THE CONTEXT OF ORGANIZATIONAL LEARNING

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My first touch with academic research was in the spring of 2004, when as a young MBA student, I worked as a research assistant at Brigham Young University. I could never have imagined where this first encounter with research would lead me. The following spring found me in the excited and confused state of preparing my return to Europe to start my PhD at London Business School. This has been a journey of a lifetime, both highly rewarding and highly challenging. It has also been a journey that I could not have taken without the help and support of many people.

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ABSTRACT

Understanding what enables effective organizational learning and adaptation is a question of great interest and relevance to strategy scholars and practitioners alike. While much has been learnt about the topic, our conceptualization of organizational learning continues to lean too heavily on the analogy of individual learning on a single task. Organizations comprise multiple individuals, with significant division of labour and mechanisms for integrating efforts. Learning in organizations thus typically occurs within teams of individuals working in a multi-task context. In this dissertation I explore two important aspects of the organizational context - *formal organizational structures* influencing interactions across functional subunits, and the *characteristics of the tasks* within which teams function. I analyse how these two aspects influence the adaptation and rate at which organizations learn by using longitudinal data combined with a natural experiment in the medical field of *in-vitro* fertilization (IVF) in the UK.

My results shed new light on the role of *integrators* (i.e., formal managerial roles entrusted to coordinate specialists that are responsible for a team product or service), as well as the knowledge spillovers arising from undertaking more difficult tasks. Specifically, I find that learning rates are higher and the adaptive responses to the exogenous shock are more effective if IVF centres use integrators; similarly, I find that the benefits of accumulated experience (i.e. learning rates) are higher if IVF centres deal with more complex cases in their portfolio. Together, the results advance novel understandings of the organizational context within which organizations learn.

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CHAPTER 1: INTRODUCTION

Learning in teams is a key mechanism through which learning organizations become strategically and operationally adaptive and responsive. Learning outcomes in particular have been the subject of extensive study and discussion in the fields of operations management, economics, competitive strategy, and technology management. This development mirrors the renewed interest of researchers, as well as decision makers, in how organizational learning relates to emerging theories of core competencies, dynamic capabilities, and resource-based views of the firm (Wernerfelt 1984; Hamel and Prahalad 1990; Teece and Pisano 1994; Moingeon and Edmondson 1996; Teece, Pisano et al. 1997). Consequently, "learning organizations" and "knowledge-creating companies" have been widely celebrated in the management literature because the ability to learn—that is, to improve organizational outcomes through better knowledge and insight (Fiol and Lyles 1985)—enables the cultivation of skills and capabilities that underlie the competitive advantage of organizations.

Understanding the processes by which organizations learn, and how these processes might be better managed, are issues of central importance for scholars and practitioners alike. Many researchers have speculated about factors contributing to the variation observed in organizational learning outcomes. In her seminal book on organizational learning, Argote (1999) concluded that empirical research on the sources of variation in organizational learning was still poorly represented. Subsequent studies have substantiated findings that alert us to the presence of a large set of factors which impact organizational learning, with a particular depth of understanding being accumulated on factors that are *internal* to teams engaged in learning (e.g., diversity, demographics, processes, and attitudes; see Argote [1999] for a comprehensive review). Yet, in addition to internal dynamics, contextual variables characterizing conditions that are *external* to teams – such as organizational structure, methods of coordination, task environment, and technology – have also been linked, albeit mostly conceptually, to team learning. This latter and less developed area of research offers new ways forward by acknowledging that teams are interdependent with and socially embedded in their organizational settings (Edmondson 2002; Gibson and Vermeulen 2003; Zellmer-Bruhn and Gibson 2006). Thus, it is important to recognize that the effectiveness with which an organization learns depends not only on factors internal to its teams but also on factors that are external to the dynamics contained within the teams.

Despite the recognition of the role played by context (Gladstein 1984; Amabile, Conti et al. 1996; Denison, Dutton et al. 2007), as of yet there is little research investigating the role of the external context in which team learning takes place. There exists, of course, a closely related literature concerned with the micro contextual features that affect teams such as diversity, demographics, processes, and attitudes (Edmondson 1999; Gibson and Vermeulen 2003; Sarin and McDermott 2003). According to this literature, leader facilitation and coaching influences team learning behaviours such as information gathering, reflecting on work processes, testing assumptions, and obtaining different opinions. Yet, although the study of micro contextual features shares a concern for the factors that trigger active search and team learning, the study of the macro context involves challenges that have not been adequately addressed by the literature on the internal dynamics of learning teams.

A critical difference between the macro aspects of context and the micro aspects is that the characteristics of the larger organizational context, e.g. organizational structure, vary little among teams and often are not open to alterations based on team response and input. Dimensions in the macro context that encourage or constrain the team's learning efforts are seldom examined due to the difficulty of data collection; most large samples of teams come from either a single division or a single organization—settings offering no variance in macro context (e.g., Gladstein 1984). For example, few studies have compared learning curves across independent organizations in the same industry (Pisano, Bohmer et al. 2001), largely leaving unanswered the question of how properties of the macro organizational context influence the actual learning achieved by the organization. Therefore, a theory of how context influences organizational learning must validate the impact of macro contextual features – in particular those which lie within the control of organizational actors and thus offer a more direct means for strategic initiatives in the macro context.

In this dissertation, I explore the question – under what conditions can a firm achieve more effective learning and adaptation; or more specifically, under what conditions of the organizational context can the learning firm achieve more effective adaptation to change or higher learning rates? In general terms, the effectiveness of learning at the organizational level depends on the learning achieved at nested levels within the organization (i.e. team and individual levels), the structural characteristics of the organization itself, and the characteristics of the task environment. As noted previously, this dissertation focuses on the impact of the macro (organizational) context of team learning, or more specifically on factors that lie outside the boundary of learning subunits. As a means to begin to develop a theory for the impact of the macro context of teams, I focus on two factors – *use of integrators* and *task complexity* – that are likely to influence the interaction of organizational subunits and the aggregation of their efforts. The effects that these factors have on team and organizational dynamics in turn determine whether they will support or stall the learning of the organization as a whole.

Integrators

Due to division of labour and its ensuing barriers to communication between specialists, organizations face challenges in learning from the individual and collective experience of their constituent parts, as well as difficulties in adapting to external change when the actions of their subunits are interdependent. Fairly little empirical research, however, has attempted to link the role of integrative structures intended for managing interdependent work to learning outcomes in organizations. Although such elements of organizational design have been discussed in prior literature (Lawrence and Lorsch 1967; Galbraith 1973; Clark and Wheelwright 1992; Galbraith 1994; Nadler, Tushman et al. 1997), the principal focus has been on how integration offsets the counterproductive consequences of functional structures to achieve coordination at lower levels of complex organizations, without appropriate consideration of their impact on collective learning and adaptation.

The literature refers to cross-functional, integrative structures by a variety of labels, including integrators (Lawrence and Lorsch 1967; Nadler, Tushman et al. 1997) lateral structures (Galbraith 1973; Galbraith 1994), boundary-spanners (Adams 1976; Aldrich and Herker 1977; Friedman and Podolny 1992), liaisons and heavyweight project managers (Clark and Wheelwright 1992). In this dissertation, I focus only on features of the formal structure, and more specifically on individuals who are *formally mandated* to fulfil a cross-functional role and are entrusted with cross-functional integration at lower levels of complex organizations. The term *integrator* refers to this particular element of formal structure.

Although a variety of elements of organizational design[1] are likely to influence learning at the organizational level, focusing on the learning dynamics induced by integrators as managerial roles superimposed on functional structures to mediate interactions among specialists sharing responsibility for a team product or service, presents an angle of particular interest for studying organizational learning. Such design choices are not only salient factors for the learning individuals and teams, but they also lie largely within the control of organizational actors and offer a more direct means to influencing organizational learning.

Task Complexity

In the management literature, discussions about complexity have emerged from a general effort to understand what it takes to deliver complex tasks successfully in all fields of business activity. The level of complexity in a firm's portfolio of activities has been suggested to be an important dimension of the task environment in which the firm operates (March and Simon 1958; Payne 1976; Campbell 1988). In defining task complexity, I build on March and Simon's (1958) approach which refers to the objective task qualities that contribute to complexity. First, complex tasks are characterized by unknown or uncertain alternatives or consequences of action (March and Simon 1958: 139-141), inexact or unknown means-ends connections (March and Simon 1958: 148-149), and the existence of a number of subtasks, which may or may not be easily factored into independent parts (Simon 1969:195). Thus, in the framework proposed in this dissertation, any objective task characteristic that implies

[1] In this study, I use indifferently the terms *organizational structure* and *organizational design*, although the latter is in principle more general - i.e. in addition to structural elements, organizational design also refers to other "*information processing mechanisms capable of coping with variety, uncertainty, coordination, and an unclear environment*" (Daft & Lengel 1986, p. 555).

an increase in information load, information diversity, or the rate of information change can be considered a contributor to task complexity (Campbell 1988).

