quine describes the process this way:

> As scientists we accept provisionally our heritage from the dim past, with intermediate revisions by our more recent forebears; and then we continue to warp and revise. As Neurath has said, we are in the position of a mariner who must rebuild his ship plank by plank while continuing to stay afloat on the open sea (2004: 308).

2.8. CONCLUSION

Schumpeter (1976) argued that nonlocal action – the introduction of new products and services, new technologies, new modes of production – has the power to dramatically remake industries and markets (c.f., Barney, 1986b; Kirzner, 1999; Gavetti, 2011). While the importance of invention, innovation, and creativity in the market process has become almost axiomatic in the strategy literature over the past several decades (e.g., Buchanan and Vanberg, 1991; Kirzner, 1999; Klein, 2008; Sarasvathy, Dew, Read, and Wiltbank, 2008; Volberda, Foss, and lyles, 2010); the actual processes underwriting these modes of strategic and entrepreneurial action remain, rather stubbornly, largely a *terra incognita*.

Strategic domain pioneering is a technology for exploration and nonlocal action. It is, in other words, a means for harnessing the power inherent in invention, discovery, and creativity for strategic ends. As such, it is complimentary to the processes of opportunity discovery and construction, capability shaping, and stakeholder management outlined in Gavetti’s (2011) new ‘behavioral theory of strategy’ and deeply congruent with Gavetti’s conception of strategic agency understood in terms of the ability to manage cognitive representations and mental processes. And like Gavetti’s behavioral theory of strategy, the theory of strategic domain pioneering ultimately seeks to shed light on the processes of strategic and entrepreneurial agency underpinning Schumpeterian modes of competition.

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3. Leveraging Dynamic Capabilities: A Contingent Management Control Systems Approach

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3.1. ABSTRACT

Dynamic capabilities help explain why some organizations survive overtime. However, they have been mostly viewed as abstract phenomena with limited attention given to the mechanisms that managers might use to create and direct them. In this chapter, we present a model that explains how contingent management control systems leverage the organizational behaviors necessary for dynamic capabilities. We focus on how variations in environmental velocity affect the characteristics of the feedback that these systems receive. This in turn influences control system emphasis and the paradoxical forces of exploitation and exploration that guide and direct the capability processes of coordination/integration, learning and reconfiguration.

3.2. INTRODUCTION

Dynamic capabilities are a firm's ability to persistently modify or create organizational configurations for competitive advantage and improved viability (Teece and Pisano 1994; Teece, Pisano, and Shuen 1997, Zollo and Winter 2002, Eisenhardt and Martin 2000, Winter 2003, Helfat 1997). They have been defined as "the ability to integrate, build, and reconfigure internal and external competencies to address rapidly-changing environments" (Teece et al. 1997: 517). Thus, dynamic capabilities are the higher order capabilities that govern the rate of change in the competences (ordinary or operational capabilities), which help firms to make a living in the short term (Collis 1994, Winter 2003, Zhara et al. 2006).

However, despite the interest in dynamic capabilities there is limited work (see Ethiraj, Kale, Khrishnan and Singh 2005, Subramanian and Youndt 2005, Zollo and Winter 2002) on how managers create and maintain them. For like the resource-based view of the firm (Wernerfelt 1984, Barney 1991), which the dynamic capability view extends, research on dynamic capabilities has been described as “conceptually vague and tautological, with inattention to the mechanisms by which resources actually contribute to competitive advantage (Eisenhardt and Martin 2000: 1106). So even though the dynamic capability view seeks to add or include the activities of management and leadership to the resource-based view, there is limited knowledge about how managers create and sustain this type of capability.

In this chapter, we argue that management control systems are tools for leveraging the organizational behaviors and outcomes necessary for dynamic capabilities. They are the formal and informal systems that managers use for decision-making and evaluation; and their effectiveness is contingent on various environmental and organizational aspects. We explain how management control uses two forms of feedback processing to provide guidance and understanding about a firm’s 'as-is' state, as well some sense of its potential 'to-be' scenarios. These inputs combine to provide information that directs and develops the three processes (coordination/integration, learning, and reconfiguration) that are the essence of a firm’s dynamic capabilities (Teece et al. 1997).

To explain how management control systems operate on these processes we use Simons’ (1994, 1995) levers of control framework, which consists of four control systems (beliefs, boundary, diagnostic and interactive) that combine to produce different behaviors for directing the operation and performance of firms. These systems provide what March (1976) calls ‘technologies of reason’ that monitor, reward and direct behavior according to pre-defined goals, and ‘technologies of foolishness’ that offset organizational rationality by promoting play, experimentation, learning so as to handle uncertainty and change. Together they help a firm’s long-term success by exploiting and refining current competences, while simultaneously exploring and installing fundamentally new ones.

We also argue that the operational and environmental context of the firm influences the design and effectiveness of its management control system. That is, different environmental conditions prompt or require firms to emphasize different combinations of belief, boundary, diagnostic, and interactive control system use. In particular, we consider how high-low variations in environmental velocity - the rate and direction of change in a firm's task environment - sway the emphasis that firms place on different control systems to create effective dynamic capabilities. The general theoretical model for these contingent control relationships are shown in figure 1.

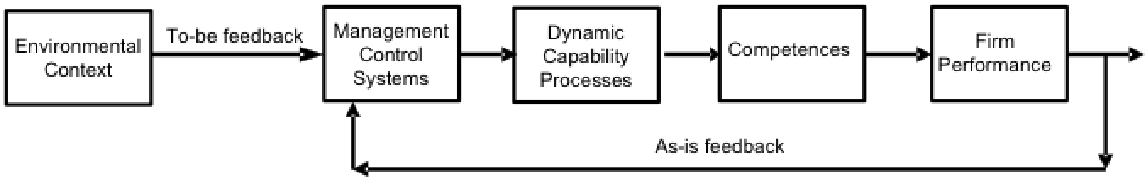


Figure 3. ***General Theoretical Model of Contingent Management Control and Dynamic Capabilities***

The rest of this chapter is organized as follows. It begins with an introduction to the concepts and relationships in figure 1. We then extend these to show how high and low environmental velocity conditions produce different types of feedback that encompass different types of control system, which then produces forces for exploration and exploitation that act on the dynamic capability processes. The paper then concludes with an account of the theoretical and practical implications of the model; and areas of future work.

3.3. Model Concepts

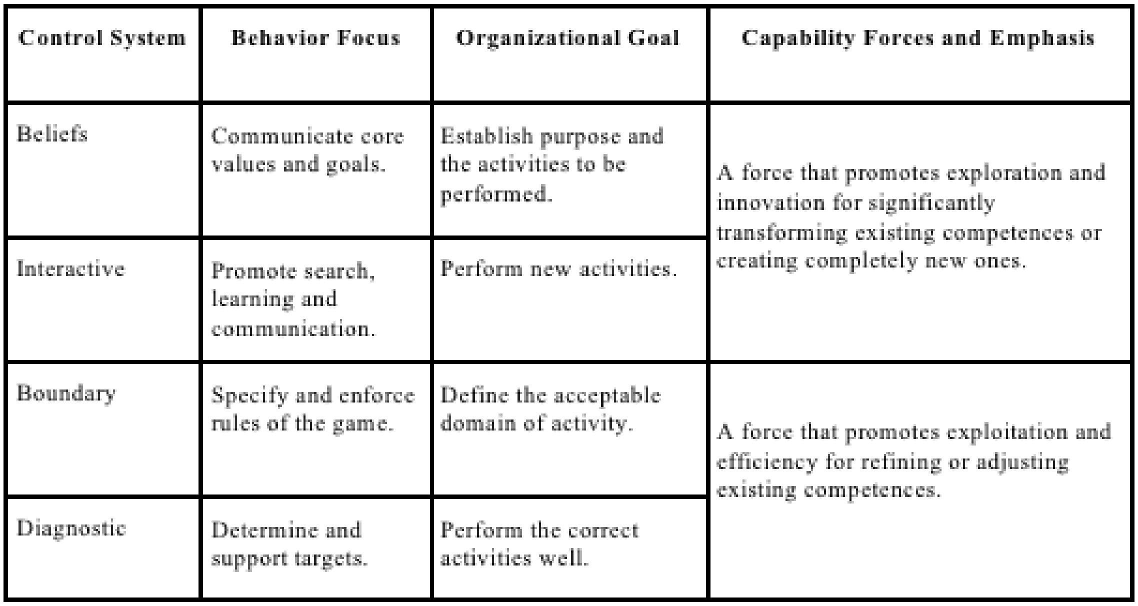
3.3.1. Management Control Systems as Dynamic Capability Levers

Dynamic capabilities provide a concept and language for considering why over time, some firms are more successful than others. As a consequence, there have been a significant number of articles that consider the concept of dynamic capabilities (e.g. Teece and Pisano 1994, Teece et al. 1997, Eisenhardt and Martin 200, Winter 2003) and their influence on firm performance (e.g. Adner and Helfat 2003, Helfat and Raubitschek, 2000, Klepper 2002). However, despite these contributions, we know relatively little about how managers actually coordinate, integrate and reconfigure existing competencies in accord with changes in the environment (see Eisenhardt and Martin 2000, Helfat 2000, Zott 2003). In this article we argue that contingent management control systems provide levers or mechanisms that managers can use to enable dynamic capabilities.

Management control systems are the planning, budgeting, measuring and communication systems that managers use for decision-making and evaluation (Langfield-Smith 1997, Marginson 2002). Research concerned with these systems originated from accounting approaches to control (Anthony 1965), but has since developed with inputs from the fields of organizational design and information management (Galbraith 1973), cybernetic control (Hofstede 1978, Edwards 1992), contingency theory (Waterhouse and Tiessen 1978, Otley 1980, Chenhall 2003) and strategic management (Ouchi 1979, Langfield-Smith 1997, Marginson 2002).

This broad view and development of management control has produced a number of insights, two of which we focus on. The first is that firms possess several control components or systems that work together, rather than separately, to influence a range of behaviors and outcomes (Otley 1980, Simons 1995). The second is that contingent management control systems provide information for planning and decision-making that fits the conditions of a firm's life-cycle and strategic and environmental context (Waterhouse and Tiessen 1978, Otley 1980, Chenhall 2003). Together these notions of control contingency and complementarity, support our view that management control systems provide levers which managers can use to maintain or alter patterns in organizational activities (Simons 1994). They are the measuring, comparing and intervention mechanisms that direct how firms explore and exploit the intangible (Shuen 1994) or invisible assets (Itami and Roehl 1987) that define their dynamic capabilities. Such control is also central to the learning needed for overcoming structural inertia (Hannan and Freeman 1977, 1984) and replacing or adjusting the 'sticky' resource endowments (Cyert and March 1963, Teece et al. 1997) that restrict the generation of new competences.

To explain the relationships between management control, capability processes and competence change, we use Simons (1995) 'levers of control' framework with its four types of control system: beliefs systems for core values, boundary systems for behavioral restrictions, diagnostic systems for monitoring and measurement, and interactive systems for consultation and proactiveness (see table 1). Together, these systems provide procedures and activities for exercising 'adequate control in organizations that demand flexibility, innovation and creativity' (Simons 1995: 80). They are complementary levers that combine to create dynamic tensions or forces that alter and enhance organizational capabilities (Henri 2006). These forces produce what Winter (2000) calls 'aspiration levels' that influence how far a firm intends to explore and create new competences, as opposed to the exploitation and refinement of existing competences. This in turn affects the type and level of coordination, integration, learning and reconfiguration.



Control System	Behavior Focus	Organizational Goal	Capability Forces and Emphasis
Beliefs	Communicate core values and goals.	Establish purpose and the activities to be performed.	A force that promotes exploration and innovation for significantly transforming existing competences or creating completely new ones.
Interactive	Promote search, learning and communication.	Perform new activities.	
Boundary	Specify and enforce rules of the game.	Define the acceptable domain of activity.	A force that promotes exploitation and efficiency for refining or adjusting existing competences.
Diagnostic	Determine and support targets.	Perform the correct activities well.	

Table 1. The Relationships Between Control System Foci and Capability Forces and Emphasis (Adapted from Simons 1995)

In table 1 the beliefs and interactive systems combine to produce behaviors that are central to the exploration and innovation needed to ensure the future survival of firms. The beliefs systems establish the purpose of the firm, by setting the domain of relevant strategic opportunities and providing an overarching framework for organizational identity and action. This involves determining the ‘explicit set of organizational definitions that senior managers communicate formally and reinforce systematically to provide basic values, purpose, and direction for the organization’ (Simons 1995: 34). Such control helps create the shared expectation and necessary unity to search for the opportunities that realize strategies (Pearce 1982, Widener 2007).

The interactive systems work in tandem with the beliefs systems to promote communication, learning and the emergence of new ideas and strategies. They help build an understanding of the strategic uncertainties facing the firm at any particular juncture in its history. This generates a form of organizational outwardness that enables the firm to search and understand its information climate, shorten the feedback cycles and influence its environment. It is a form of control that promotes sensemaking (Weick 1988) and helps reduce the negative consequences of limited, infrequent and degraded feedback by detecting and warning managers of any significant perturbations (Aguilar 1967, Daft and Weick 1984).

