R&D MANAGEMENT

Achieving contextual ambidexterity in R&D organizations: a management control system approach

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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.

1. 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 et al., 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 et al., 2006; Jansen et al., 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 et al., 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.

2. 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.

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., Chiesa and Masella, 1996; Bremser and Barsky, 2004), 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 et al., 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 (i.e., 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.

Table 1. Review of empirical studies within the R&D management control literature

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 and 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 and 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 and 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 and 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 and 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 and Söderquist (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 et al. (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 et al. (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

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 ex 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: Schainblatt, 1982; Bart, 1993; Chiesa et al., 2009b). 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.

3. 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.

3.1. 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

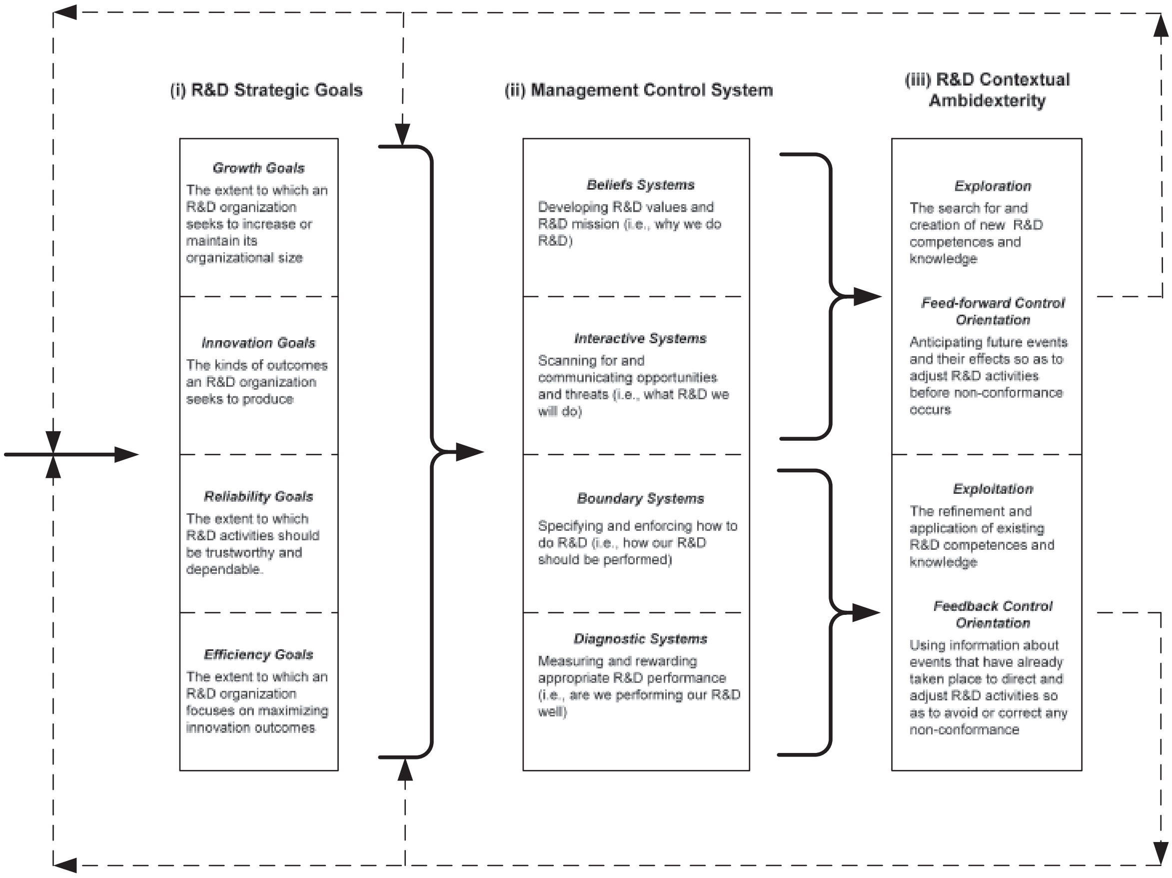

Figure 1. Relationships between R&D strategic goals, control system type and R&D contextual ambidexterity.

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 and 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 et al., 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 use 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.

3.2. 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 (Schainblatt, 1982; Bart, 1993; Chiesa et al., 2009b).

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 (Schainblatt, 1982; Bart, 1993; Karlsson et al., 2004; Chiesa et al., 2008). 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 toward 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 et al., 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 et al., 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.

3.3. *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. 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 et al., 2008), user innovation (Berthon et al., 2007) and external technology commercialization (Bianchi et al., 2009).

4.1. *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

Table 2. Companies and Respondents

Firm*	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

*Pseudonyms and basic descriptions of the area of biotechnology areas are used to protect the anonymity of firms and respondents.

systems within their firms. From 2006 to 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 case studies for inductive theory building, or 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 10 people, ensuring that they were likely to employ some form of formal management control system (Davila and Foster, 2007).

Given our illustrative aims, the data collection began by presenting our conceptual framework (Figure 1) to groups of between five and 10 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).[1] 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.

Table 3. Illustration of Model Elements

Model elements	Representative and abbreviated answers*
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)
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)

Table 3. (Contd.)

Model elements	Representative and abbreviated answers*
	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)
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 6 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 do not know what to do with it (Firm L). Reviews, audits and certifications – these are all industry-recognized ways of obtaining feedback (Firm G).

*Some of the answers have been abbreviated to protect to protect the anonymity of firms and respondents.

4.2. 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.

4.2.1. 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. 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 toward 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.'

4.2.2. 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 and 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 et al., 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, and regulations from institutions such as the US Food and Drug Administration and the European Medicines Agency. Furthermore, there are certification regimes such as Good Laboratory Practices, 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 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.

4.2.3. 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 toward 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.'

5. 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 (Marginson, 2002; Widener, 2007). 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 et al., 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 toward 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 et al., 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 et al. (2006) call 'capability toggling', and Thomas et al. (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.

6. 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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Notes

1. Some of the answers have been abbreviated to protect the anonymity of firms and respondents.

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