Although from a practitioner's perspective the complexity of work has become an important and recurrent issue, there is hardly any academic work that clarifies the processes by which complexity sources affect collective learning processes. In terms of problem solving activities evoked by complexity, the work of Simon and his colleagues (March and Simon 1958; Simon 1969; Newell and Simon 1972) is particularly relevant. Complexity will stimulate the review of already stored heuristics (i.e., "programs") to determine if any are likely to apply to the organizational task. If this review fails to provide a useful program, then new programs are developed specifically geared to address the source of complexity. Together, these processes have implications for learning cycles within the firm, which in turn should affect the learning outcomes.

Focusing on the use of integrators and task complexity, I develop arguments and empirical tests that explain in part the variance in learning outcomes attained at the organizational level. I conduct both quantitative and qualitative research in the medical domain of *in-vitro* fertilization (IVF) focusing on two specific types of learning outcomes: organizational learning rates and organizational adaptation to a disruptive change in the field of IVF. The IVF domain is an ideal setting for exploring these ideas for a number of reasons including the criticality of experiential learning and adaptability for the organizations engaged in this medical practice.

The dissertation is organized as follows. In the next chapter, I review the prior literature on the macro context of organizational learning and I examine its applications to two forms of organizational structure (i.e., whether the formal structure is characterized by the presence or absence of integrators), and one attribute of task environment (i.e., task complexity). In chapter 3, I develop specific hypotheses for the impact of formal integrators on the learning processes and outcomes at the organizational level. Using a large sample dataset of clinic-level characteristics observed for all providers of IVF in the United Kingdom, I empirically test hypotheses on the moderating effect of using integrators for the learning outcomes of the IVF centres. In chapter 4, using the same dataset, I develop and empirically test hypotheses relating to the moderating effect of task complexity on organizational learning rates. In chapter 5, I discuss the implications of these findings for practice and research and offer suggestions for future research.

With this dissertation I aim to contribute to three main areas of research. First, this research extends work in organizational learning by unpacking two sources of variance in organizational learning rates which haven't yet been addressed—formal structure and task attributes. Whereas existing research on learning curves has focused primarily on documenting performance improvements resulting from cumulative experience, few studies have attempted to test for and explain differences in rates of improvement across firms (Argote 1999; Pisano, Bohmer et al. 2001; Reagans, Argote et al. 2005). Second, this dissertation explores a previously un-addressed area of organization design – the learning consequences of coordination through integrators when the nature of interdependence is not perfectly understood. Moving beyond static representations of interdependence, this facet of the research is complementary to recent studies focusing on the impact of organizational structure on adaptation (Siggelkow and Rivkin 2005; Jacobides 2007; Knudsen and Levinthal 2007; Puranam and Swamy 2008). Lastly, this dissertation contributes to the general literature on task complexity (March and Simon 1958; Payne 1976; Campbell 1988), by beginning an exploration of what is gained for collective learning when complexity is allowed into the firm's portfolio of activities.

CHAPTER 2: LITERATURE REVIEW – THE MACRO CONTEXT OF ORGANIZATIONAL LEARNING

Although management scholars have recognized that organizational learning is an indispensable constituent of strategic management, there are still fundamental questions about the macro context of team learning for which we do not have answers. Two of those questions are the focus of this dissertation: (1) Are the processes of team learning influenced by different characteristics of the formal structure? (2) Does task complexity, as a characterization of task structure, influence team learning? In this chapter, I review relevant research from the literature on organizational design, task complexity, and information processing, and I apply the key insights to my research question.

The context of organizational learning

The organizational context encompasses stimuli and phenomena that surround the learning teams within the organizational boundaries. In this dissertation, I show that organizational context—the collection of "*overarching structures and systems external to the team that facilitate or inhibit its work*" (Denison, Hart et al. 1996 p. 1006), is not monolithic but rather that its impact can be conceptualized in terms of two main influences: the local aspects of context that influence internal team dynamics, and the macro contextual features characterizing the larger organization in which teams function.

As of yet, team learning research has largely overlooked the context outside the team boundary, and has primarily focused on factors in a team's local, or micro context, such as group composition (Hyatt and Ruddy 1997; Pelled, Eisenhardt et al.

1999), leader characteristics (Edmondson 2003; Sarin and McDermott 2003), and rewards for team performance (Gladstein 1984). According to this perspective, the micro context influences team learning by increasing or decreasing the frequency of behaviors associated with information gathering, reflecting on work processes, testing assumptions and comparing opinions (Edmondson 1999; Edmondson 2003; Gibson and Vermeulen 2003). Moreover, this stream of research highlights the considerable variance that exists across teams in terms of micro contextual features, and suggests that teams can influence their micro organizational context more readily than they can infuence the larger organizational context. This distinction allows for a better conceptualization of the macro contextual features which represent the focus of this dissertation.

Although existing research on the macro organizational context and team learning is sparse, research more broadly concerning contexts for creativity and product innovation supports the value of considering macro organizational context variables in studies of learning (Amabile, Conti et al. 1996). For example, Woodman, Sawyer, and Griffin (1993) suggest that creative behaviour within organizations is a function of two categories of work environment inputs beyond the characteristics of the individual people involved in doing the work: (1) group characteristics such as norms, group cohesiveness, size, diversity, roles, task characteristics, and problem-solving approaches used in the group (i.e. the micro context); and (2) organizational characteristics consisting of organizational culture, resources, rewards, strategy, structure, and focus on technology (i.e. the macro context). While the model of Woodman and his colleagues is useful for distinguishing various elements of both micro and macro context, I adopt an approach which is congruent with the viewpoint of the group-performance research tradition (Hackman 1986). In that view, the organizational setting—the structure of the task and the contextual supports and circumstances under which the team is formed—precede and condition the interaction that transpires among members.

Dimensions of the macro organizational context

This dissertation focuses on the superordinate aspects of learning teams, and more specifically on two factors: the structure of the organization in which teams are nested, and the nature of the tasks that they undertake. In doing so, this research investigates organization-wide elements which impact the effectiveness of experiential learning or adaptation, but which vary little among the teams within the same organization and are seldom open to alterations based on input from teams.

The assignments, resources, and requirements for the success of organizational task groups emanate usually from outside the groups (Gladstein 1984, Hackman 1986). Hence, to fully understand team learning, one should consider the impact of a team's broader macro context alongside micro context features. For example, while some researchers emphasize the properties of the learning units themselves, such as their absorptive capacity (Cohen and Levinthal 1990), other researchers emphasize properties of relationships between units, such as the network structure in which the units are embedded (Reagans and McEvily 2003). Yet, due to difficulties of data collection, most studies which refer to contextual variables that affect learning behaviours do not capture macro features of context in their analysis (e.g. most large samples of teams come from either a single organization and offering little or no variance in macro context).

Among few published studies addressing this shortfall, Edmondson (2003), Zellmer-Brun and Gibson (2006), and Schilling and colleagues (2003) demonstrate the relevance of a distinction between micro and macro context and include macro features of the context in their analysis. Edomondson's (2003) research in a health care context assessed such macro context variables as structural limitations (e.g., number of operating rooms), senior management support of change initiatives, and organizational innovation history. Although she found that the macro organizational context did not affect team learning behaviours, she speculated that the specifics of the surgery teams (highly self-sufficient units that are relatively independent from senior management and macro context) might explain the lack of findings, and did not conclude that macro context doesn't matter to team learning. Similarly, in their study of teams in multinational organizations, Zellmer-Brun and Gibson (2006) found that organizational contexts emphasizing global integration reduced team learning while corporate-level strategies emphasizing local responsiveness and knowledge management increased team learning. Finally, Schilling, Vidal, Ployhart and Marangoni (2003) showed how related and unrelated variance in the nature of the tasks influence team learning differently, further emphasizing how external aspects of task attributes impact team learning behaviours.

While a comprehensive study of the macro contextual factors that impact organizational learning is beyond the scope of this dissertation, it is important to note that structural features of the context and the tasks in which teams act represent major determinants for collective learning processes. These two dimensions – organizational structure and task structure – cover a sizable fraction of contextual variables that describe the macro organizational environment. In the next section I discussed them in more detail.

Organizational Structure

Organizations are unique social entities consisting of specialized subunits attending to particular parts of the environment. As Thompson (1967), Lawrence and Lorsch (1967), and Tushman and Nadler (1978) have emphasized, such conceptualization calls attention to the underlying phenomenon of interdependence between different subunits (March and Simon 1958; Simon 1991), and the heightened importance of managing cross-unit interactions appropriately. While much attention has been devoted to how organizational structure affects performance, most studies in the organizational design stream have taken a static approach to analyzing the relationship and have discounted the temporal nature of learning processes. Hence, we know relatively little today about the problems of organizational learning and adaptation over time for organizations displaying particular structural attributes.

In this dissertation, I draw on the research tradition of organizational design by taking a dynamic approach in analyzing the link between formal structures and organizational outcomes. For instance, in analyses of organizational structure, "programs" and "hierarchical supervision" are central features of formal structure enabling organizations to overcome the challenges of subunit specialization (March and Simon 1958; Galbraith 1973). Programs refer to the use of plans, standards, schedules, forecasts, formalized rules, policies, and procedures (Mintzberg 1980), and together with hierarchical supervision, they enable reciprocal predictability of actions (i.e. coordination). Little is known, however, about the long term consequences of one type of coordination mechanism over the other, or the impact of these structures on important intra-organizational processes. This dissertation reaches beyond a postulate concerning the relationship between structure and coordination to address issues of organizational learning over time when the nature of the underlying interdependence among organizational subunits is ambiguous.