The diagnostic systems and boundary systems coalesce to help firms focus on competences that ensure efficiency and survival in the short-term. The diagnostic systems motivate, measure and reward progress towards specified goals. They also identify nonconformance and adjust organizational behaviors accordingly. This makes them important instruments for supporting the execution of intended strategies (Merchant 1990) and ensuring that firms perform the right activities well. However, this focus on efficiency can constrain innovation and opportunity seeking, hence why Simons (1995) argued that firms also need appropriate interactive and belief systems to encourage search and learning.

Boundary systems ‘are like an organization’s brakes’ (Simons 1995: 84), they help restrain and focus employees to ensure that the firm does not constantly wander off course. They use rules, policies, codes of conduct and operating directives, to explicitly delimit what portions of the strategic opportunity space will not be sought by the firm and what is the acceptable domain of activity (Simons 1994). This helps prevent firms from over exploring and becoming stretched and unfocused; as well as helping prevent the occurrence of institutionalized and systematic rule breaking that can sometimes occur as firms strive to consistently achieve ever-increasing performance goals.

3.3.2. As-Is and To-Be Feedback

For the process of control to exist there must be some form of ‘cybernetic validity’ (Beer, 1981), whereby negative feedback loops act as sensors and regulators. This feedback stimulates action to negate any discrepancies between environmental conditions and the performance of the firm (Beer 1981, Edwards 1992, Welsh and Green 1988). Without cybernetic control (Ashby 1966, Wiener 1948) firms are unable to self-regulate or reconfigure their competences in accord with any discrepancies they may have with their external environments. The result would therefore be stasis or inertia, which over time leads to firm mortality (Hannan and Freeman 1977).

For self-regulation to function, firms receive two types of negative feedback: ‘to-be’ feedback, which provides information about the conditions of the external environment (e.g. strategic scanning and acquisition of information about industry events, relationships and trends); and ‘as-is’ feedback, which provides information about the operational, financial and market performance of the firm. Together these two types of feedback provide signals and measurements that management control systems use to measure, compare and alter any inconsistencies between the as-is state, and potential to-be scenarios. Assuming that appropriate resources and abilities are in place, any discrepancy between these feedback conditions will energize a firm’s management control system to maintain or alter the distinctive processes (how a firm coordinates, integrates, learns and reconfigures its resources) that govern its position (the firm’s existing strategic assets and configuration) and potential paths (where a firm can go based on its current position) (Teece et al. 1997).

In table 2 we show how as-is and to-be feedback act on the three organizational and managerial processes, proposed by Teece et al. (1997): coordination/integration, learning and reconfigurability.

Coordination and integration provide two complementary activities. Coordination is concerned with how firms allocate, plan and efficiently organize resources and activities. Integration is the activity of obtaining, assimilating and developing new resources (e.g. acquisitions or alliances for accessing technology) to generate new routines or patterns of current practice

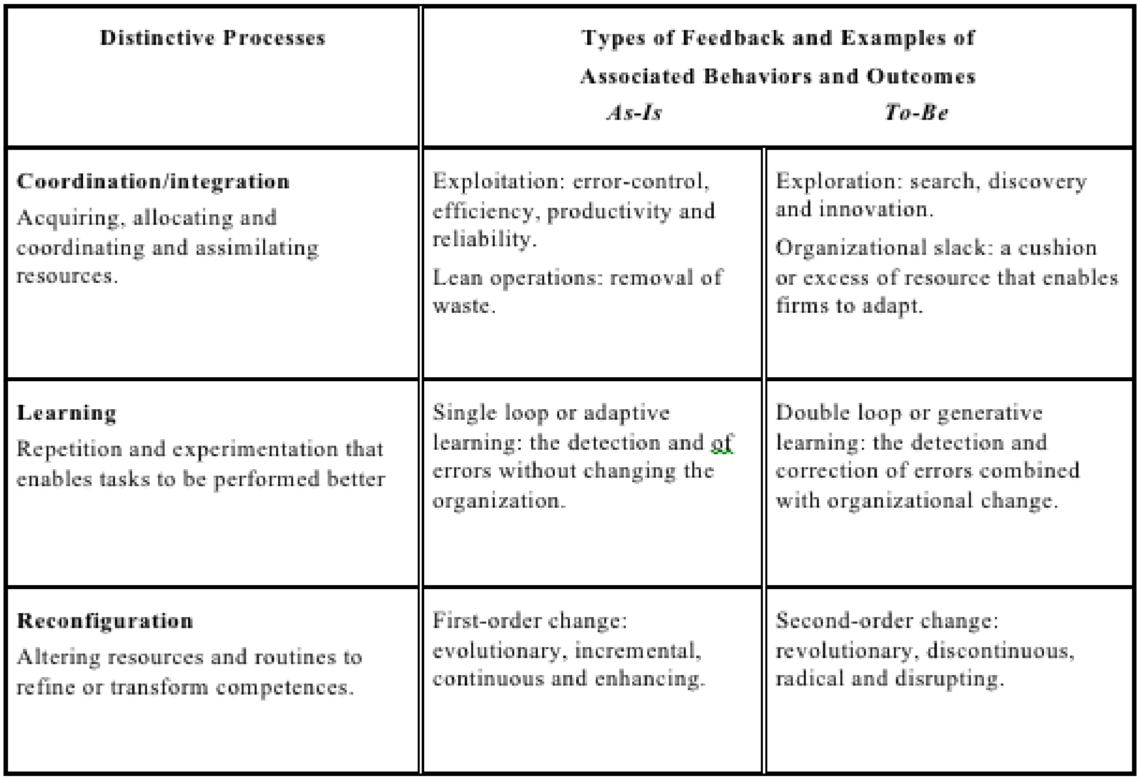
The process of learning provides different types of exploration and experimentation. It is a process that enables existing tasks to be performed better, quicker and more efficiently; or to produce novel thinking and resources that allow new competences to be identified and adopted. While, such learning is inherently a multi-level, self-organizing social activity, it also requires management control to promote common values and goals (beliefs systems) and to manage search procedures (interactive systems).

The process of reconfiguration is at the heart of a dynamic capability. It draws upon coordination/integration and learning, so as to scan for and monitor opportunities and threats. It then initiates the necessary change to ensure a better fit with the environment. As change is costly, the process of reconfigurability benefits from management control that calibrates and implements the change in a congruent, timely and efficient manner.

Each of these three dynamic capability processes receives as-is and to-be feedback which influences different process activities. For instance, as-is feedback prompts internal error-control behaviors, which measure, compare and alter process activities to help ensure the firm is in conformance with predetermined objectives and goals. Thus, behaviors induced by as-is feedback (see column of table 2) are normalizing, refining and modulating in nature. They include behaviors such as exploitation, whereby firms improve, optimize, upgrade or execute existing competences

(March 1991); lean operations which focus on removing waste from existing competences (Womack et al. 1991); single loop (Argyris and Schon 1978) or adaptive (Senge 1990) learning whereby incremental change is implemented without transforming core aspects of the firm. This as-is feedback induced activity also directly promotes continuous or first-order reconfigurability (Watzlawick, Weakland and Fisch 1974, Meyer 1982), whereby firm change is relatively incremental or conserving/entrenching in nature (Abernathy and Clark 1985).

As firms are complex open systems that interact with their environments, this firm-environment dependence also generates to-be feedback that complements and works with the as-is feedback. The to-be feedback is searching and anticipatory in nature. It stimulates behaviors (see the third column of table 3) that help lessen the negative consequences of uncertainty by providing adequate notice and information of changing environmental conditions for generating new organizational configurations. For example, firms might maintain excess or slack resource levels which are used for exploring and developing new knowledge (Barnard 1938, Thompson 1967, Bourgeois 1981). Such resource conditions promote double-loop (Argyris and Schon 1978) or generative learning (Senge 1990) where both the competences and the norms of the firms are challenged and changed.



Distinctive Processes	Types of Feedback and Examples of Associated Behaviors and Outcomes	
	As-Is	*To-Be*
Coordination/integration Acquiring, allocating and coordinating and assimilating resources.	Exploitation: error-control, efficiency, productivity and reliability. Lean operations: removal of waste.	Exploration: search, discovery and innovation. Organizational slack: a cushion or excess of resource that enables firms to adapt.
Learning Repetition and experimentation that enables tasks to be performed better	Single loop or adaptive learning: the detection and of errors without changing the organization.	Double loop or generative learning: the detection and correction of errors combined with organizational change.
Reconfiguration Altering resources and routines to refine or transform competences.	First-order change: evolutionary, incremental, continuous and enhancing.	Second-order change: revolutionary, discontinuous, radical and disrupting.

Table 2. Affect of Feedback on Dynamic Capability Processes

3.3.3. Environmental Velocity

As management control research recognizes that contingency impinges on the design (Chenhall 2003, Waterhouse and Tiessen 1978, Otley 1980), the interdependent use (Merchant 1990, Otley 1999) and the emphasis placed (Merchant 1990, Widener 2007) on different control systems, we enrich our model by explaining how a specific characteristic of a firm's context, environmental velocity, can influence the function and emphasis of its management control system.

Environmental velocity is defined as the rate and direction of change in demand, competition, technology and/or regulation (Bourgeois and Eisenhardt 1988). We focus on this environmental characteristic for three reasons. First it is a contingency factor that affects management control in terms of the decision-making processes (Bourgeois and Eisenhardt 1988 Eisenhardt 1999, Judge and Miller 1991) and the decision rules (Oliver and Roos 2005, Eisenhardt and Sull 2001) that firms use. Second it is an environmental characteristic that is central to Teece et al.'s (1997) notion of 'rapidly-changing environments' and related environmental phenomena such as turbulence (Dess and Beard 1984), hyper-turbulence McCann and Selsky 1984), clockspeeds (Fine 1998) and hyper-competition (D'Aveni 1994). And thirdly, for the reason that researchers have argued that there is a misconception that dynamic capabilities are useful only in rapidly changing, or high velocity environments (Moorman and Miner 1998, Zhara et al. 2006).

While this emphasis on high-velocity has been both valid and interesting, we agree with Moorman and Miner (1998) that it has overshadowed other scenarios, specifically the value of dynamic capabilities for organizations that face uncertainty and constraints from low rates of environmental change. Thus, with our model we contrast how high-low variations in environmental velocity affect the feedback that management control systems receive, which in turn influences how control systems combine and work to produce exploration and exploitation forces that act on dynamic capability processes.

To explain how high and low velocity environments differ in terms of characteristics and consequences, we can consider differences in the contexts of new technology-based firms. These organizations have internal and external conditions that span the temporal and innovation-based characteristics that demand dynamic capabilities. They are young, small, independent ventures that focus on the development and exploitation of technology (Bollinger et al. 1983, Rickne and Jacobsson 1999) and face liabilities of newness (Stinchcombe 1965) and smallness (Hannan and Freeman 1984). These conditions warrant some form of management control, which is regarded as a sign of legitimacy and professionalism and is positively related to firm survival and growth (Flamholtz and Randle 2000, Baron, Burton and Hannan 1996).

As new technology-based firms develop and exploit a technology independent of its newness or novelty (Bollinger et al. 1983), they can be concerned with leading edge science-driven research and radical innovations, or with applied product development and incremental innovations. Such variations in the basic-science intensity and the newness of the technology are crudely associated with different levels of environmental velocity. For instance, new technology-based firms concerned with basic-science research activity (e.g. biotechnology and nanotechnology firms) tend to operate in low-product velocity environments with lead-times in the region of 10-20 years. While, new technology-based firms concerned with applied research and development activities (e.g. computer games and consumer electronic firms), typically face high-velocity environments with product development lead-times of about 1–3 years.

These high-low variations in environmental velocity entail particular forms of technological and market uncertainty that produce to-be feedback which has variations in “grain” (Hannan and Freeman 1977). That is to say, a high-velocity environment generates to-be feedback that is frequent and short in duration (fine-grained) and firms operating in such environments require management control systems that cybernetically adjust, but also remain focused on core activities. Whereas low-velocity environments produce to-be feedback that is sporadic, degraded and long-term in nature (coarse-grained), requiring management control systems to emphasize organizational purpose and activities such as search, learning and communication.

3.4. CONTINGENT MANAGEMENT CONTROL AS A DYNAMIC CAPABILITY INSTRUMENT

This section provides a detailed theoretical model of how contingent management control leverages dynamic capabilities (figure 2.). It extends the relationships depicted in figure 1 by combining the effects of environmental context with control system foci (table 1) and the role of different types of feedback (table 2).