Organizations can undoubtedly benefit from designs that structure the interaction of their subentities in ways which influence aggregations of local actions, and engender desirable outcomes at the collective level. For example, research employing agent-based simulation has explored the adaptive properties of various organizational designs and found that formal structure may bear differential problem solving advantages (Dosi, Levinthal et al. 2003; Ethiraj and Levinthal 2004; Knudsen and Levinthal 2007), and could influence the effectiveness of incremental adaptation within a given technological paradigm (Rivkin and Siggelkow 2003; Siggelkow and Rivkin 2006). More recent work in this line of research has taken a step further by investigating the role of formal (but fallible) coordinating units in the context of shifting technological paradigms (Ethiraj and Levinthal 2004) and joint learning problems (Puranam and Swamy 2009).

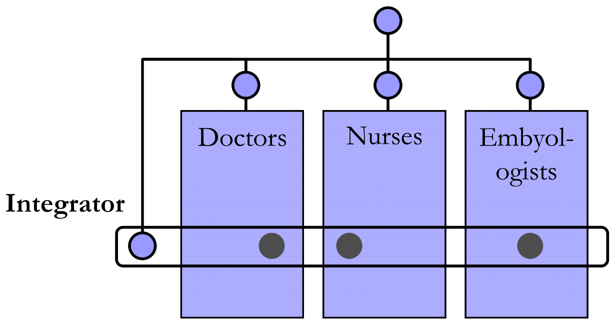
In line with recent developments in this stream, I focus on the role of integrative structures for organizational learning and adaptation. Integrating specialized contributions in a team task is difficult in most circumstances, but is particularly challenging in firms with strong functional groups, extensive specialization and multiple, ongoing operating pressures. The physical and organizational distance between team contributors turns the leading an effective cross-functional effort into a major undertaking. Moreover, when the nature of interdependence between contributors is not perfectly known or unstable, both individual and joint learning become particularly challenging. This research zeroes in on one type of integrative structure – the integrator – on which firms may rely to address coordination challenges across functional departments and which may also enable them to learn and adapt more effectively.

Integrators as elements of formal structure

In the functional form of organization, organizational members are grouped principally by discipline, each working under the direction of a functional manager. The different functions coordinate their work through "programs" on which all parties agree at the outset and through occasional meetings where issues that cut across functions are discussed. Over time, primary responsibility for the team task passes sequentially from one function to the next, a process often referred to as "throwing it over the wall." The strength of this type of formal structure lies in the ability of functional managers to prescribe performance targets and task-related behaviours in their functional area, thus allowing responsibility and authority for actions to be aligned. However, on most cross-functional efforts, not all required contributions are known at the outset, nor can they all be easily and realistically subdivided. Hence, the associated disadvantage is that the feedback received by a contributor as result of her actions is often confounded by the actions of others, further impeding her learning as well as the whole group's ability to learn experientially by mapping actions to outcomes.

The integrator is a formally mandated managerial role which is superimposed on the functional structure and is filled by one individual for the duration of the team task. Integrators have direct access to and responsibility for the work of all contributors to the team task, may or may not have authority over specialized contributors in the team, and may exercise a functional role in addition to the integrator role. As illustrated in Figure 1, the integrator acts as a mediator for specialists sharing responsibility for a team outcome by verifying the appropriateness of their interactions against an existing (imperfect) representation of the underlying task interdependence (Galbraith 1973; Nadler, Tushman et al. 1997). In this dissertation, I will focus on formally mandated integrators who have authority to direct task contributors in a work setup where individual contributors report both to their functional managers and the team integrator.

FIGURE 1. The integrator is a structural add-on to the functional structure



By expediting work across individual contributors, integrators enable coordination at the lower levels of the organization in addition to the hierarchical supervision exercised by functional managers. Organizations which employ these structural add-ons may handle cross-functional integration more effectively because integrators are a source of consistency across subtasks and individual contributions. For example, in a fertility clinic where the primary organization is by functional group (e.g. doctors, nurses and embryologists) and specialists involved in treating a focal patient also report to an integrator (e.g. a dedicated physician), the embryologist may develop a fertilization procedure that is more fitting with the patient's physiological profile and with prior interventions within the focal IVF cycle than the procedure which would have been routinely applied in the absence of an the integrator. Because the integrator had coordinated across the previous treatment stages, the embryologist is more apt at addressing the idiosyncrasies of the case, and contributes to the task in a manner that is complementary with the efforts of the other contributors.

While prior research has shown that this method of organizational integration affects the time required for coordination and the quality of information flows across functional specialities (Clark and Wheelwright 1992), evidence for the impact of this type of organizational arrangement on team learning has proved elusive. The challenges of investigating the role of integrators for learning reside in the low frequency with which these structural features can be observed reliably in practice, as well as in the difficulty of collecting longitudinal data across a large number of comparable organizational settings.

Task Structure

Task characteristics have been an important concern to management scholars. Since organizations depend on inputs from the larger environment, task attributes such as predictability (Galbraith 1973), sub-task interdependence (Tushman and Nadler 1978), routinness (Perrow 1967), and analyzability (Daft and Macintosh 1981) have occasionally been included in studies of team learning. However, as task type is usually implicit in the choice of research setting, efforts to develop and test theory about how task attributes affect team learning continue to be isolated, small-scale and facing many hurdles (for a review see Edmondson, Dillon et al. 2007).

Among the parameters characterizing the task environment of organizations, the properties of the task at hand may pose challenges for the ability of teams to process information. For example, when tasks are nonroutine or highly complex, the uncertainty for organizational members is high and their information-processing requirements are much greater for achieving effective performance (Lawrence and Lorsch 1967; Galbraith 1977). A considerable amount of research has been directed towards conceptualizing task elements as stimuli that vary systematically across work settings and translate into more or less uncertainty for participants, who may then respond with information-processing activity (Daft and Macintosh 1981). While a review of these studies is beyond the scope of this dissertation, it is nonetheless important to consider the theoretical basis of task structure as informed by research in organizational design.

Studies concerned with characterizing the task environment have mainly focused on the relationship between task attributes and optimal ways to organize around these attributes, further emphasizing that task variability, diversity or difficulty are systematically related to organizational structure and decision processes. Though the focus of this dissertation is qualitatively different, by exploring the link between task attributes and the learning outcomes of organizations, research in the stream of organizational design has made two important contributions which are important to this dissertation. First, studies of organizational design have shown that the essential processes of coordinating across specialized contributors to a focal task are affected by attributes of the task itself; secondly, these studies indicate that *complex* tasks necessitate more acts to achieve completion and higher coordination requirements among teams. I use these results as starting premises for studying how aspects of the task influence learning processes and outcomes.

The aspects of the task that are of interest to this dissertation relate to the number of sub-tasks and the flows of materials and information between sub-tasks. Puranam, Goetting and Knudsen (2010) refer to this representation of task structure as “task architecture” and emphasize that the true task configurations are externally determined and imperfectly known by organizational actors. By conceptualizing the subcomponents of a task as a production function with inputs and outputs (i.e. each sub-task has an output, and the whole task architecture as an output), considerations of task division – or the partitioning of the focal task into sub-tasks – become relevant to theoretical understandings of how the structure of a task impacts the learning processes. Hence, I treat variables that capture the variety of task subcomponents and how they are interdependent as antecedents of learning and I argue that these variables serve to differentiate effective from less effective learning.

Task complexity as attribute of task structure

The purpose of the research reported here is to expand on the conceptualization of task complexity and to explore further the relationship between this task characteristic and team learning. In doing so, I follow Simon (1969) in maintaining that complexity stems from "*a large number of parts that interact in non-simple ways,…* [such that] *given the properties of the parts and the laws of their interactions, it is not a trivial matter to infer the properties of the whole*" (Simon 1969:195). This representation of task complexity conveys not only the notion of multiple task elements with which teams must interact, but also the imperfectly known nature of the relationships between the elements involved in a complex task. This formulation also improves upon prior representations of task complexity which have related task complexity to the amount of information available to participants (Galbraith 1973; Tushman and Nadler 1978).

Discussions about task complexity in human information processing have suggested a contingency relationship between task complexity and other dimensions of human psychology. For example, a number of studies in this domain have found that the performance of a more complex task requires the learner to generate a more elaborate mental model (Wilson and Rutherford 1989; Bannert 2002) that more complex tasks are associated with an increase in cognitive load with implications for the performance and learning of the individual (Sweller, 1989). However, research exploring these relationships has focused on the individual level while leaving other questions unexplored, central among which are those posed by organization scientists concerned with these relationships at more aggregate levels of analysis.

During the past decades, there has been an increasing tendency to draw attention to the challenges posed by significant aspects of complex projects (Campbell 1988; Williams 1999; Hobday 2000) or by complexity in projects (Baccarini 1996; Mihm, Loch et al. 2003; Sommer and Loch 2004; Richardson 2005). However, while the level of complexity in a firm's portfolio of activities has been shown to be an important dimension of the task environment (March and Simon 1958; Payne 1976; Campbell 1988), task complexity remains an understudied antecedent of learning outcomes. Some notable exceptions in the project management literature have made a first attempt to link the complexity of work to performance (Baccarini 1996; Mihm, Loch et al. 2003; Sommer and Loch 2004). However, with the exception of Sommer and Loch (2004) which show that the type of complexity influences the quality of the solution contingent on the type of learning mechanism, these studies do not focus on learning as an organizational outcome but rather as a mediating process towards achieving better performance.

For the most part, prior theory on the effect of task complexity suggests that the effect of task complexity on learning would most likely be negative. Nevertheless, some studies focusing on the benefits of developing absorptive capacity (Cohen and Levinthal 1990), heterogeneous experience (Haunschild and Sullivan 2002) and task variation (Schilling, Vidal et al. 2003), suggests that in fact, under certain conditions an increase in task complexity could improve learning outcomes. Thus, while it is clear that task complexity is likely to have an effect on the effectiveness of experiential learning, the direction of the effect is not clear from previous research on task structure.

Summary of key ideas from prior research

Although there has been little previous work in strategy and organizations research on how the macro-organizational environment influences the learning processes and outcomes of firms, a number of related research streams inform my research question. Together, the literatures on organizational design, task complexity, and information processing provide a basis for theorizing about the conditions under which the learning outcomes of organizations are more effective.

A review of prior research investigating micro-contextual factors of organizational learning together with literature on organizational structure and task structure supports the notion that the aspects of the macro-context, while understudied to this point, are important for understanding the learning dynamics within organizations. The macro organizational context of team learning – or more specifically the organizational structures and task inputs within which teams function – is critical to the efficiency and effectiveness by which collectives learn. Because the macro-organizational context affects interractions among organizational members and aggregations of their effforts, the contextual factors deserve special attention and should play an important role in the study of organizational learning.

The first of these factors relate to choices of organizational design. A review of the literature on organizational strucutre, in particular formal structures which employ integrators for interdependent work, suggests that learning processess are necessarily affected due to the interventions of integrators in team interactions. This is further supported by the fact that, in the context of imperfectly known or shifting interdependence among contributors, firms benefit from the use integrators by ensuring that knowledge exchange is more fluid and individual contributions are consistent with each other.

The second factor is task complexity. Theory on information processing in the strategy literature supports the idea that in general an increase in the complexity of the task environment increases the difficulty to accurately map outcomes to actions and places demands on the processing of information of firms. Drawing on the prior research, I introduce the construct, task complexity, to describe the extent to which the structure of the tasks undertaken by the firm include varied numbers of interdependent elements. There are indications in recent literature that the complexity component in the portfolio of activities undertaken by firms, though often detrimental to short term performance, may be beneficial to firms in the long run. Therefore, task complexity is also a an important factor to consider when explaining the variance in learning outcomes when firms engage in repetitive operations.

FIGURE 2. The structure of the organization and of the task relate to the effectiveness with which organizations learn

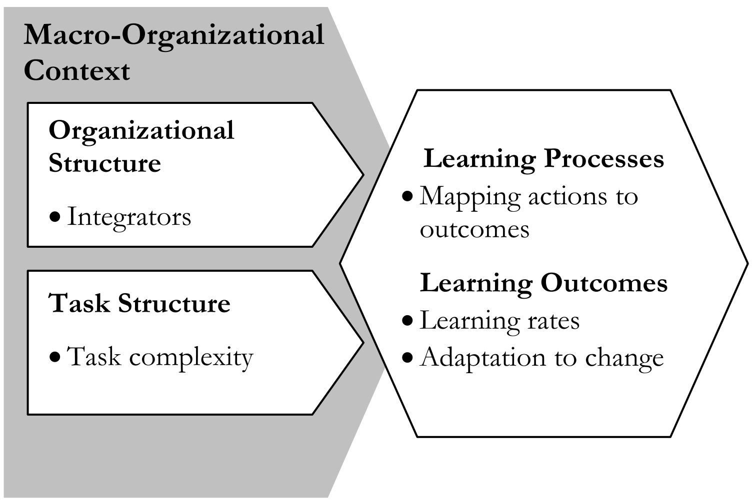


Figure 2 summarizes the key relationships that represent the key research questions and relationships that are examined in this study. The presence of integrators as choices of organizational structure and the task complexity that characterizes the portfolio of activities undertaken by the organization are expected to impact both the processes by which experiential learning occurs and the learning outcomes.

Building upon and extending these literatures, in the following chapters I develop theory and hypotheses for the effect of these factors on the effectiveness with which firms learn. I focus my arguments on two specific categories of learning outcomes – learning rates and adaptation to external change. I conduct an empirical test of these arguments regarding the magnitude of the learning rates and the changes in operational performance within the medical field of *in-vitro* fertilization (IVF). First, I examine the effect of formal integrators which coordinate interdependent work on the attainment of superior learning outcomes. Second, I explore how the incidence of complex cases in the portfolio of IVF clinics affects their learning rates. Finally, I discuss the implications of my results for the development of a theory for the impact of macro-contextual factors on organizational learning.

CHAPTER 3: THE IMPACT OF INTEGRATORS ON ORGANIZATIONAL LEARNING

The presence of integrators, or the extent to which firms employ formally mandated managerial roles that cut across functional boundaries, can alleviate coordination challenges for interdependent contributors to a joint task. While much has been learned about how design choices in general, and integrators in particular, can improve coordination, less is known about the impact of integrators on organizational learning rates and adaptation. For example, we don't know how the presence of integrators affects critical subprocesses of experiential learning, such as the mapping actions to outcomes at the individual and its consequences for overall reciprocal predictability of action (e.g., Puranam and Swamy 2008) and effective learning at the group level (Reagans, Argote et al. 2005).

The question I focus on this chapter, is how do integrators impact the learning dynamics of interdependent contributors to a focal task. While there are many likely mechanisms that affect the learning outcomes of a group in the presence of an integrator, I focus on three levels of impact: the integrator (1) ensures consistency of individual inputs, (2) coordinates the joint learning of interdependent contributors, and (3) manages the exceptions in the macro environment of the team. To understand why the presence of an integrator would lead to better organizational learning, I analyse these effects for two learning outcomes, incremental and radical learning. Exploring the effect of the integrator on these outcomes makes it possible to illustrate how integrators as design choices shape collective outcomes beyond better coordination –in particular how they facilitate learning when underlying conditions remain stable and when they shift.

In this chapter, I focus on the impact of integrators on two types of organizational learning: *incremental learning* as reflected in the effectiveness of learning from cumulative experience when the nature of task interdependence is stable but not perfectly understood, and *radical learning* as indicated by adaptive outcomes achieved when the underlying nature of interdependence shifts. The approach of conceptualizing learning outcomes as incremental and radical learning extends the work of Miner and Mezias (1996) and Edmondson (2002) who introduced the constructs of incremental and radical to emphasize the distinction between incremental improvements to existing routines and deeper change in knowledge structures as result of addressing new challenges.

I test my theoretical predictions in the context of fertility care in the UK, and I focus on medical centres which have provided *in-vitro* fertilization (IVF) during the last two decades. There are a number of reasons why the domain of IVF constitutes an appropriate setting to study the role and impact of integrators. First, the setting allows for designing a natural experiment by observing the performance of IVF centres before and after an external disruptive shock which changed the production technology but was exogenous to the organizational structure. Second, this medical sector allows the identification of two modes of coordination achieved in workgroups: centres which integrate efforts on the basis of programs, rules and feedback channels allowing ongoing communication, and centres which in addition to these mechanisms also employ integrators[2] who coordinate across the functions of doctors, nurses and embryologists to ensure continuity of care at the patient level. Third, the performance of each IVF provider can be assessed objectively using the live-birth rate for the standard patient group, which is a commonly used method to assess clinical

[2] In IVF, the labels used to describe the integrator role are "*dedicated physician*" and "*one physician throughout treatment*."

performance in IVF. Lastly, the setting provides detailed longitudinal data for a relatively large sample of centres and their portfolio of activities, prior experience, technologies used, and institutional constraints. This research design permits to isolate the effects of structure on operational performance over time while controlling for various other factors.

The analyses indicate that the lack of integrators retards the organization's ability to learn and to adapt to unfavourable external change. The findings have practical significance because they raise attention to the value-creating role of integrators and the mechanisms through which they enable superior learning outcomes. While I cannot make normatively strong statements, the results have important implications for our understanding of the relationship between organizational structure and dynamic organizational outcomes.

THEORY AND HYPOTHESES

Interdependence and Learning

In this paper, I start with the premise that a pervasive feature of organizational life–*interdependence*[3]– influences the organization's ability to learn. Determining the link between actions and outcomes occupies a central role in learning-by-doing because it allows the learner to select effective actions. To learn, an agent needs feedback on outcomes and must know what actions were taken in order to assign correct evaluations to the choices.[4] Moreover, there must be a mechanism for

[3] Interdependence refers to the relationship between two decision making entities. Given actors A and B with independently definable outputs, a situation of interdependence between A and B exists if the outcomes of actions taken by A depend partly on the actions taken by B, and vice versa.