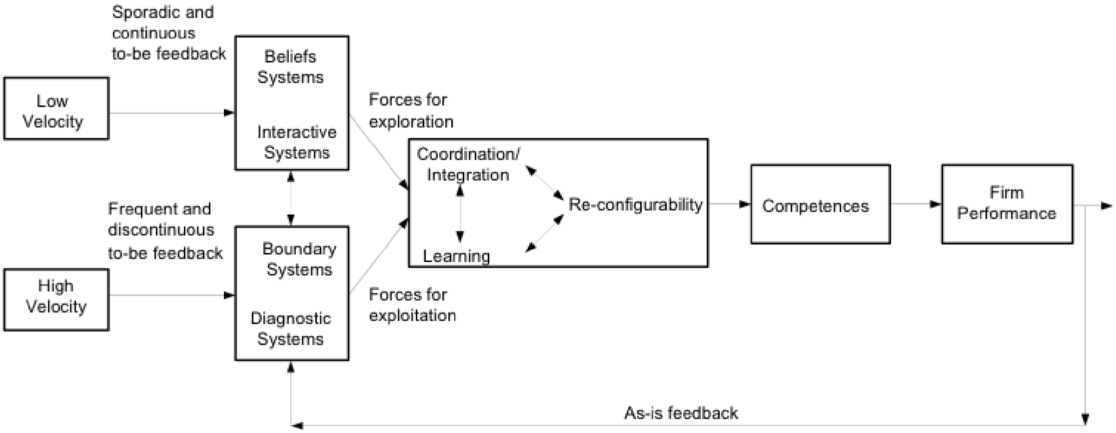


Figure 4. The Relationships Between Environmental Velocity, Management Control and Dynamic Capability Processes

As previously mentioned, variations in environmental velocity generate different forms of uncertainty and to-be feedback. The rapid and irregular change found in high-velocity environments tends to produce to-be feedback that is frequent and discontinuous in nature, as markets quickly change or new ones regularly emerge (Moriarty and Kosnik 1989). These conditions make it difficult for firms to develop a clear and comprehensive understanding of their environment, as the feedback soon becomes inaccurate, unavailable, or obsolete (Eisenhardt and Bourgeois 1988).

To search for, receive and process this type of to-be feedback, firms must be outward and responsive, but also formal, rational and comprehensive in terms of their internal planning and control (Bourgeois and Eisenhardt 1988, Eisenhardt, 1999). Such requirements call for management control systems that allow firms to process to-be feedback in a vigilant and sagacious manner, so as to monitor and restrict any inappropriate reactions to the frequent and discontinuous change. Therefore, we propose that in high-velocity environments, a joint emphasis on boundary systems and diagnostic systems will help screen, restrict and adjust organizational behaviors in line with environmental changes. The diagnostic systems promote adaptive and corrective action. While the boundary systems proscribe and limit strategically undesirable behaviors that may be triggered by the diagnostic systems as they continually consider and respond to high-velocity changes.

In contrast, low-velocity environments produce to-be feedback that is sporadic and expected in nature. Such long-term changes produce a perceived environmental stability that make it difficult to monitor and predict the patterns that eventually give rise to industry change. Thus, low-velocity environments produce to-be feedback that imposes unique cognitive challenges upon firms in terms of their ability to understand their environment through systematic scanning (Bogner and Barr 2000, Nadkarni and Barr 2007).

This type of to-be feedback necessitates a management control system that mutually emphasizes beliefs and interactive systems. The beliefs systems promote purpose and core values that enthuse employees to search, explore and create opportunities. Meanwhile the forward looking interactive systems watch for threats and opportunities, thus allowing for emergent strategy to serve changes in the environment (Widener 2007). Consequently, we propose that beliefs and interactive systems combine to help focus and motivate employees to achieve appropriate searching for and processing of feedback in low-velocity environments. This is necessary because coarse-grained to-be feedback demands organizational behaviors that promote structuration and exploration for present and future time frames.

Thus, for the first part of the model we posit that high-velocity conditions produce frequent and discontinuous to-be feedback that requires firms to jointly emphasize their diagnostic and control systems; and low-velocity conditions generate infrequent and sporadic feedback that requires firm to jointly empathize their interactive and beliefs systems. Such relationships are consistent with Simons (1995) arguments that the four control systems create complementary tensions. The beliefs and interactive control systems create positive energy for exploration and innovation, and the boundary and diagnostic systems produce a negative energy for exploitation and efficiency. This combination of feedback processing and control system emphasis provides stimuli for proactively and reactively achieving a dynamic capability (Hayes and Clark 1988, Dierickx and Cool 1989, Prahalad and Hamel 1990, Chandler 1990, Teece 1993, Teece et al. 1997).

The next stage of the model is concerned with how beliefs and interactive systems, and boundary and diagnostic systems, collectively act on dynamic capability processes to induce appropriate levels of exploitation and exploration (March 1991). This ambidextrous capacity (Duncan 1976, Tushman and O'Reilly 1997) is the basis of a dynamic capability, as firms must engage in "sufficient exploitation to ensure its current viability and, at the same time, devote enough energy to exploration to exploration to ensure its future viability" (March 1991: 105).

As shown in table 1 the beliefs and interactive systems work in tandem to promote forces for the scanning, searching, discovery and innovation activities that define exploration. And the diagnostic and boundary systems work together to generate forces for the error-control, efficiency, productivity and reliability activities that define exploitation. Both the exploration and exploitation forces act on a firm's resources via the distinctive processes of coordination/integration, learning and reconfigurability; and the emphasis between exploration and exploitation that these processes receive is dependent on the control system leverage. Thus, our theoretical model articulates how contingent management control systems facilitate the ambidextrous balance of exploration and exploitation required by a dynamic capability.

As different forces for exploration and exploitation act on the three distinctive capability processes, this will trigger different approaches to assigning resources and tasks, synchronizing activities, and searching for, acquiring and exploiting knowledge (see table 2). This control over the dynamic capability processes helps initiate a process of reconfiguration that refines or transforms competences in accord with the management control force imposed. Thus, we propose that if a firm's management control system is organizationally and environmentally congruent, it will be a significant determinant of dynamic capabilities and differential firm performance.

The final part of the model addresses the role of as-is feedback, which provides performance information that works with and complements to-be feedback. Consequently, as-is feedback is a control loop that directly connects firm outputs to the diagnostic part of the model to ensure that organizational processes receive sufficient cybernetic control. This provides goal oriented feedback that involves setting performance goals, measuring actual performance and comparing actual performance to the goals. It is a feedback cycle that provides motivational properties when discrepancies between actual performance and desired performance exist, thus altering or transforming organizational processes to reduce or eliminate the identified performance discrepancy.

Whereas to-be feedback helps firms to predict and compensate for disturbances that could create performance discrepancies, the as-is feedback detects errors or deviations from strategic and operational goals, after they have occurred. Thus, as-is feedback complements to-be feedback by counteracting any accrual of to-be errors that might occur as the firm responds to perturbations from the environment. And likewise for as-is feedback to function according to goals, the firm via its management control system, receives to-be information to form strategic scenarios.

Since as-is feedback focuses on performance measurement and conformance it tends to only prompt exploitive and reactive behaviors. These create changes in competences that are incremental or first-order in nature. If this corrective process keeps pace with the rate of performance discrepancies that a firm encounters, then single-loop learning and first-order change could be sufficient to ensure survival. However, if the discrepancy delta is too large for first-order change, then as-is and to-be feedback combine, via the management control system, to shift the forces for exploitation to exploration.

In summary, the relationships in figure 2 provide a picture of the interplay between variations in environmental velocity, interdependent control system components and the three dynamic capability processes. The model shows how these factors combine to process different types of to-be feedback, which produce and direct exploitation and exploration forces that ensure the current and future viability of a firm. We posit that this contingent management control approach provides a theoretical framework for addressing some of the ambiguities about how managers develop, maintain and direct dynamic capabilities.

3.5. CONCLUSIONS AND IMPLICATIONS

In the years since Teece and Pisano (1994) asked us to think about how firms extend, modify or create competences, and Simons (1994, 1995) proposed his levers of control framework, it has generally been recognized that individually each of these frameworks is positively associated with firm performance. However, the significance of combining the two has been overlooked. The aim of this chapter has been to help address this gap by integrating both frameworks with contingency theory. The resulting model helps explain how this contingent management control provides guidance and coordination that is both exploitative and explorative for achieving dynamic capabilities.

The model presents a number of broad and related contributions that have implications for both theory and practice. First, it represents how management control systems act as levers for dynamic capabilities, in a similar way to which Eisenhardt and Martin (2000: 1118) argue that “dynamic capabilities are best conceptualized as tools that manipulate resource configurations”. These control levers process feedback and generate forces that prompt and direct exploitative and explorative behaviors for refining or transforming existing competences.

A second core contribution is the notion that dynamic capabilities are achieved via multiple interdependent and complementary control systems. Specifically, we used Simons ‘levers of control’ framework to show that beliefs and interactive systems coalesce to promote apt search, discovery and learning, via the dynamic capability processes. Working in tandem with these two control systems are boundary and diagnostic systems, which combine to monitor, measure and if necessary restrict or alter the behaviors induced by the beliefs and interactive systems. These systems promote exploitation and the correction of performance discrepancies, while allowing exploration within pre-defined limits of freedom.

A third contribution of our model is that a firm’s organizational and environmental contexts will functionally and causally influence the effectiveness of its management control system and the potential for a dynamic capability. In particular, we argue that variations in environmental velocity affect control systems because of differences in the decision horizons, information quality and rates of change. High-velocity environments produce frequent and discontinuous to-be feedback, which suits the regulating and controlling nature of boundary and diagnostic systems. And low-velocity environments generate to-be feedback that is relatively sporadic and expected. This necessitates a commitment to organizational purpose and experimentation and learning, via the beliefs and interactive systems.

The practical implications of this work are that managers should note the characteristics of their environments and design management control systems to encourage process behaviors that ensure current and future survival. This contingency view recognizes that management control requires particular kinds of feedback to operate well, which also means that the environmental context acts as a filter that selects or permits fit management control systems, while rejecting unfit ones. Thus, regardless of the functional or causal influence, management control system contingency means that in some environments particular aspects of a management control system will work well, while in others they could be relatively ineffective at best, or pernicious at worst.

We also help to inform practice by explaining how contingent management control relates to a firm's dynamic capability potential. In particular, it indicates how managers might overcome the challenge of creating and managing the ambidextrous organizational form that is deemed central to a dynamic capability. We suggest that contingent management control also requires a 'dynamic' or adaptive perspective to achieve this organizational form. That is, the configuration and use of a management control system, like a firm's processes and competences, can be changed, or toggled over time to produce behaviors and outputs in accordance with environmental expectations.

This notion of dynamic and contingent management control is also the essence of capability learning, whereby the control systems act as levers for starting, stopping and re-directing different types of learning (Winter 2000). The degree of deviation from a desired performance level provides stimuli that influence the aspirations to new competences, the level of adjustment required and the amount of organizational energy needed. These factors affect a firm's ability to adapt to changing circumstances and alter their resources and routines over time.

Furthermore, the acknowledgement that management control systems and corresponding competences should learn and adapt, helps avoid unfit legacy systems that maintain existing coordination/integration practices and keep the firm rooted to existing competences. To overcome such inertia, management control systems can be adjusted to redirect the resources and routines for attaining the coordination/integration, learning and reconfiguration needed for strategic renewal.

While this chapter highlights and explains the role of contingent management control systems in enabling dynamic capabilities, there are some limitations which provide opportunities for further research. First, this study is deliberately restricted in environmental scope, in that it focuses only on variations in velocity. Although this was intentional to illustrate the effect of a relevant environmental characteristic, it is acknowledged that this introduces a simplification. Further research might consider the effect of other environmental characteristics such as munificence (Aldrich 1979, Castrogiovanni 1991) and complexity (Emery and Trist 1965, Cannon and St John 2007) on management control system effectiveness.

In summary, the problem of achieving and using dynamic capabilities involves a number of strategic and organizational issues. By focusing on management control systems, we suggest that its scope and influence are broad enough to balance a firm’s as-is feedback and to-be feedback processing. This is essential for resolving the ambidexterity demands of dynamic capability, as control systems harmonize the energies and tensions that drive and balance exploitation and exploration. This helps avoid the effects of too little feedback (to-be and as-is) that would fix a firm to its current configuration, while limiting the consequences of excessive to-be feedback that keeps the firm in a constant flux, unable to deliver value.

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4. Achieving Contextual Ambidexterity in R&D Organizations: A Management Control System Approach

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4.1. Abstract

Research on how managers control R&D activities has tended to focus on the performance measurement systems used to exploit existing knowledge and capabilities. This focus has been at the expense of how broader forms of management control could be used to enable R&D contextual ambidexterity, the capacity to attain appropriate levels of exploitation and exploration behaviors in the same R&D organizational unit. In this paper, we develop a conceptual framework for understanding how different types of control system, guided by different R&D strategic goals, can be used to induce and balance both exploitation and exploration. We illustrate the elements of this framework and their relations using data from biotechnology firms, and then discuss how the framework provides a basis to empirically examine a number of important control relationships and phenomena.

4.2. Introduction

Controlling R&D is a challenge. Managers have long struggled to develop effective control systems for directing and adjusting R&D behaviors and outcomes. Consequently, researchers have been motivated to examine R&D control from three complementary levels of analysis: the firm, the market, and the innovation system (Chiesa and Frattini, 2009). This has resulted in studies that explore how R&D activities and outputs should be measured (e.g., Souder, 1972; Schumann, Ransley and

Prestwood, 1995; Werner and Souder, 1997; Kerssens-van Drongelen and Bilderbeek, 1999; Chiesa and Frattini, 2007); how R&D organizations should be designed and managed (e.g., Tymon and Lovelace, 1986; Whittington, 1991); and how markets and governments can support R&D (e.g., Moravesik, 1973; Martin and Irvine, 1983).

A feature of research on R&D control is that it has largely focused on the design and impact of performance measurement systems, which are only one type of control system - the diagnostic control system (Otley, 1980; Simons, 1994). As diagnostic systems are used to evaluate and reward organizational activities, they tend to induce relatively measurable exploitation behaviors that ensure current viability, at the expense of the more intangible exploration behaviors needed for ensuring future survival. This bias is counter to the notion that sustained organizational performance requires an organization to effectively balance exploitation with exploration (March, 1991), a capability known as “organizational ambidexterity” (Duncan, 1976; Tushman and O’Reilly, 1996).

Although sustained organizational performance is associated with a firm’s ability to be ambidextrous, it is a capability that is conceptually ambiguous and difficult to achieve. On the one hand, ambidexterity is viewed as the attainment of a balance between exploitation and exploration, whereby “organizations make explicit and implicit choices between the two” (March, 1991, p. 71) to attain an “optimal mix” (March, 1991, p. 75). On the other hand, exploitation and exploration are considered to be mutually enhancing, so that it is possible for firms to attain high levels of both (Gupta, Smith and Shalley, 2006; Jansen, van den Bosch, and Volberda, 2006). In our paper we follow the “balanced” view of ambidexterity, and assume that R&D managers face decisions about allocating resources and attention to activities that can be relatively explorative or relatively exploitative in nature.

Although the classic definition of ambidexterity provided by March (1991) would seem to suggest that R&D is exploration, the dilemma of balancing exploitation and exploration clearly exists in R&D organizations. Ahuja and Lampert (2001), for example, explain how R&D activities vary across the exploitation-exploration continuum. They define R&D exploration as activities and outputs that focus on novel, emerging and pioneering technologies; they define R&D exploitation as activities and outputs concerned with mature, familiar and propinquituous technologies. Similarly, McNamara and Baden-Fuller (1999; 2007) argue that ambidexterity is fundamentally about different forms of learning, and that R&D organizations, in common with other types of organization, must maintain a balance of short-term exploitation and long-term exploration to be successful over time. These characterizations of R&D exploration and R&D exploitation follow the view that ambidexterity is the capability to balance different types of knowledge production (Levinthal and March, 1993).

While organizational ambidexterity is a relatively straightforward concept to understand, it is not an easy capability to attain. Exploration and exploitation have fundamentally different qualities. Exploitation is characterized by short-term time horizons, efficiency, reliability and refinement, while exploration involves long-term time horizons, search, experimentation, innovation and adaptability. To simultaneously induce and balance these differences, there are two recognized approaches. One is “structural ambidexterity” (Tushman and O’Reilly, 1996), which involves splitting exploitation and exploration into different organizational units (i.e., separate divisions, departments or teams). It is then the task of senior managers to ensure that the respective exploitation and exploration outcomes of each organizational unit are integrated to create value. This integration task, however, can also be difficult to achieve because the organizational units are disconnected. A second complementary approach is “contextual ambidexterity” (Birkinshaw and Gibson, 2004; Gibson and Birkinshaw, 2004; Raisch and Birkinshaw, 2008). It involves creating an organizational context – the organizational stimuli that inspire, guide and reward people to act in a certain way (Ghoshal and Bartlett, 1997) – that will allow exploitation and exploration behaviors to transpire in the same organizational unit.

We argue that contextual ambidexterity is important and suited to R&D organizations for at least two major reasons. First, the problems of attaining ambidexterity by structural separation are compounded for R&D organizations. R&D activities are often already structurally separated and operationally distinct from other organizational activities such as legal, manufacturing or sales. Thus, any further partitioning (i.e., separating the “R” from the “D”) increases the problem of integrating and utilizing R&D outputs throughout the organization. This is especially so for small- to medium-sized organizations, whose R&D activities are tightly intertwined. Second, we suggest that contextual ambidexterity is suited to the “clan control” typically found in R&D organizations (Ouchi, 1979), as it involves using “processes or systems that enable and encourage individuals to make their own judgments about how to divide their time between conflicting demands for alignment and adaptability” (Gibson and Birkinshaw, 2004, p. 211).

In this paper we focus on the problem of how to attain contextual ambidexterity in a single R&D organizational unit. We present and illustrate a conceptual framework that shows how broader forms of control system, guided by R&D goals, could be used to encourage teams and individuals in R&D organizations to simultaneously pursue both exploitation and exploration. We present our arguments in four major sections.

First, we review the R&D management control literature, highlighting the need to move beyond exploitation and metric-focused performance measurement. We identify the importance of linking the design and use of control systems to the R&D goals of the organization. Second, we develop our conceptual framework by synthesizing R&D control concepts with control theories developed in the fields of accounting and strategic management. Specifically, we adapt Simons’ (1994) “levers of control” framework, which consists of four types of control system: beliefs systems, boundary systems, diagnostic systems and interactive systems. We explain how these four types of control system, guided by R&D strategic goals, can work together to develop and harness both exploitation and exploration in an individual R&D organization. Third, although studies have recognized that beliefs, boundary, diagnostic and interactive systems work together to create different behaviors and outcomes (e.g., Widener, 2007; Chiesa, Frattini, Lamberti and Noci, 2009a), significant ambiguity remains in the literature regarding what these systems actually are. That is, what actual rules, policies, procedures, processes, technologies and incentives might R&D managers use to create the control associated with each type of control system? In response, we presented our framework to managers and scientists employed by small- and medium-sized biotechnology firms. This was not done to inductively derive the framework, nor to provide strong empirical support for it. Rather, we sought examples to help describe and illustrate the framework, to provide some preliminary face validity for our arguments, and to exemplify what these control systems actually are. Fourth, we discuss some general implications of our conceptual framework for R&D management, each of which points to future areas of research. We suggest that our framework provides a basis for empirically studying the extent to which multiple R&D strategic goals drive the use of different types of control system. We also contend that our framework provides a starting point from which to examine how the use and attention of different management control systems can be altered over time so that R&D managers can "dynamically" manage the exploitation-exploration balance.

4.3. R&D MANAGEMENT CONTROL: MOVING BEYOND PERFORMANCE MEASUREMENT

When Freeman (1969, p. 11) argued "if we cannot measure all of the information generated by R&D activities because of a variety of practical difficulties, this does not mean that it may not be useful to measure part of it", he spurred a generation of scholars to understand what constitutes effective R&D management control, in both industrial and government settings. Table 1 presents a selection of control system studies published in leading R&D management and innovation journals. For each study, the table lists the type of control system examined, according to the control systems in Simons' (1994, 1995a) framework. These are (i) beliefs systems that are used to inspire employees to engage in activities central to the values, purpose and direction of the organization; (ii) boundary systems that limit strategically undesirable activities and outcomes; (iii) diagnostic systems that measure activities to ensure they are in accordance with organizational objectives; and (iv) interactive systems that scan for and communicate strategic information to employees so as to adjust the direction of the organization. For each study we also list the type of analysis undertaken, and the contribution made.

Article	Control Systems Examined	Empirical Analysis	Findings
Schainblatt (1982)	Diagnostic	Literature and company survey that compared the use of R&D productivity measurement systems	Systems should differ according to research activities and development activities, and overall R&D goals
Martin & Irvine (1983)	Diagnostic	Measures for allocating funds to scientific research institutes	A system of indicators for assessing scientific research progress
Cooper and Kleinschmidt (1986).	Diagnostic; Boundary	How variations in the structure and stages of the new product development process influence innovation outcomes	A model that explains how control efficiency and control reliability influence project outcomes
Cordero (1990)	Diagnostic	A study the links between firm level R&D investments, productivity and reward allocation	A model that combines technical and commercial performance and specifies how measures vary according to organizational levels and process stages
Whittington (1991)	Boundary	A study of in-house and independent R&D organizations and three types of structural control: market, hierarchical and professional	R&D organizations with market control are more productive than those with hierarchical and professional control
Bart (1993)	Diagnostic; Boundary; Interactive	Interviews with R&D managers in large companies on the tightness or formality of their control systems	The importance of balancing formal and informal controls, in line with R&D goals
Hauser and Zettelmeyer (1997)	Diagnostic	Interviews with CEOs, CTOs and researchers at ten research-intensive organizations on the use of performance measures	Effective measures depend upon the goals and research intensity of the R&D and engineering activity
McGrath & Romeri (1994)	Diagnostic	Determining R&D effectiveness in electronics companies by assessing investment versus new product performance	Firms with a high R&D effectiveness index are more productive, reliable and innovative
Kerssens-van Drongelen & Cook (1997)	Diagnostic	Literature review, company survey and in-depth interviews to assess use of R&D measures and system design principles	Outlines the importance of contingency factors and specifies control system requirements and design parameters
Werner & Souder (1997)	Diagnostic	Survey to understand measurement philosophy and perceived usefulness of measurement	Control system design is dependent on control aims, type of R&D activity, data availability and cost
Kerssens-van Drongelen & Bilderbeek (1999)	Diagnostic; Beliefs	Survey of performance measurement practices and effectiveness	Explores the importance of contingency factors and highlights the importance of feedback and feed-forward control
Godener & Soderquist (2004)	Diagnostic	Use and impact of performance measurement on decision-making and operations	Using performance results will improve R&D relevance and coherence, decision-making and employee motivation
Karlsson, Trygg, & Elfstrom (2004)	Diagnostic	Case study that examines product and process development	Systems should be designed to suit type of R&D activity, control needs and strategic goals
Yawson, Amoa-Awua, Sutherland, Smith, & Noamesi (2006)	Diagnostic; Beliefs	Case study that examines balanced-score card use in a research institute	Systems can align measurement with strategic objectives and address capability and utilization issues
Chiesa et al (2009a)	Diagnostic; Beliefs, Interactive, Boundary	Case studies that examine how these systems are employed in different phases of the radical innovation process	Beliefs and interactive systems are more prominent in the early stages of the process, while diagnostic systems are more prominent in the later stages of the process

Table 3. Review of Empirical Studies Within the R&D Management Control Literature

Looking across these studies, we identify four themes that characterize much of the existing research in the area, and provide the motivation for the conceptual framework that we develop. First, existing studies have predominantly focused on how performance measurement systems (i.e., diagnostic control systems) promote the efficiency of behaviors central to R&D exploitation. Although there are some studies that examine broader forms of control, including the effects of process formality (Bart, 1993), project structure (Cooper and Kleinschmidt, 1986), professional rituals (Whittington, 1991), and goal setting activities (Kerssens-van Drongelen and Bilderbeek, 1999; Yawson et al., 2006), there is only one study we know of that has used Simons' (1994) control framework in an R&D context (see: Chiesa, et al., 2009a). Furthermore, although Table 1 only lists empirical studies (so as to focus and limit our review to established R&D control concepts), a wider reading of the R&D management control literature reveals that diagnostic control has so far dominated prior work on R&D control frameworks (e.g., Bremser and Barsky, 2004; Chiesa and Masella, 1996), taxonomies (e.g., Tymon and Lovelace, 1986), and reviews of R&D measures (e.g., Werner and Souder, 1997; Geisler, 2002; García-Valderrama and Mulero-Mendigorri, 2005). Consequently, the motivation for our paper follows the view that although "measuring performance is helpful, it is only part of the story" (Chiesa, Coughlan and Voss, 1996, p. 105). In particular, we argue that different types of control system, guided by R&D strategic goals, can work together to balance different levels of exploitation and exploration in individual R&D organizations.

Second, research on the diagnostic control of R&D has traditionally focused on the performance measures as opposed to the systems (e.g., the rules, procedures and technologies) that managers might use to direct and adjust R&D behaviors. This measure-based approach treats R&D organizations as "black boxes", ignoring their inner workings and the relationships between goals, controls, behaviors and outcomes. By focusing on the different types of control system used, and collecting data from managers and scientists in biotechnology firms, we aim to provide examples of these systems. This follows other studies of R&D control that focused on the actual systems used (e.g., Szakonyi, 1995; Chiesa et al., 1996) and emphasized that control is about more than choosing a set of metrics (Kerssens-van Drongelen and Cook, 1997; Kerssens-van Drongelen and Bilderbeek, 1999).

Third, by definition, research on the diagnostic control of R&D tends to highlight what we call a specific “control orientation”. This is the extent to which individuals and teams conceive and undertake control in an e*x post* (after-the-event) or *ex ante* (before-the-event) manner. Prior research on R&D control has tended to focus on the “feedback control orientation”, which is when after-the-event information (e.g., errors, failures and other unsatisfactory organizational outcomes) is used to direct and adjust organizational behaviors. This feedback control orientation is central to exploitation as it promotes single-loop learning and the continuous refinement of organizational practices and capabilities (Argyris and Schön, 1978; Kerssens-van Drongelen and Bilderbeek 1999). In contrast, a “feed-forward control orientation” involves seeking and receiving before-the-event information about future trends, events and their effects (e.g., changes in regulations, competition and demand). This information is used to adjust organizational behaviors so as to prevent unacceptable outcomes from occurring. It is a control orientation that energizes the exploration and double-loop learning needed for individuals and organizations to radically rethink and alter their existing capabilities (Argyris and Schön, 1978; Kerssens-van Drongelen and Bilderbeek, 1999). Using our conceptual framework, we explain how different types of control system work together to generate both feedback and feed-forward control orientations, which together provide informational stimuli to induce the behaviors necessary for contextual ambidexterity.