[4] More generally, this challenge is known as the *credit assignment problem* because in interdependent work only at the end of a long sequence of actions there is a discernable payoff (Minsky, 1966). This delay in realizing feedback complicates learning.

reinforcing successful actions and extinguishing unsuccessful ones—such as incentives tied to performance. In situations of interdependence both these properties are compromised: others' actions may remain unknown and feedback may be available only at the group level and not at individual levels (Herriott, Levinthal et al. 1985; Lounamaa and March 1987).

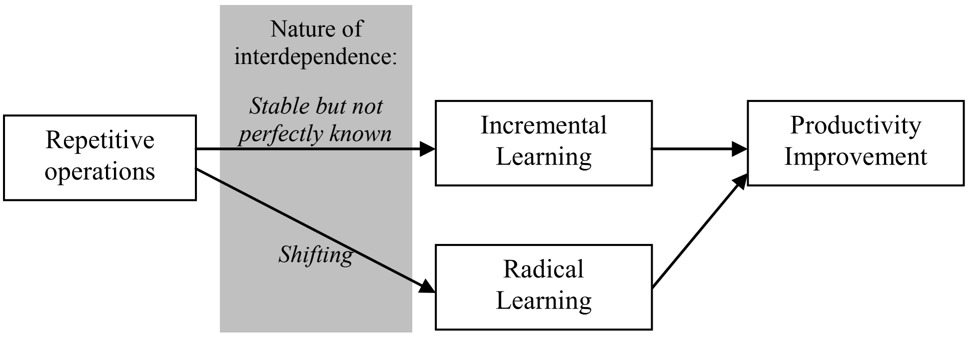
A large number of studies suggest that technological and organizational interdependence limit the ability of firms to learn from experience or to adapt to shifting conditions (March and Simon 1958; Simon 1962; Rivkin 2000; Sorenson 2003; Puranam, Goetting et al. 2010). These studies argue that *systemic interdependence* arising from a series of interdependent activities contained within firm boundaries (Chesbrough and Teece 1998, p. 130) poses important challenges to effective coordination. In reiterating this idea, Sorenson (2003) stresses that vertical integration, for example, engenders the development of interdependence within the firm, and that such integration hinders organizational learning in more stable environments. Thus in the presence of interdependence, learning is challenging. However, formal structures which enable better coordination among interdependent agents may ameliorate these challenges.

I draw on two established research paradigms which conceptualize aggregations of individual-level patterns and which, to some extent, have recently departed from the assumption that the nature of interdependence between individuals is always perfectly understood and stable: the research tradition of *organizational design* with its focus on the link between formal structures and organizational outcomes, and the field of *organizational learning* which views learning as the process of taking action, obtaining and reflecting upon feedback, and making changes to adapt or improve. A number of studies in both streams of research have begun to portray how interdependent agents work out optimal courses of action or achieve advantageous modes of organization with special attention to whether the agents have or do not have an understanding of how their various actions interact (Reagans, Argote et al. 2005; Puranam and Swamy 2008; Puranam, Goetting et al. 2010). In other words, both types of aggregations (i.e., individual learning into collective learning, and individual action into optimal organizational structure) are shown to start with the crucial premise that interdependent agents or their superordinates do not fully understand the nature of their interdependence and that agents must learn how their individual contributions interrelate. In this paper, I depart from the common assumption that the underlying interdependence is understood and I focus on the role of the integrator in facilitating the process through which interdependent contributors to a team output learn about how their actions are interdependent. I consider the role of the integrator under two conditions: when the nature of interdependence between agents is stable but not perfectly known, and when it shifts due to external change.

A number of organizational learning scholars have pointed to the distinction between learning within a technological paradigm and learning to adapt to changes in the underlying paradigm. Scholars of discontinuous change have noted how field-level changes of great magnitude sweep through industries, permanently altering their features (Meyer, Gaba et al. 2005). In a similar vein, terminology employed in agent-based NK simulation models draws the same distinction by using the analogy of organizations climbing local peaks in stable task environments versus gradient search within landscapes where peaks shift due to dramatic discontinuous change. These ideas are also echoed by conceptual work in the organizational learning literature pointing to the contrast between improving existing routines or capabilities and developing new ones to address changing conditions. Indeed, current work maintains that no theory of organizational learning is complete without this distinction (Crossan, Lane et al. 1999).

In keeping with the research terminology employed by Miner and Mezias (1996) and Edmondson (2002) to characterize the two types of learning discussed above, I use the terms *incremental* and *radical* to distinguish between intra-organizational learning when underling conditions are stable and when they shift. As illustrated in Figure 3, I consider a model in which structural considerations are linked to learning from repetitive operations within a stable paradigm (incremental learning) and to adaptive responses to discontinuous change (radical learning) when the nature of interdependence is imperfectly known.

FIGURE 3. Types of learning when firms engage in repetitive operations



The effect of integrator on incremental learning

Building on Cyert and March (1963)'s behavioural theory of the firm and March and Simon (1958)'s seminal work on the role of hierarchy, recent work in organizational design continues to explore how structure influences the information that is available to actors (Jacobides 2007; Knudsen and Levinthal 2007), and how it screens out the information available at higher levels (Siggelkow and Rivkin 2005;

Siggelkow and Rivkin 2006). Although this work is not explicitly directed at distinguishing the roles of integrators, it illustrates the mechanisms by which structural characteristics influence gradient search within stable technological paradigms. Particularly relevant are results suggesting that if the interdependence of decisions across learners is difficult to analyze, a coordinating unit with high processing capacity is beneficial despite the hazard of imperfect evaluation (Rivkin and Siggelkow 2003) and problems of shielding—i.e. learners screening out proposals to the coordinating unit if said proposals yield lower performance at their level (Siggelkow and Rivkin 2006).

Although anecdotal evidence in the organizational learning literature suggests that learning activities are affected by the manner in which individuals and teams are managed (Hayes and Clark 1985; Adler and Clark 1991; Pisano, Bohmer et al. 2001), few research efforts have been aimed at investigating how structural features of organizations influence the rate of incremental improvements in production efficiency—also known as the learning curve (Yelle 1979). To the best of my knowledge, none of these studies have focused on the role of integrators as choices of organizational design that influence incremental learning. While some indications exist that learning is promoted by team leaders because they emerge as focal points for coordination efforts (Edmondson 2003), my focus is on the significance of integrators for the learning dynamics of internally differentiated workgroups engaged in repetitive operations. This emphasis is particularly useful when assessing how individual and system learning curves (Argote 1993) are affected by the presence or absence of an integrator.

In particular, I propose that integrators promote incremental learning by providing more fine-grained feedback, by solving credit assignment problems

(Minsky 1961; Denrell, Fang et al. 2004) and by avoiding the dangers of fast and slow learning (Lounamaa & March, 1987). The integrator enables better communication between specialized contributors separated by functional boundaries by translating intermediate outcomes into the different perspectives of each contributor, and hence by facilitating a more consistent mapping of actions to outcomes than what it would be achieved in her absence. Another important role of the integrator is to provide for the team a direct (albeit imperfect) interpretation of the latent task interdependence.

As suggested by Weick (1995) that "any map may do" – a conjecture tested recently by Puranam & Swamy (2008) who used a simulation model to test the usefulness of dedicated coordinators – even flawed representations can help in avoiding coordination failures arising from the absence of a shared understanding in joint learning problems. By offering a platform for interaction, the integrator prevents multiple simultaneous adjustments of functional contributors, which had been shown to be detrimental for collective learning (Lounamaa & March, 1987; Levitt & March 1988; Levinthal & March, 1993). Finally, the integrator also may inhibit the learning of one contributor in order to make it more effective for another or by keeping learning rates of individual contributors from reaching extreme levels in either direction (Puranam and Swamy 2008).

To conclude, by clarifying to each individual learner the actions taken by others, by offering representations of the underlying interdependence, and by preventing multiple adjustments, integrators enable more effective collective learning when the nature of interdependence in an ecology of learners is not known. Hence, the integrator fosters a more effective use of experience at both individual and group level, as opposed to situations when the integrator is absent and individuals observe each other's actions and payoffs less accurately.

Hypothesis 1a: *Learning rates are higher for organizations which employ integrators.*

Though a thorough review of the literature did not reveal studies that could suggest an alternative hypothesis, it is important to consider the possibility that integrators could be detrimental to incremental learning. In building this argument, I draw on an analogy from the vertical integration literature. As Sorenson (2003), points out in his study of workstation manufacturers, integration of interdependent activities under the same hierarchy could stifle learning-by-doing in stable environments. This may occur because the interdependence generated by the broader organizational design could cause decision makers to map actions to outcomes erroneously, to miss the actual sources of poor performance, and to cause a series of domino-effect problems when correcting errors. While these arguments have been made in the context of vertical integration, where coordination is implied to happen mainly at the top levels of the organization, coordination through integrators may display similar challenges even if it occurs at lower organizational levels.