Fourth, it is clear from the studies listed in Table 1 that the effectiveness of R&D control is contingent on a number factors, one of the most prominent of which is the R&D goals of the organization (see: Bart, 1993; Chiesa et al. 2009b; Schainblatt, 1982). Thus, in the next section of our paper we describe how four R&D goals - growth, innovation, reliability and efficiency – relate to and drive the use of control systems and the attainment of R&D ambidexterity.

4.4. A Management Control Framework for R&D Contextual Ambidexterity

In this section of our paper we develop our conceptual framework. We synthesize management control ideas and advances from the fields of accounting and strategic management, and apply these to the domain of R&D control. In particular, we explain how the use of the four types of control system proposed by Simons (1994), guided by different R&D strategic goals, can be used to induce and balance the exploitation and exploration behaviors, and the feedback and feed-forward control orientations necessary for attaining contextual ambidexterity.

4.4.1. Simons' Levers of Control

In the fields of accounting and strategic management, researchers have argued that management control involves using a number of different, but inter-related types of system (Ouchi, 1979; Otley, 1980; Eisenhardt, 1985; Marginson, 2002; Turner and Makhija, 2006). To explain how control systems can vary and function, Simons (1994) proposed an influential framework of management control built around what he termed the "four levers of control" - beliefs systems, boundary systems, diagnostic systems and interactive systems. Collectively these four types of control system represent the policies, procedures and technologies that influence the cultural norms, behaviors and outcomes of individuals and groups. Each type of control system has unique effects but, importantly, they also work in conjunction with one another to manage "the inherent tensions between (1) unlimited opportunity and limited attention, (2) intended and emergent strategy, and (3) self-interest and the desire to contribute" (Simons, 1995a, p. 28). We place Simons' (1994) four types of control system as the central element in our conceptual framework (see Figure 1), and argue that R&D managers, guided by R&D strategic objectives, can use Simons' control systems to shape the organizational conditions necessary for contextual ambidexterity. We now discuss each type of control system in more detail.

Beliefs systems are "the explicit set of organizational definitions that senior managers communicate formally and reinforce systematically to provide basic values, purpose and direction for the organization" (Simons, 1995a, p. 34). They help ensure that the attitudes and behaviors of individuals are aligned with the R&D strategic goals and the scientific principles that underpin the R&D organization. They provide the "positive energy" necessary for exploration (Simons, 1995a), and the strategic coherence necessary for R&D employees to search for new knowledge and opportunities in an autonomous, but focused manner.

Interactive systems enable “top-level managers to focus on strategic uncertainties, to learn about threats and opportunities as competitive conditions change, and to respond proactively” (Simons, 1995b, p. 81). These systems are used by R&D managers to scan, “explore” and acquire information about events and trends in their organization's external environment (Daft & Weick, 1984). They also include the communication processes that R&D managers use for instigating debate with colleagues about the future of the organization. Intra-organizational networks (Swan, Newell, Scarbrough and Hislop, 1999), information technology (Alavi and Leidner, 2001), and group based processes such as brainstorming and sand-pit events (Cummings, 2004), are all example of interactive systems that managers can employ to engage in exploration and knowledge sharing.

Boundary systems delineate “the acceptable domain of strategic activity for organizational participants” (Simons, 1995a, p. 39). These are the systems that define and enforce the limits beyond which employees must not stray. This demarcation role of boundary systems helps prevent R&D organizations from over-exploring and becoming too stretched. Thus, boundary systems are central to reliability-based exploitation behaviors, in that they “transform unbounded opportunity space into a focused domain that organizational participants can be encouraged to exploit” (Simons, 1995a, p. 41).

Diagnostic systems are the “feedback systems used to monitor organizational outcomes and correct deviations from preset standards of performance” (Simons, 1994, p. 170). If non-conformance is identified this can prompt changes in organizational activities and in the other types of control system, to adjust what is done and how it is done. As highlighted by our review of the R&D control literature, diagnostic systems tend to focus on measuring tangible and exploitation activities, which in turn motivate R&D employees to be productive and efficient. Consequently, strong diagnostic systems, if used in conjunction with weak or inappropriate boundary and beliefs systems, can promote the “what you measure, is what you get” phenomenon, which can sometimes lead to unintended and undesirable consequences.

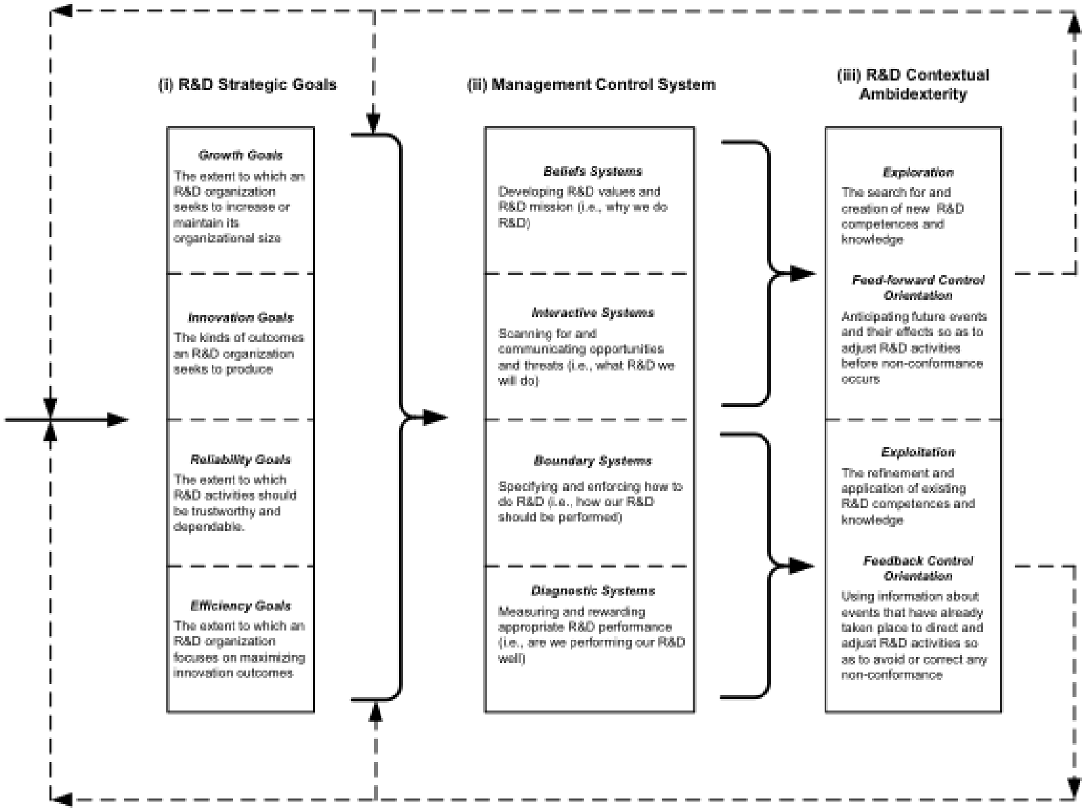


Figure 5. Relationships Between R&D Strategic Goals, Control Systems Type, and R&D Contextual Ambidexterity

4.4.2. R&D Strategic Goals

One of the earliest definitions of a management control system describes it as a collection of systems that managers use to “ensure that resources are obtained and used effectively and efficiently in the accomplishment of the organisation’s objectives” (Anthony, 1965, p. 17). Similarly, R&D management scholars have argued that for an R&D management control system to be effective it should be aligned with the R&D strategic goals of the organization (Bart, 1993; Chiesa et al., 2009b; Schainblatt, 1982).

We define R&D strategic goals as statements that motivate R&D organizations to attain a level of proficiency in a specific R&D capability. In terms of what these goals might be, we follow studies that emphasize the importance of R&D goals to control system design and use (Bart, 1993; Chiesa et al., 2008; Karlsson et al., 2004; Schainblatt, 1982). Together these studies suggest that R&D goals can vary in terms of how they specify different types of research activity (i.e., basic research, applied research, and development), innovation activity and outputs (i.e., incremental and radical), so as to support the overriding business strategy and rules of competition governing the R&D organization. The four R&D strategic goals we use - growth, innovation, reliability and efficiency - are distilled from these principles, and from the notion that each of the control systems proposed by Simons (1994, 1995a) is individually oriented towards one of these strategic goals. This is indicated by the goal-control linkages in Figure 1: growth-beliefs, innovation-interactive, reliability-boundary and efficiency-diagnostic. These relationships are not exclusive however, and this is indicated by the single arrowed line that broadly connects all of the R&D strategic goals with all of the control system types.

We define R&D growth goals as the extent to which an R&D organization seeks to increase or maintain its organizational size (e.g., number of employees, R&D capacity and R&D outputs). They indicate the degree to which an R&D organization is concerned with developing its innovative capacity by increasing its project portfolios, the number of R&D employees and other related resources (Addison, Litchfield, Hansen, 1976). This is consistent with Simons' (1995a) claim that managers will use beliefs systems to inspire employees to overcome organizational inertia and grow (i.e., build), or alternatively to focus, be persistent and complete existing projects (i.e., harvest). Consequently, we suggest that the nature and use of beliefs system in an R&D organization will be linked to its growth goal.

Innovation goals define the kinds of outcomes that R&D organizations seek to produce. At the most general level, this involves specifying the velocity, magnitude, and application range of technological change (McCarthy, Lawrence, Wixted and Gordon, 2010). In an effort to be parsimonious, we focus only on the magnitude of change in a technology's capability and the degree of benefit it brings to the market (Wheelwright and Clark, 1992; Maine and Garnsey, 2006). As recently argued by Chiesa et al. (2009a, p. 419), such innovation differences significantly influence "the adoption of specific managerial approaches, organizational solutions and operative instruments", i.e., the design and use of appropriate control systems. Furthermore, it is argued, as interactive control systems promote exploration and learning they are more prominent in the early stages of the radical innovation process (Chiesa et al., 2009a). On this basis, we suggest that R&D organizations in pursuit of radical innovation goals would benefit from greater use of interactive control systems; conversely, R&D organizations in pursuit of more incremental innovation goals would require less use of interactive control systems.

Reliability goals indicate the extent to which the activities of R&D organizations should be trustworthy and dependable (Kiella and Golhar, 1997). This type of goal has become important, with R&D organizations increasingly undertaking quality improvement programs. Reliability goals determine the extent to which an R&D organization should be proficient at reaching project milestones on time (Cooke-Davies and Arzymanow, 2003), and the propensity of the organization to engage in post-project assessments that promote organizational learning (von Zedtwitz, 2002). As these activities involve adhering to acceptable R&D domains and practices, we suggest that the degree to which the R&D organization desires high levels of reliability, will determine the extent to which boundary systems are used to "establish explicit limits and rules which must be respected" (Simons, 1994, p. 170).

Efficiency goals define the extent to which an R&D organization focuses on using its resources to maximize the production of innovations. As discussed in our review of the R&D control literature, this particular goal has captured the attention of managers and scholars who have focused on performance measurement systems and exploitation-related criteria such as R&D productivity. Consequently, the attainment of this goal is closely linked to diagnostic control systems that establish targets, and measure activities and outcomes to help ensure that the other R&D strategic goals are being achieved efficiently.

4.4.3. R&D Contextual Ambidexterity

We define R&D contextual ambidexterity as the ability to attain appropriate levels of exploitation and exploration behaviors in the same R&D organizational unit. The right-hand element of our framework indicates how the four control systems combine to produce the behaviors and control orientations necessary for this ability. We suggest that beliefs systems and interactive systems jointly produce exploration and a feed-forward control orientation. Beliefs systems provide "momentum and guidance for opportunity-seeking behaviors", and interactive systems "focus organizational attention on strategic uncertainties and thereby provoke the emergence of initiatives and strategies” (Simons 1994, p. 172). Together these two types of control system promote prospecting, experimentation and sense-making; all of these are not only central to exploration, but also promote a feed-forward control orientation for anticipating future events and their effects. Thus, beliefs systems and interactive systems underlie the proactive scanning and planning behaviors essential for determining when and how R&D activities should be modified.

Our framework also suggests that the exploitation aspect of R&D contextual ambidexterity is linked to the joint use and effects of diagnostic and boundary systems. Boundary systems permit discovery and learning, but within clearly defined limits of freedom. Diagnostic systems monitor R&D activities and outputs and use this after-the-event information to reward conformance, or to modify processes and systems to correct non-conformance. Diagnostic systems measure activities and outputs so that R&D managers know when things are going well, or are going wrong. This creates a context for making informed decisions about resource allocation and process redesign. Thus, together diagnostic and boundary systems induce exploitation as employees are directed and rewarded to refine and apply existing knowledge and competences.

4.5. Framework Illustration: The Case of Biotechnology Firms

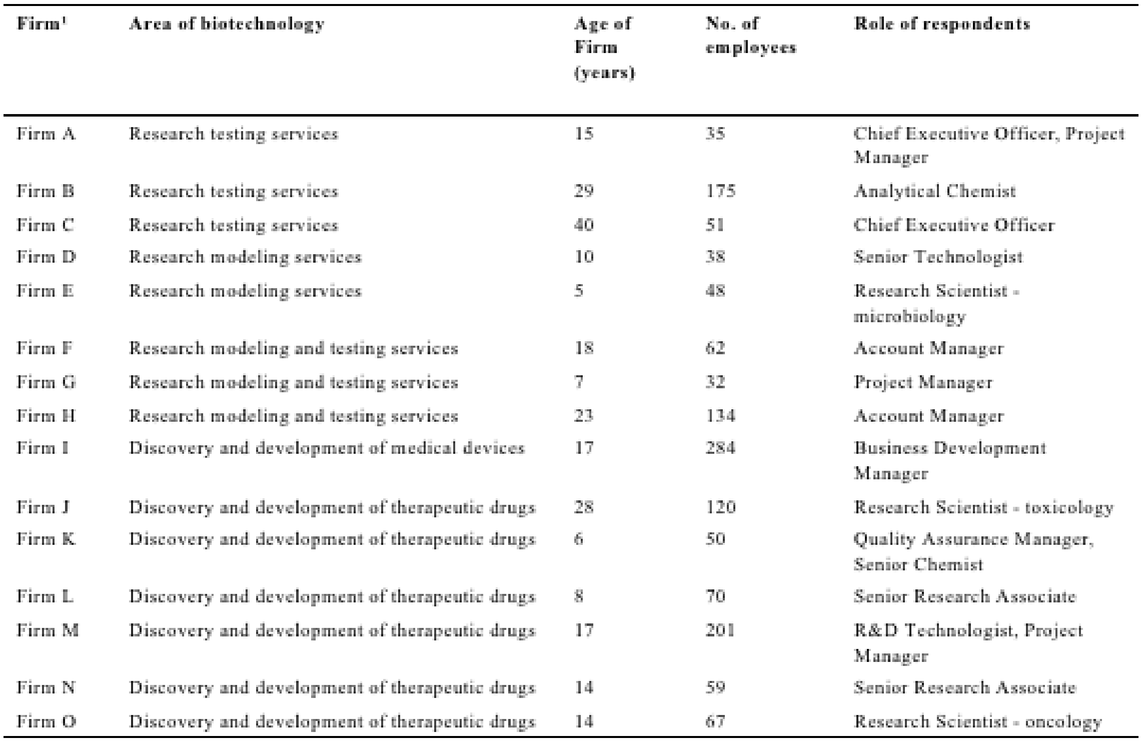
In this section, we present data to exemplify the elements of our framework in terms of what they are (i.e., the actual goals, systems and behaviors), and what they do (i.e., their effect on other elements of the framework and on an R&D organization). These data are used to illustrate the framework, and make it more connected to R&D reality. Similar approaches have been used to illustrate conceptual frameworks dealing with R&D performance measurement systems (Chiesa, Frattini, Lazzarotti and Manzini, 2008), user innovation (Berthon, Pitt, McCarthy and Kates, 2007), and external technology commercialization (Bianchi, Chiesa and Frattini, 2009).

4.5.1. Setting and Methodology

We focused on biotechnology firms, defined broadly as those firms that undertake life-science research to develop therapeutic products, medical devices, or biotechnology related services. Biotechnology firms are particularly appropriate for illustrating our framework, for several reasons. First, they are often considered to be a prototypical example of an R&D organization. Second, even though researchers have argued that the long-term success of these firms depends on continued exploration (e.g., discovery, product formulation and preclinical trials), *and* effective exploitation (e.g., clinical trials and the new drug application stage) (McNamara and Baden-Fuller, 1999, 2007), we know relatively little about how this R&D ambidexterity can be attained. Third, the exploitation and exploration activities of these firms are significantly intertwined with each other. This means that biotechnology firms are suited to contextual ambidexterity, because it is problematic to structurally separate these intertwined activities. This is especially the case for small- and medium-sized biotechnology firms as their organizational size limits any major and viable separation of resources. Lastly, by focusing only on biotechnology firms, our data are bounded, helping to provide a focused illustration of the elements of our framework.

To collect the data, we took advantage of a biotechnology management education program, led by one of the authors of this paper. The learning nature of this university-industry program was useful for our research, as it provided respondents with the opportunity and environment to reflect, analyze and discuss the control systems within their firms. From 2006 – 2008 we collected data from over 40 senior managers and scientists, from 15 different biotechnology firms whose organizational size ranged from 35 to 284 employees (see Table 2). With this number of firms we did not seek to develop rich cases studies for inductive theory building, nor to provide strong empirical support for our framework. Instead, we sought multiple sources of data to help describe and tentatively validate the elements and logic of our framework.

All of the firms were located in Western Canada, and undertook biotechnology related R&D. Approximately half of the sample, Firms A – H, were research service organizations that undertook R&D activities to develop their portfolio of testing and modeling services for drug development and healthcare organizations. The other half of our sample, Firms I – O, were involved primarily in the discovery and development of drugs or medical devices. All 15 firms were at least three years old and employed more than ten people, ensuring that they were likely to employ some form of formal management control system (Davila & Foster, 2007).



Firm[1]	Area of biotechnology	Age of Firm (years)	No. of employees	Role of respondents
Firm A	Research testing services	15	35	Chief Executive Officer, Project Manager
Firm B	Research testing services	29	175	Analytical Chemist
Firm C	Research testing services	40	51	Chief Executive Officer
Firm D	Research modeling services	10	38	Senior Technologist
Firm E	Research modeling services	5	48	Research Scientist - microbiology
Firm F	Research modeling and testing services	18	62	Account Manager
Firm G	Research modeling and testing services	7	32	Project Manager
Firm H	Research modeling and testing services	23	134	Account Manager
Firm I	Discovery and development of medical devices	17	284	Business Development Manager
Firm J	Discovery and development of therapeutic drugs	28	120	Research Scientist - toxicology
Firm K	Discovery and development of therapeutic drugs	6	50	Quality Assurance Manager, Senior Chemist
Firm L	Discovery and development of therapeutic drugs	8	70	Senior Research Associate
Firm M	Discovery and development of therapeutic drugs	17	201	R&D Technologist, Project Manager
Firm N	Discovery and development of therapeutic drugs	14	59	Senior Research Associate
Firm O	Discovery and development of therapeutic drugs	14	67	Research Scientist - oncology

Table 4. Companies and Respondents

[1] Pseudonyms and basic description of the area of biotechnology areas are used to protect the anonymity of firms and respondents.

Given our illustrative aims, the data collection began by presenting our conceptual framework (Figure 1) to groups of between five and ten respondents. During these presentations, each element of the framework was defined and explained. This was followed by a discussion to further clarify the function and scope of each element of the framework. Next, we collected data from individual respondents using a semi-structured interview. Respondents were first asked to confirm that their firms had an active R&D capability, and to provide the following background information about their firms: age, size in terms of employee numbers, and the area of biotechnology the firm focused on. The respondents were then asked to comment on the validity of the logic of the framework in general terms, and to consider the extent to which their firms focus on and use the different types of control system. This latter point required the respondents to reflect on the number of people, rules and processes associated with each type of system. Next, the respondents were asked to give examples of how each element of the framework exists, and to exemplify links between the different elements of the framework (see Table 3). The aim was to elicit actual examples of the goals, the control systems, and the associated behaviors and control orientations. The final stage of data collection involved a number of follow-up interviews, where respondents were contacted to either seek further information or to clarify aspects of their answers.

4.5.2. Analysis and Findings

We approached our analysis from a broadly descriptive perspective, focusing on how the data illustrate the elements and relationships in our framework. Following guidelines for presenting qualitative case data (see Eisenhardt, 1989), and the format used by Nag, Corley and Gioia (2007) for their study of strategic change in R&D organizations, we present our questions and illustrative answers in Table 3. This summary information complements our narrative in the following sections, where we describe, using examples, the conceptual logic and reality of our proposed framework. It is important to note that even though there were no major contradictory comments or negative assessments of the framework, this does not constitute empirical support for the framework. The data are simply used to illustrate the elements of the framework.

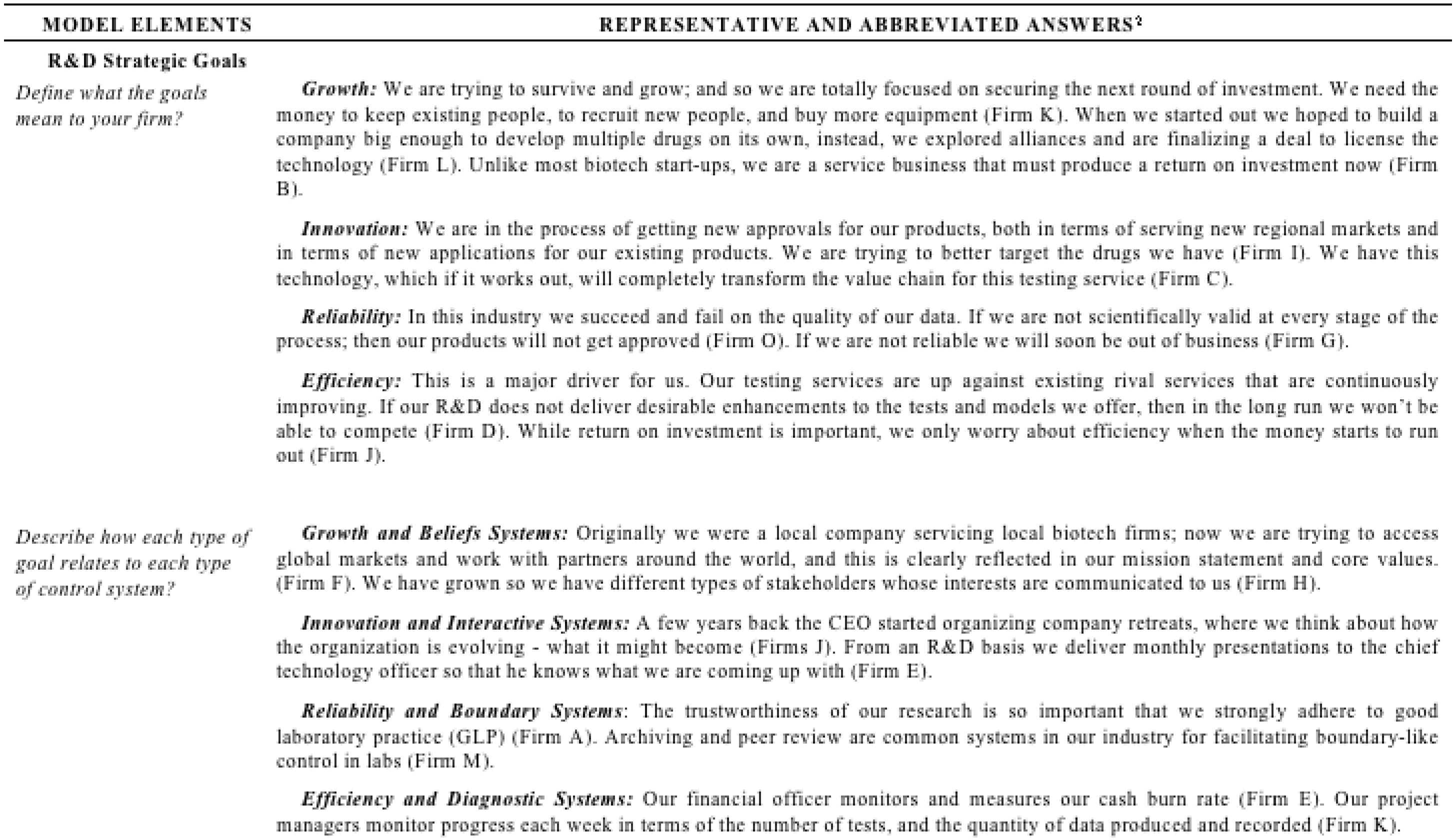
4.5.2.1. R&D Strategic Goals in Biotechnology Firms

In terms of R&D growth goals, our framework and data indicate that this varied largely according to the lifecycle stages of the firm, its markets and its products. This is consistent with strategic options which characterize the extent to which firms focus on appropriating returns from stable and limited project portfolios (harvest), versus building capacity to create new knowledge and technologies for new products and markets (build) (Gupta and Govindarajan, 1984). Firms E, G and K, for instance, focused on securing new sources of investment funding so as to grow R&D capacity, and to develop their early stage technologies. These firms were relatively young, small, idea-rich, but resource-poor, and thus concerned with building R&D capacity in a way that the larger and more established firms were not. The larger, more mature biotechnology organizations (e.g., Firms B, H, I and M) were more concerned with developing efficient R&D processes to capture returns from existing resources and projects, and thus their investment intensity in new R&D projects was much smaller. A respondent from Firm M, for example, stated that “once our company became public the whole nature of our R&D operations dramatically shifted from creating new technologies, to marketing and selling our approved product line”. Furthermore, respondents reported that this type of goal was linked to the use of beliefs systems which help create a common language, a shared understanding and strategic coherence within an R&D organization. For instance, the respondent from Firm N reported that “when we were first formed we didn’t have a mission statement. We were simply a group of researchers who did research. Sixteen years later, however, we have had four or five different mission statements, with the current one emphasizing our commitment to provide value to shareholders”. Similarly, the respondent from Firm E reported that “We all know that the goal is to build a company that will be big enough, in terms of talent and promising intellectual property, so as to attract partners or buyers. …….. and in terms of the control system that reminds us of this goal – it is communication, communication, and more communication.”