In other words, given a hypothetical organizational setting where specialized contributors have a perfect understanding of how their actions interact, the presence of an integrator could introduce noise into the pattern of interactions, affecting well-rehearsed processes that would have otherwise been accurately executed. Moreover, the presence of the integrator may interfere with learning processes of cross-functional teams, by preventing them from making incremental refinements to operations which result in sub-optimal utilization of prior experience. This argument leads to the following alternative hypothesis:

Hypothesis 1b: *Learning rates are lower for organizations which employ integrators.*

Although prior literature has not found evidence of a negative impact of integrators on performance or learning, the discussion of alternative hypothesis included here, cautions against the expectation for a positive impact of integrators. Hence, reliance on two-tailed tests would be strongly preferred in the analyses employed to verify this relationship.

The effect of integrator on radical learning

A useful conceptualization of organizational learning must include the notion of purposeful adaptation when important underlying conditions change. Following the terminology employed by Miner and Mezias (1996) and Edmondson (2002), I use the term radical learning to denote the adaptive outcomes achieved by organizations when they face mismatches between the current set of routines and new requirements imposed by changing conditions in the environment. In doing so, I am able to focus on learning processes triggered by dramatic shifts in underlying technological paradigms which alter relationships of interdependence within organizations.

Changes in the nature of task interdependence present a particular challenge for workgroups engaged in joint learning because they reset the links between actions and outcomes and render current knowledge about interactions obsolete. When interdependent learners confront these types of changes, they look to authority for cues on appropriate behaviour (Tyler and Lind 1992) and seek out representations however inaccurate they may be. While the mechanisms through which integrators enable more effective incremental learning may also play a role in radical learning, (i.e. providing representations and feedback on intermediate outputs), the environmental jolts that shift the nature of interdependence give impetus to the role of the integrator in enabling transition to the new organizational and environmental conditions.

The findings of Puranam and Swamy (2008) regarding the usefulness of dedicated coordinators, corroborate the predictions put forth by Pisano and his colleagues (2001) in their study of 16 surgical teams faced with the introduction of a radical new procedure in cardiac surgery. Upon identifying significant variation in team capacity for radical learning, Pisano his colleagues speculated that among other factors, the physician taking an integrative role (e.g. mandating stability of team composition and surgical procedure) enabled surgical teams to achieve better treatment outcomes during the ramp-up phase of the new technology. Garicano (2000) hints to this role of the integrator when describing the "knowledge-based hierarchy", where knowledge of solutions to common problems is located on the production floor and knowledge about more exceptional or harder problems is located at higher organizational levels. Thus, integrators may act as "*problem solvers specialized in acquiring and transmitting knowledge in the form of directions about what to do when the production worker confronts a problem she does not know of the role of problem-solvers*" (Garicano 2000 p.897). When faced with an external shock that changes the nature of interdependence between contributors, the presence of an integrator buffers interdependent learners from deleterious effects of such shifts (i.e., threat-rigidity responses, escalation of commitment, etc.) by its ability to rein in routine responses through exception management.

Hypothesis 2a: *Adaptive responses to external change are more effective for organizations which employ integrators.*

With only one exception (Sorenson 2003), the current literature is silent regarding the possible mechanisms through which integrators may deter effective organizational responses to disruptive changes in the environment. However, as it was the case with the role of integrators for incremental learning, it is necessary to consider the drawbacks that make integrators unsuitable for radical learning. Sorenson (2003) suggests that tightly coupled organizations may hinder the development of dynamic routines, the iterative processes of enacting new routines and the implementation of higher-level codes of action (Sorenson 2003, p. 458). While his arguments focus on the suitability of vertical integration for different types of learning, other forms of integration, such as integrators, may also be detrimental. For example, an integrator may heighten the propensities for escalation of commitment by coupling the justification of past decisions with the assumption that they still apply to the new environmental conditions. In sum, integrators may induce entrapment in the status quo, further preventing cross-functional groups from learning how the nature of their interdependence has changed and how to improve their coordination and group performance.

Hypothesis 2b: *Adaptive responses to external change are less effective for organizations which employ integrators.*

METHODS

To test these hypotheses empirically, it was necessary to select a context which allows the examination of organizational outcomes over time and under circumstances characterized by significant division of labour. The medical domain of *in-vitro* fertilization met these conditions because there is known to be wide variation in organizational attributes and performance across providers of *in-vitro* fertilization, as well as well-defined, specialized roles for the health care professionals in IVF. In the United Kingdom, performance data and other statistics for establishments providing fertility treatments have been recorded since 1992, several months after *in-vitro* fertilization was authorized by UK regulators. Historical data on various attributes of fertility centres have been collected and published by the Human Fertility and Embryology Authority (HFEA), which is the independent regulator overseeing the use of human gametes and embryos in the United Kingdom.

The setting: In-vitro fertilization (IVF)

The setting offers the rare opportunity to measure learning outcomes in multiple organizations for the same task and at the same time. The task of completing an IVF cycle for the female patient consists of several stages (i.e., ovarian stimulation, egg extraction, gamete manipulation, and embryo transfer), and requires the joint participation of medical personnel coming from three areas of specialization (i.e., fertility doctors, embryologists and nurses). To understand the challenges of achieving coordinated action among these specialists, it is important to note that IVF continues to be a highly uncertain treatment[5] with many biological, physiological and clinical variables confounding the outcome of the interventions.

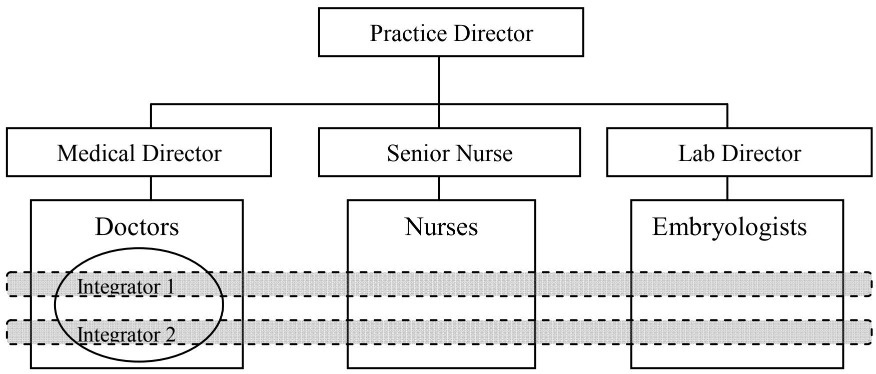
In addition to unknown biological factors that routinely confound feedback, coordination failures resulting from interdependent specialists having different domains of action and learning rates constitute an important and most debated[6] aspect

[5] The theoretical likelihood of achieving a live-birth per egg in any one IVF cycle is estimated to be in the 20-30% range. However, increasing age of the female patient lower significantly the probability of per-cycle success.

[6] Ongoing conversations and studies published in this field emphasize the importance of establishing "action plans", refining codes of practice and developing tools that synchronize the inputs of IVF specialists involved in a particular cycle (cf. interview data).

of this medical domain. For example, IVF cycles require doctors, nurses and embryologists to leverage technology and know-how within their departmental boundaries (see Figure 4). Due to conflicts between the timing of patient visits and internal rota systems, the continuity of care (i.e., the stability of the IVF team which treats the patient throughout the treatment timeline) is often compromised. To address these challenges, some IVF centres display organizational arrangements in which the doctor sees the patient at each visit and acts as liaison with the other specialists involved. These doctors often circumvent the routine mode of operation.

FIGURE 4. Integrators as structural add-ons to functional structures in IVF



While intermediate outputs (e.g. achieving fertilization) and partial checklists may still guide the action of IVF specialists, joint interventions performed by doctors, embryologists and nurses within a given IVF cycle are characterized by both sequential and reciprocal interdependence (Thompson 1967). In these conditions, the reciprocal predictability of action is often muddled by noise and problems of shielding.

To address the problems associated with interdependent work some clinics employ “integrators” – i.e. organizational arrangements which allow the active involvement of a lead doctor throughout the stages of the IVF treatment and regardless of whether the intervention performed by the specialist falls within her domain of action or not. As discussed in the data section, this characterization of structure displays virtually no variation over time for the observed clinics and allows the sample to be treated as being comprised of two subpopulations defined on the basis of whether the medical centres use integrators or not. Insights from the industry support this treatment and corroborate the existence of strong imprinting effects at founding which relate to this structural attribute and explain its stability across time.

An exogenous shock to IVF

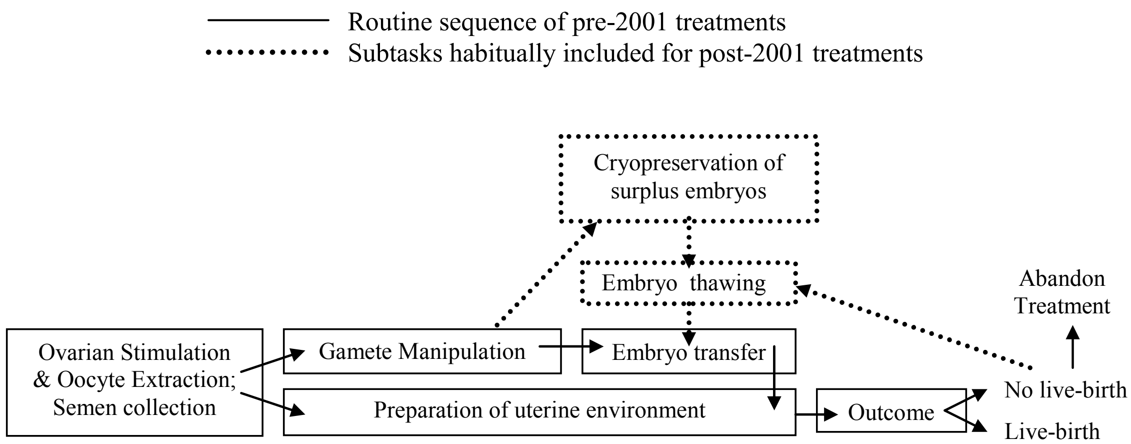
Although in prior years the majority of the IVF cycles involved the transfer of three or more embryos, in 2001 HFEA recognized multiple gestations as an undesirable complication of IVF and allowed only a maximum of two embryo transfers per patient.[7] The medical literature in human fertility provides overwhelming evidence about the strength of the relationship between the amount of embryos transferred to the patient and the likelihood of multiple pregnancy. Hence, a decrease in the number of embryo transfers was expected to reduce the incidence of multiple births and IVF-related complications in the UK.