Innovation goals delineate the kinds of outcomes that R&D organizations seek to produce. Although these goals can vary in a number of ways, we focused solely on the magnitude of change in a firm’s technology, and the degree of benefit it brings to the market (e.g., incremental versus radical) (Wheelwright and Clark, 1992). In terms of our data, respondents from Firms A and B reported that their R&D focused on incrementally enhancing their existing service offerings for existing customers in the biotechnology and pharmaceutical industries. In contrast, Firm O focused on adapting its existing technologies for human therapeutic disorders for animal care (farm and pet) markets. Our data also indicated that when an innovation goal specified radical innovations, then this was associated with greater use of interactive control than if the goal stipulated incremental innovations. For instance, a respondent from Firm A reported that his organization’s focus on refining existing technology for existing customers was largely driven by the occasional project meeting with top managers, intended to “boost organizational dialogue” about how to improve existing testing services. Whereas in the case of Firm O their desire to develop radically new platform molecular technologies, for different end-use markets, meant that they faced many technological, regulatory and market uncertainties. This required their top-management team to develop and continuously use interactive systems: “We set up committees to collect and report information on who was doing what in our industry. This information was internally communicated to the necessary project teams, so they could comment on and help us plan for the opportunities and threats that we were facing.”

Reliability goals specify the extent to which R&D will be conducted in a timely fashion, and in accordance with expected standards and codes of practice. Our data indicated that this goal is central to biotechnology firms, with all of the respondents in our study making statements that concurred with the view that “the success of any biotech firm is dependent on producing and reporting good data, before funding runs out” (Firm L). The importance of R&D reliability to biotechnology firms is reflected in the demands of their various stakeholders (e.g., patient groups, investors, collaborators and government agencies), who expect biotechnology firms to closely follow good scientific practice and conform to recognized rules and guidelines. Consequently, in terms of the link between reliability goals and control system use, our illustrative data support the link to boundary systems. All of the respondents provided comments similar to those listed in Table 3, indicating that reliability requires strong and effective boundary systems to reduce the risk of improper behaviors that might cause a project or service failure.

The fourth goal in our framework, efficiency, specifies the extent to which R&D organizations are concerned with productivity and cost effectiveness as ways to maximize returns on investment. Our data indicate that while efficiency is on the whole important to all the biotechnology firms in our study, it was less significant to the six drug development firms (Firms J, K, L, M, N and O), and the one medical device firm (Firm I), than it was to the nine research services firms (Firms A, B, C, D, E, F, G and H). The view of efficiency held by the drug and medical device firms, is reflected in the statement that the “major time lag between R&D action and R&D outcome, typically limits our ability to efficiently control our activities, and as a consequence being efficient is not really a top priority. We just focus on doing good science” (Firm J). In contrast, the research service organizations considered efficiency goals to be central to their R&D, which must continuously produce innovations that help keep their services cutting edge and competitive. This variation in attitudes towards efficiency was also linked to variations in the extent to which firms used diagnostic systems. For instance, the respondent from Firm B stated “many of our R&D projects are in collaboration with customers who have time, quality and cost expectations, …… and to meet these we have numerous budget and project monitoring systems.”



MODEL ELEMENTS	REPRESENTATIVE AND ABBREVIATED ANSWERS[2]
R&D Strategic Goals	
Define what the goals mean to your firm?	***Growth:*** We are trying to survive and grow; and so we are totally focused on securing the next round of investment. We need the money to keep existing people, to recruit new people, and buy more equipment (Firm K). When we started out we hoped to build a company big enough to develop multiple drugs on its own, instead, we explored alliances and are finalizing a deal to license the technology (Firm L). Unlike most biotech start-ups, we are a service business that must produce a return on investment now (Firm B). ***Innovation:*** We are in the process of getting new approvals for our products, both in terms of serving new regional markets and in terms of new applications for our existing products. We are trying to better target the drugs we have (Firm I). We have this technology, which if it works out, will completely transform the value chain for this testing service (Firm C). ***Reliability:*** In this industry we succeed and fail on the quality of our data. If we are not scientifically valid at every stage of the process; then our products will not get approved (Firm O). If we are not reliable we will soon be out of business (Firm G). ***Efficiency:*** This is a major driver for us. Our testing services are up against existing rival services that are continuously improving. If our R&D does not deliver desirable enhancements to the tests and models we offer, then in the long run we won't be able to compete (Firm D). While return on investment is important, we only worry about efficiency when the money starts to run out (Firm J).
Describe how each type of goal relates to each type of control system?	***Growth and Beliefs Systems:*** Originally we were a local company servicing local biotech firms; now we are trying to access global markets and work with partners around the world, and this is clearly reflected in our mission statement and core values. (Firm F). We have grown so we have different types of stakeholders whose interests are communicated to us (Firm H). ***Innovation and Interactive Systems:*** A few years back the CEO started organizing company retreats, where we think about how the organization is evolving - what it might become (Firms J). From an R&D basis we deliver monthly presentations to the chief technology officer so that he knows what we are coming up with (Firm E). ***Reliability and Boundary Systems***: The trustworthiness of our research is so important that we strongly adhere to good laboratory practice (GLP) (Firm A). Archiving and peer review are common systems in our industry for facilitating boundary-like control in labs (Firm M). ***Efficiency and Diagnostic Systems:*** Our financial officer monitors and measures our cash burn rate (Firm E). Our project managers monitor progress each week in terms of the number of tests, and the quantity of data produced and recorded (Firm K).

Table 5. Illustration of Model Elements

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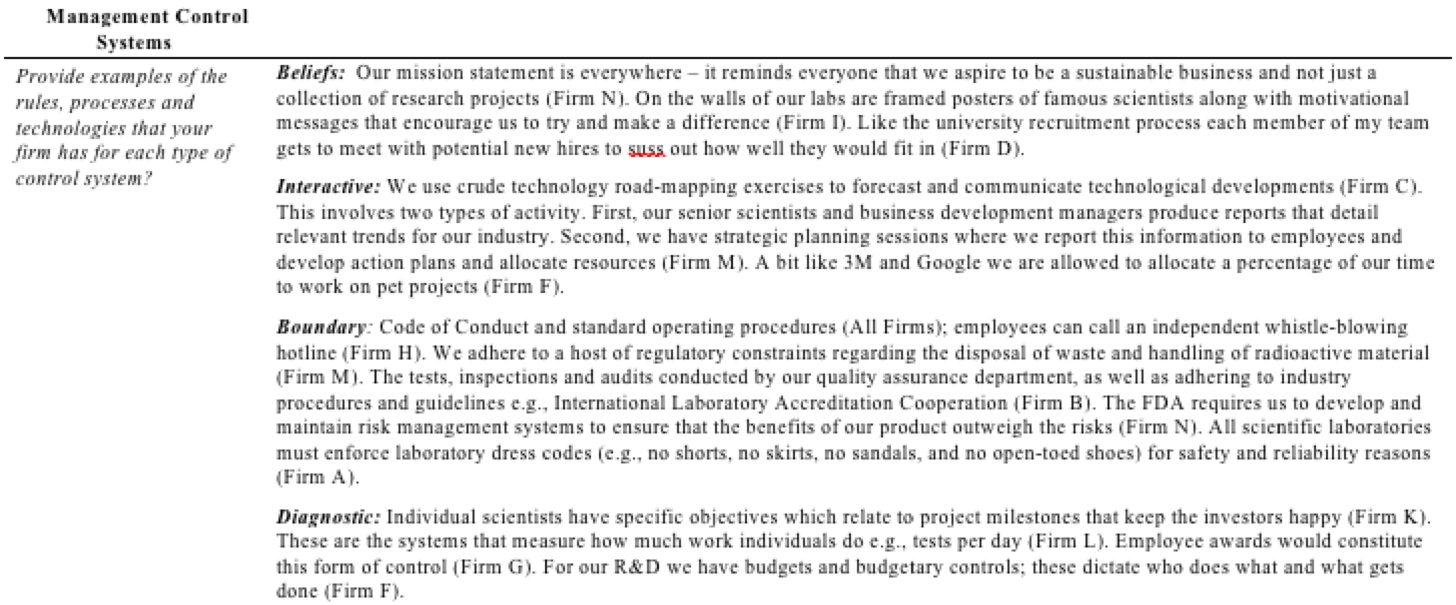
[2] Some of the answers have been abbreviated to protect the anonymity of firms and respondents.



Management Control Systems	
Provide examples of the rules, processes and technologies that your firm has for each type of control system?	***Beliefs:*** Our mission statement is everywhere – it reminds everyone that we aspire to be a sustainable business and not just a collection of research projects (Firm N). On the walls of our labs are framed posters of famous scientists along with motivational messages that encourage us to try and make a difference (Firm I). Like the university recruitment process each member of my team gets to meet with potential new hires to suss out how well they would fit in (Firm D). ***Interactive:*** We use crude technology road-mapping exercises to forecast and communicate technological developments (Firm C). This involves two types of activity. First, our senior scientists and business development managers produce reports that detail relevant trends for our industry. Second, we have strategic planning sessions where we report this information to employees and develop action plans and allocate resources (Firm M). A bit like 3M and Google we are allowed to allocate a percentage of our time to work on pet projects (Firm F). ***Boundary****:* Code of Conduct and standard operating procedures (All Firms); employees can call an independent whistle-blowing hotline (Firm H). We adhere to a host of regulatory constraints regarding the disposal of waste and handling of radioactive material (Firm M). The tests, inspections and audits conducted by our quality assurance department, as well as adhering to industry procedures and guidelines e.g., International Laboratory Accreditation Cooperation (Firm B). The FDA requires us to develop and maintain risk management systems to ensure that the benefits of our product outweigh the risks (Firm N). All scientific laboratories must enforce laboratory dress codes (e.g., no shorts, no skirts, no sandals, and no open-toed shoes) for safety and reliability reasons (Firm A). ***Diagnostic:*** Individual scientists have specific objectives which relate to project milestones that keep the investors happy (Firm K). These are the systems that measure how much work individuals do e.g., tests per day (Firm L). Employee awards would constitute this form of control (Firm G). For our R&D we have budgets and budgetary controls; these dictate who does what and what gets done (Firm F).

Table 5 – continued

R&D Contextual Ambidexterity	
Describe how the different types of control system work together to generate the exploitation and exploration behaviors in your firm?	***Exploration (Beliefs and Interactive):*** Some of the biggest successes in our industry have involved companies changing direction with only six months of operating cash left. To do this required beliefs and interactive systems capable of helping management to first spot the opportunity and then to steer the company in a new direction (Firm O). Our beliefs systems direct what we do and why we do it, while our interactive systems provide the freedom and mechanisms to rethink what we do and what we do it (Firm B). ***Exploitation (Diagnostic and Boundary):*** First and foremost we are a service company, and we view innovation and learning as necessary but costly and hard to justify. As a consequence our control systems focus on improving project efficiency and optimizing revenues from existing assets (Firm H). Our boundary and diagnostic systems help us to reassess risk and revise the go/no go guidelines for research activities (Firm O). I feel that the whole drug development process, with all its checks and regulations, creates a high level of consumer protection but also a risk averse product development culture (Firm N).
Describe how the different types of control system involve a feedback and/or a feed-forward control orientations in your firm?	***Feed-forward Control Orientation (Beliefs and Interactive):*** I would say these systems are much more open and intangible in nature - they have to be - because we use them to try to make sense of all uncertainty in our industry (Firm I). What typically happens is that we use the industry forecasts and scenarios to see if we should maintain our current portfolio of projects if a major change is required then that would almost certainly require a change in aspects of our mission statement and project activities (Firm F). We could do with formalizing these systems a lot more. This would help stop all the micro-management we have, and free these guys to see problems coming in time so that we can do something about them (Firm C). ***Feedback Control Orientation (Diagnostic and Boundary):*** These systems are obviously feedback in nature – they are all about doing checks and tests to see what has happened or should have happened (Firm E). There is a view in my company that we have too many of these systems and they provide so much feedback that we don't know what to do with it (Firm L). Reviews, audits, and certifications – these are all industry recognized ways of obtaining feedback (Firm G).

Table 5 – continued

4.5.2.2. Management Control Systems in Biotechnology Firms

The most common examples of beliefs systems identified by our respondents were the company reports, mission statements and website pages that each firm used to articulate the research vision and values of the organization. For drug development firms, beliefs systems typically focused on installing in employees the noble vision of serving patients, saving lives, and eliminating pain and suffering, while being guided by research values such as respect, ethics, and team work. In contrast while the research service firms we surveyed had similar statements about research values, their visions focused more on being the best or first choice service provider in their market. Other types of beliefs systems reported by our respondents included the company recruitment process that “seeks to attract and recruit talent with attitudes and skills that are consistent with our research values” (Firm K), and the training process, which “develops people in the “company way” by continually communicating our goals and achievements to all staff” (Firm O). Respondents also reported the use of intra-company challenges and socialization events to promote fun and creative thinking, and to build organizational coherence. Also in some cases the architecture and decor of company buildings, along with the pictures on the walls of corridors and laboratories, were all designed to inspire employees with creative, funky, free-thinking values. All of these examples of beliefs systems are intended to focus and energize employees in a way that is necessary for the exploration and feed-forward control aspect of R&D contextual ambidexterity.

In terms of interactive systems, our framework and data indicate that these include R&D specific systems such as technology road-mapping (Phaal, Farrukh and Probert, 2006) and real options methods (Barnett, 2005), all of which help companies understand the effects of emerging technologies. There are also more general strategic scanning and monitoring systems (e.g., market research, competitor analysis and technology benchmarking) that collect and analyze data on changes in demand, products, technology, competition and regulation. Respondents also reported how R&D projects were started, adjusted and stopped using information from forecasting and assessment systems. Forecasting systems provide projections about when things will happen (i.e., a drop in the demand for existing products and services, or the approval of a new regulation or competitive product), while assessment systems provide estimations of the impact of these changes on the organization and its R&D portfolio. Such interactive systems are also “interactive” in the sense that the managers use the information they uncover “to continuously and directly involve themselves in the decisions and behavior of their subordinates” (Chiesa et al., 2009a, p. 421). For instance, respondents reported the use of planning sessions “to distribute strategic information to employees, and then work with them to develop action plans and allocate resources for existing and new projects” (Firm I). Respondents also reported that project and organizational based interactive systems are used by managers and their teams to speculate on future R&D scenarios, and to ensure that the foci and aims of the other types of control system are adjusted as R&D strategic goals shift. Furthermore, all of the firms in our study had scientific advisory committees that provided advice that could alter the strategies for planned, pipeline and approved R&D projects. These committees dictated the direction of exploration and the scope of feed-forward control, necessary for R&D contextual ambidexterity.

Boundary systems act “like an organization’s brakes” (Simons, 1995b, p. 84). They restrain and guide employees so that the firm does not experience an accident, i.e., a failure and crisis. For biotechnology firms the systems are typically built into a firm’s laboratory practices, project management methods, and resource allocation decision making processes. For instance, many respondents reported that their firms had “a Code of Conduct that all our employees must be certified to” (Firm D) and that “product approval is dependent on us producing, analyzing and archiving risk data to ensure that the benefits of our planned drug outweigh the risks” (Firm L). There are also non-firm specific boundary systems, which for biotechnology firms included regional and national laws, regulations from institutions such as the U.S. Food and Drug Administration (FDA) and the European Medicines Agency (EMEA). Furthermore, there are certification regimes such as Good Laboratory Practices (GLP), which are “primarily intended to guarantee safe animal and toxicology testing, yet also help to ensure that laboratory results are internally peer-reviewed. This helps to limit the risk of producing results that are wrong, fabricated or massaged” (Firm K). In summary, as R&D researchers enjoy relatively high levels of job autonomy, boundary systems are used to avoid or mitigate unsafe or unethical behaviors, or actions that constitute scientific misconduct. These systems counter the effects of diagnostic systems, and are most likely to produce the risk averse behaviors associated with exploitation and the checking of conformance that goes with feedback control.

In terms of diagnostic systems, our framework and data indicate that these include project planning systems for target drug approval dates, budget systems for project costs, laboratory management information systems (LIMS) for recording and analyzing sample tests, and clinical trial systems for measuring the performance or efficacy of a drug. Such systems are progress-focused. Managers, boards and regulatory agencies identify research project goals, review progress, and arrange post-project reviews to identify lessons and corrective actions. In terms of R&D output, both the drug development firms and the modeling and testing service firms in our study used a number of corporate level diagnostic systems. These measured the production of scientific papers, returns from R&D collaborations, the creation and approval of patents, and the revenue from new service technologies, licensed patents and approved products. Thus, by their very nature, diagnostic control systems are central to exploitation behaviors in that they provide feedback, or after-the-event information, that is used to adjust and improve the performance of existing processes.

4.5.2.3. Contextual Ambidexterity in Biotechnology Firms

In terms of exploration, our framework and data indicate that beliefs systems and interactive systems work together to generate search and discovery that are relevant and adaptable. Beliefs systems such as the mission statement, the recruitment process, employee training, and the company rhetoric and symbols, are all used to focus and guide employees to search for and create new competences and knowledge. In combination, interactive systems such as technology road-mapping, market forecasting and impact assessments are used to maintain or adjust the specific direction of this exploration activity over time. For example, a respondent from Firm K described a situation in which his biotechnology firm was unable to make sufficient progress towards developing its sole technology for a specific therapeutic disorder, and thus was struggling to attract further investment. With only a few months of funding remaining, the company identified a completely different disease, with a much greater market value, which could be treated using their core platform technology. The discovery of this opportunity is credited to the Chief Scientific Officer “The fact is - his job was to continuously search for, evaluate and share new technological opportunities with the board and project teams. He was our interactive control system - charged with worrying about our future.”

Similarly, in terms of control orientation - the extent to which control is *ex post* (after the event) or *ex ante* (before the event) in nature - our framework and data suggest that beliefs systems and interactive systems work together to promote a feed-forward control orientation. This follows the original thinking of Simons (1995a, p. 108) who argued that interactive systems promote “reforecasting of future states based on revised current information”; however, for this to occur, the projections must be focused and appropriate to the needs of the organization. Thus, beliefs systems work with interactive systems to ensure that information is sought and used in a way that promotes prediction and change that are relevant to the organization. These systems are feed-forward in nature because they help managers to anticipate or forecast events and trends before they occur, allowing them to proactively redirect organizational values and activities. For instance, one respondent reported “we know that the patents on our products and our competitors’ products will expire someday, and even though we cannot be certain what the impact will be when these expiries occur, we still monitor, forecast and develop scenarios so that we are prepared for these events” (Firm I).

In terms of exploitation, our framework and data suggest this is attained by boundary systems and diagnostic systems working in tandem. Boundary systems moderate exploration behaviors, induced by beliefs systems and interactive systems, by defining and restricting the search space and activities that can be undertaken (Simons, 1995a; Widener, 2007). They reign in employee freedoms to counter the autonomy and inspiration that drive the exploration for new knowledge. Diagnostic systems also counter exploration, by using relatively short-term efficiency measures to refine and extend existing competencies. These systems typically focus on and require exploitation related outcomes that are “positive, proximate and predictable” in nature (March, 1991, p. 85). These combined effects of boundary systems and diagnostic systems were exemplified by the statement that “we use boundary control in conjunction with our project performance systems to examine and check that everything is going according to plan. We don’t like surprises and nor do our customers” (Firm E). This type of control counters the instability, uncertainty and serendipity often associated with R&D exploration.

In terms of control orientation, our framework and data suggest that boundary and diagnostic systems in biotechnology firms jointly promote a feedback control orientation. Diagnostic systems are used to monitor, review and test, so as to ensure things are on track in terms of “what” is being done. If they are not, then other control systems and activities can be adjusted accordingly. Managers also use this after-the-event information to motivate and reward the behaviors of individuals, teams, and organizations. In contrast, boundary systems specify and check “how” things are done, in accordance with pre-defined standards and regulations. These systems also provide error-based feedback control, i.e., any deviation from specified practices leads to corrective action and if these deviations persist, then stronger more influential boundary systems are installed. For instance, one of the respondents from Firm M reported that “if biotechnology firms experience one major incident or repeated minor incidents of scientific misconduct, then this typically leads to a corrective action where guidelines and checks for laboratory practice are tightened up.”

4.6. Implications and Future Research Opportunities

The central contribution of our paper is the development and illustration of an R&D management control framework for attaining contextual ambidexterity in R&D organizations. We now discuss several implications of the framework, of relevance to both management practice and future empirical research.

First, our framework posits that there is a strong (though not exclusive) relationship between individual R&D goals and the use of different types of control system. An important implication of this is the need to empirically examine to what extent the different R&D strategic goals influence the attention placed on different types of control system. As the use of multiple control systems can require considerable managerial attention, management should prioritize where to focus their attention and resources (Widener, 2007; Marginson, 2002). Also, as different goals can have different and sometimes conflicting implications for organizational behavior, the use of different control systems could help to manage any potential conflicts presented by multiple goals. This can be examined by surveying employees, to assess the extent to which their R&D organization is guided by different goals and the number of people hours associated with each type of control system (Chiesa and Frattini, 2007).

Second, with our framework and illustrative data, we claim that beliefs and interactive systems provide a feed-forward control orientation that generates or enhances exploration; whereas boundary and diagnostic controls provide a feedback control orientation that generates or enhances exploitation. While we consider this to be true, all frameworks are simplified representations of reality (Box, 1979). Consequently, we suggest that our framework provides a starting point for unpacking the complexities of the control-behavior relationship. For example, it is not just the combination of control systems used that matters, but also the substantive content of the controls- what is dictated, discussed, projected, measured, monitored and evaluated. Thus, knowing that an organization is using a certain type of control system provides a first-order level insight into the control-behavior relationship. The next level is to understand the effectiveness of the different rules, procedures, technologies and incentives that R&D managers use in conjunction with each type of control system.

Third, researchers could explore how control systems could be used to attain low or high levels of balanced ambidexterity (Cao, Gedajlovic and Zhang, 2009). Low balanced ambidexterity is when a firm’s level of exploitation is significantly lower than that of exploration, and vice versa; while high balanced ambidexterity is when a firm has similar moderate levels of both exploration and exploitation. By emphasizing different control system combinations, it could be possible for R&D managers to attain, at specific periods in time, different mixes of this exploitation-exploration balance.

A fourth implication of our framework concerns the influence of other contingency factors such as the size, age and life-cycle of the R&D organization, and its industry conditions, on the use of different management control systems. Although the focus of our paper was on understanding how different types of control system, guided by different R&D strategic goals, can be used to induce contextual ambidexterity, the illustrative empirical evidence we present hints at the role of these factors. For instance, some organizations (e.g., Firms E, G and K) were relatively young and small, and concerned with goals and controls that sought to build R&D capacity in a way that the larger and more established firms were not (e.g., Firms B, H, I and M). Thus, the framework we present could be modified by other researchers to explore how such antecedents drive the use and outcomes of R&D control systems.

A fifth implication of our framework concerns how R&D managers might use control systems to “dynamically” shift, over time, the exploitation-exploration balance. The balanced viewed of ambidexterity (March, 1991; Cao et al., 2009) is largely “static” in nature, in that it refers to an optimal mix of exploitation and exploration at a point in time. However, as discussed above, R&D control is driven and constrained by environmental antecedents such as the size, age and life-cycle of the R&D organization, as well as by changes in industry conditions such as demand, competitors, technologies, products, and regulation. As each of these conditions has a distinct velocity (a rate and direction of change (McCarthy et al., 2010)), - an optimum mix of exploitation-exploration at one point in time is likely to become unsuitable as industry conditions change over time. This makes the balancing of exploitation and exploration a dynamic problem. This is tentatively supported by our data where respondents explained how the balance of exploitation and exploration altered over time as a firm advanced through its life-cycle or changed the focus of its R&D activities (see: Table 3, the R&D contextual ambidexterity section). For instance, the respondent from Firm O explained how different beliefs and interactive systems were required to shift the balance towards exploration so as to help take the company in a new direction. The importance of this implication has been highlighted by scholars who suggest that “given the dynamism of markets and organizations, it is important to develop theories that combine static elements with more dynamic perceptions of ambidexterity” (Raisch, Birkinshaw, Probst and Tushman, 2009, p. 686). Thus, we suggest that our framework can be used to explore how R&D managers use different control systems to dynamically shift the balance or mix between exploitation and exploration over time. This follows what McCarthy, Tsinopoulos, Allen and Rose-Anderssen (2006) call “capability toggling” and Thomas, Kaminska-Labbé and McKelvey (2005) call “irregular oscillation”, where the balancing of exploitation-exploration tensions is much like riding a bike - it requires a continuous and irregular shifting of control system use over time.

4.7. Conclusion

In this paper, we introduced a framework that shows how four types of control system, each guided by an R&D goal, combine to induce the behaviors, outcomes and control orientations (feedback versus feed-forward) necessary for contextual ambidexterity. We illustrated these framework elements and their linkages, using data from biotechnology firms, so as to clarify what these elements are and what they do. While this helps to make the framework more useful and meaningful to scholars and practitioners, this illustration might also suggest that R&D control is a straightforward task. However, this is not the case. An inherent challenge to understanding and practicing effective R&D management control is the fact that it is concerned with controlling the production of knowledge, something that is inherently unobservable. As knowledge increasingly redefines the wealth of nations, firms and individuals, the challenges and benefits of effective R&D control will continue to capture the attention of scholars and managers. Thus, we hope that our framework will motivate researchers to further examine how broader forms of control, guided by R&D objectives and other environmental factors, act as organizational levers for balancing different forms of knowledge production over time.

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