The intervention changed the production technology of IVF in several ways. First, it affected the link between two stages in the treatment, the stage of gamete manipulation and that of embryo transfer (Figure 5). Second, it triggered within-stage search by influencing the nature of work at each step in the treatment (e.g. embryologists would adopt techniques making more efficient use of egg cells; doctors

[7] The centers must report in writing deviations from this policy, along with detailed descriptions of the exceptional circumstances. Since 2004, only 4 in every 100 treatment cycles (4%) involved three embryo transfers (cf. HFEA website).

would apply ovarian stimulation techniques that maximize the number of egg cells collected, nurses would employ embryo transfer procedures that would enhance the chance of implantation, etc.). The first change corresponds to what organizational theorists call architectural change, while the second reflects a series of component changes (Henderson and Clark 1990) that had system-level implications. Thus, the constraints placed on the input side correspond to a shift in the technological paradigm which affected interactions among interdependent IVF specialists as well as individual and collective learning processes.

FIGURE 5. Stages in the IVF treatment cycle



To briefly illustrate how the interactions across treatment stages were affected by the change, it is useful to briefly consider two examples of how doctors, embryologists, and nurses engaged in both within-domain search and joint learning. The first case relates to the observation that in the pre-shock period nearly all suitable embryos obtained in the lab would have been transferred to the female patient in one cycle.[8] This pattern changed dramatically after the policy was implemented due to couples increasingly requesting the preservation of surplus embryos. The introduction of cryopreservation techniques introduced novel interaction effects between the work of the doctor and that of the embryologist by requiring both agents to learn how their choices interact (e.g. certain choices regarding egg collection and embryo transfer would be incompatible with choices regarding lab work). The second example relates to the interface between the phase of egg collection – normally performed by doctors in an operating theatre – and the phase of egg manipulation performed by embryologists in the laboratory. Because the new embryo transfer policy criticized treatment approaches maximizing embryo counts, the specialists performing ovarian stimulation had to adjust their protocols such that they would extract not necessarily more eggs, but rather better quality eggs. To achieve this, stimulation protocols underwent a period of significant experimentation and revision, often causing the choices made in the early stages, by the doctor, to remain unknown to the embryologist who would later micro-manipulate the reproductive cells in the lab. The ways in which choices in either stage interact are generally unknown in IVF (Personal interview notes, February 2010), and joint learning is further complicated by high individual learning rates and multiple simultaneous changes being undertaken.

To conclude, the restrictions on the input side (i.e. having to use less embryos) triggered IVF centres to compensate for the decline in treatment effectiveness through various component and architectural changes which altered the nature of the interaction between specialists involved in IVF. Given the ambiguity characterizing the task environment in IVF, fast learning in each domain of action, and highly interdependent choices across contributing specialists, the new policy on embryo

[8] Prior to cryopreservation techniques becoming reliable in the late 1990s, any unwanted embryos were donated or discarded depending on the patient's preferences.

transfer raised new obstacles for achieving reciprocal predictability of actions and maintaining adequate levels of operational performance.

It is important to emphasize that although the shock allows for the design of a quasi-natural experiment, the treatment effect considered in this study is whether the clinic employs integrators for interdependent work at the patient level. Correspondingly, the outcome is defined in two ways: the learning rate of the centre throughout the period of observation, and the performance change after the externally enforced restriction on the use of multiple embryos. The 2001 policy change was unambiguously determined by public health considerations regarding the risks of obstetric and neonatal complications following multiple pregnancies, thus placing its occurrence beyond the control of the IVF centres.

Sample

Although the first in-vitro fertilization (IVF) baby was born in 1978 as the result of the pioneering work of two British scientists, Robert Edwards and Patrick Steptoe (1980), it wasn't until 1992 that regulators in the United Kingdom permitted fertility centres to offer IVF treatment under full legal endorsement. Ever since, data on all IVF centers within the UK have been collected and published by the Human Fertility and Embryology Authority (HFEA), which is the independent regulator overseeing the use of gametes and embryos in infertility treatment and research in the UK. Having received permission from the HFEA, I was able to trace back variables such as experience and success rates for the population of all fertility clinics based in the UK since 1991, the year prior to the introduction of IVF as an authorized treatment. The final year made available was 2006.

This setting and these data were ideal to test the relationship between contextual factors and learning outcomes for a variety of reasons. First, the measure of success is unambiguous: whether a cycle of IVF treatment results in a live birth or not is a clear goal and outcome. Furthermore, because each patient and treatment cycle is distinct, cumulative experience is also clear to operationalize and measure, namely as the prior number of treatments performed. Moreover, the functional structure displayed by all clinics in the sample has its roots in an established system of medicine and can enable the identification of the two variants relevant to this study: functional structures with integrators as structural add-ons, and functional structures without integrators.

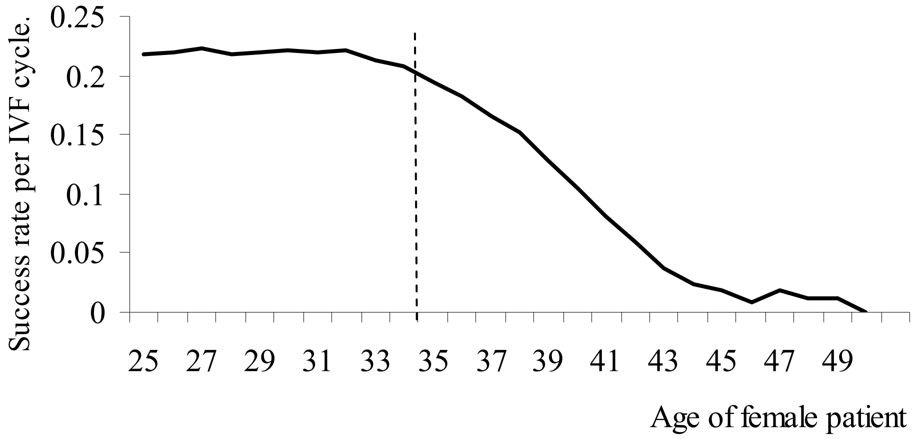
While many studies in this area are hampered by selection bias and serious left-censoring effects, the sample included the entire population of UK medical centres that provided IVF from 1992 to 2006, with only 12 centres missing data on the intercepts of their experience curves (due to being established prior to 1992). The total number of centres with at least one attempt to perform IVF rises to 116, but only 103 centres continued to provide the treatment for at least three consecutive years. Where data were not available for at least three consecutive years, centres were dropped from the sample due to insufficient information necessary for longitudinal analysis. This pattern is explained by the fact that some centres failed to finalize the licensing agreements required by HFEA. Further, 39 centres in the initial sample, have not been in operation both before and after the regulatory shock observed in 2001, which is necessary to test the adaptive response of the centres to shifting conditions in their environment.

The final sample with complete data for all independent variables included 852 centre-years for the 64 IVF centres which constitute the units of analysis. These clinics have performed just under 350,000 IVF cycles on nearly 300,000 female patients, resulting in almost 70,000 IVF babies by the end of 2006. Data on centre-level live-births and patient base came from the database maintained by HFEA, while supplementary data on other centre attributes have been obtained from published patient guides. The information in the HFEA database and patient guides has been collected annually and is subject to regular verifications during internal audits and onsite inspections at the supervised clinics. Table 1 provides more descriptive statistics regarding the sample.

Dependent and independent variables

The *dependent measure* in the main set of models is the annual IVF success achieved by the clinic. As the patients' main aim is to "have a baby", this measure of operational performance allows for cross-centre comparisons in IVF as it reflects the chance of success in each clinic. To aid the comparison of these results, I use the success rate for the "standard patient group" in this medical domain (Johnson, El-Toukhy et al. 2007), which refers to women under the age of 35. As indicated in Figure 6, the chance of success through IVF decreases with the age of the female patient, and displayes a particularly sharp decrease after the age of 35 (HFEA, 2007). Several studies published in the medical literature suggest that comparing success rates for the more homogenous patient group below the age of 35 eliminates the necessity of accounting for most sub-fertility related pathologies (Sharif and Afnan 2003 pp. 484). In line with the qualitative data collected via interviews and with the recommendations from the medical literature, I calculated the performance measure as the percent of female patients under 35 who had a live-birth as a result of undergoing IVF at the focal clinic in year *t*.

FIGURE 6. IVF success rates are significantly lower for female patients over 35



Independent variables. The testing of Hypothesis 1 requires the development of two measures which must be interacted: the cumulative IVF experience of the centre, and whether the centre uses integrators to coordinate the workgroups that emerge around each patient. To measure *centre experience*, I follow the learning curve tradition by cumulating all prior IVF cases and applying a log-linear transformation.[9] Although some studies also examine cumulative years of operating experience as a measure of learning (e.g., Ingram and Baum 1997), cumulative production experience remains the preferred specification as it relates more closely to the number of trial-and-error experiments that have occurred.

Descriptions of the structures employed by centres to conduct their work are published in the annual patient guides as listings of "support services" offered by each centre. To interpret this data, I drew on my field notes[10] to clarify the terminology and

[9] This specification assumes diminishing marginal returns to cumulated experience. I estimated several alternative specifications (e.g. linear specification, depreciation) but none fit the data significantly better than the loglinear approach.

[10] This study is part of a larger project which involves ongoing and extensive consultation with IVF practitioners. To date, I have participated in 16 field interviews, 6 site visits and numerous industry events and conferences. In addition to recording and transcribing the majority of the meetings and interviews in which I took part, I am also constantly surveying the medical publications in human fertility to gain a deeper knowledge of the clinical, therapeutic and administrative aspects specific to IVF.

identify whether in addition to functional managers (e.g., medical director, head of laboratory and head of nursing), centres also employ organizational arrangements for coordinating the work of interdependent contributors at the patient level. The investigation led to the identification of the construct of *one physician throughout treatmen*t, which denotes the role of integrator fulfilled by a doctor when the treatment of a patient requires the participation of various specialists. I coded the occurrence of the term as a binary variable (*integrator*) which takes the value of 1 if it is reported by the centre and 0 otherwise. Surprisingly, this characterization of structure displays very low within-centre variation with no instances of integrator adoption and only three centres eliminating the option of offering integrators.[11] To improve the empirical strategy and the clarity of the results, I excluded the clinic-years observations which occurred after the integrator option was abandoned by the three clinics in question. This measure addresses the concern that structural changes may be behind the results of the analysis.

To account for the change introduced by the technological shift in IVF, I include a binary variable (*post-2001*) indicating whether the observation occurred after (i.e. equal to 1) or prior (i.e. equal to 0) to the policy change regarding multiple embryo transfers. The interaction term between *post-2001* and *integrator* is used to test whether the use of integrators enables firm-level adaptation to systemic change, as predicted by Hypothesis 2. Since the shock is exogenous to the structural attributes of the IVF centres (i.e. the choice for integrator was predetermined and remained constant throughout the period of observation due to imprinting effects at founding),

[11] Two private centers and one centre affiliated with the National Health System (NHS) ceased to report the use of integrators towards the end of the period of observation (post 2003). Their subsequent center-year observations were dropped from the analysis to guard against misleading results.

this research design rules out the possibility that medical centres in the sample chose to use integrators with the intention to respond to change.

Centre capacity measured as the number of patients treated in the year of observation was used as a control for centre size. The variable for the age of the centre (i.e., number of years since the centre was established) is included to offset for the lack of data concerning the experience accumulated in the 1980s by a minority of clinics in the sample. To control for vicarious learning and the state of the art in IVF each year,[12] I include a measure of industry-level experience which consists of a log transformation for the count of patients treated in the UK prior to the year of observation. To control for the nature of the IVF technology used, I specify the percent of cycles which involved more invasive micro-manipulation of gametes during the year of observation (i.e. *intra-cytoplasmic sperm injection*, henceforth ICSI). A measure describing the age profile of the patient base was also included to account for the complexity characterizing the task environment of the clinic. Finally, I also include centre dummies to control for other unobserved centre characteristics which may affect clinical performance (e.g. they are training centres for junior specialists or may be affiliated with a university or a research centre; they may have different structures in place that are not captured by the integrator variable; they may operate in areas where the population has lower fertility rates, etc.). These clinic-specific characteristics affect success rates across clinics and it is important to acknowledge them in the model through a centre fixed effect which captures the time-invariant quality of IVF provision for each centre.

[12] Early model specifications have included year dummies in addition to controls for industry experience, center age and technology. However, year effects were not significant.

Analysis

The statistical analysis used standard procedures for longitudinal data. The modelling approach consists of linear regression analysis for cross-sectional time-series data with robust estimation. Preliminary analyses considered Tobit models (as the dependent variable is a fraction, and hence non-negative), random effects estimation and general linear models (to attempt estimating the effect of *integrator*), and estimation with centre fixed effects. For brevity and in accordance with standard tests[13] for determining the appropriate estimation method, I present only the results of the last approach.

The following regression model was developed to test H1 and H2:

$$Y_{it} = \alpha + \beta_1 \, EXP_{it} + \beta_2 \, POST_t + \beta_3 \, INT_i + \Sigma \, \eta_j Z_{ijt} + \nu_i + \varepsilon_{it} + \boldsymbol{\delta_1} INT_i \times EXP_{it} + \boldsymbol{\delta_2} INT_i \times POST_t$$

Where Y_{it} is the success rate of the clinic i in year t, EXP_{it} is the prior experience, INT_i indicates whether the centre uses integrators (i.e., equal to 1 if the centre uses one clinician throughout treatment, and 0 otherwise), $POST_t$ is the post-2001 period dummy variable (i.e., 0 for the 1991-2000 period, and 1 for the 2001-2006 period), Z is a set of control variables, ν_i the firm-specific residual, and ε_{it} is a standard residual (with mean zero, homoskedastic, and uncorrelated with itself, ν_i and independent variables). Coefficient δ_1 tests H1, and δ_2 tests H2.

My main analyses used as a dependent variable (Y_{it}) the annual live-birth rate for the patient group under the age of 35. As there are multiple observations for each centre, I used fixed effects regression to correct for centre-specific autocorrelation and robust variance estimates to correct for outliers and heteroskedasticity. As discussed

[13] In deciding whether to use the fixed or the random effect technique, I carried out the Hausman specification test which justified the use of the fixed effect estimation (p-value < 0.01).

in the previous section, centre-specific characteristics affect success rates across centres and also mean that the longitudinally clustered data violate the underlying assumption of independence. One way to account for unobserved heterogeneity with this type of data is to estimate an OLS regression with fixed-effects estimation which accounts for within-effects information.

Due to the measure for integrator (*INT*) being time-invariant, model specifications which include centre fixed effects do not allow direct estimation of β_2. However, to test the association between *INT* and clinical performance, I develop a second model where the dependent variable is the centre fixed effect ν_i and the independent variables are *INT* and another time-invariant clinic characteristic, whether the centre is NHS-affiliated or a private practice.

RESULTS

Table 1 presents the descriptive statistics and correlations for key study variables. The only high correlations among independent variables occur between centre experience and three other covariates: centre size (0.64), centre age (0.76) and industry experience (0.55). However, the large sample size produces high level of statistical power, which can overcome even extremely high correlations among variables (Mason and Perreault 1991). I also assess the results independent of collinearity concerns by using nested models which allow comparisons of fit across models and help to overcome problems of interpretation that may be caused by multicollinearity among independent variables.

Table 2 presents the results of the fixed-effects OLS regression by incrementally adding the independent variables of theoretical interest. Model 1 of Table 2 includes only the control variables, showing that older clinics tend to have better results than younger clinics. This may suggest that that in addition to accumulated experience, the age of the clinic taps into a distinct dimension of capability which contributes to performance. As expected, the more invasive the IVF technology used, the higher the chances of success, further corroborating industry accounts that advances in the micromanipulation of human gametes have played an important role in overcoming the challenges of achieving pregnancies through IVF.

Although marginally significant in the first two models, the effect of the policy change appears to have had a marginally negative impact on the operational performance of the centres in the sample. The results suggest that the operational performance of some centres has suffered as a result of the restrictions imposed by public legislators on the number of embryos to be transferred back to the patient. According to Model 3, and as reflected in the size of the coefficient, and given that the average baseline success rate in the sample is 27%, the policy shock decreased success rates by nearly 10%. This is not a trivial effect for a treatment which continues to involve a high degree of uncertainty.

Cumulative experience has a positive and significant effect on the likelihood of treatment success and validates the existence of productivity gains from experience for centres in this medical domain. The economic significance of the estimated effect for cumulative experience at the mean of the experience measure can be illustrated as an increase in the success rate by one percent if experience increases with 1,500 cases. Finally, the estimated centre fixed effects are significant and provide strong evidence in favour of using panel data techniques which address the problems of correlation between regressors and the time-invariant error term. Regression models using random effects lead to similar results. In these models I was able to estimate the effect of the variable *integrator* as having a positive impact on the success rate. Although

TABLE 1. Descriptive Statistics and Correlations

Note: The analysis represents a longitudinal examination of 64 centres, with an average of 13.3 years of observation per centre (min of 6 years; max of 15 years).

Level of analysis: clinic-year observations	Obs.	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9
1. Success rate for the standard patient group (%)	852	0.27	0.1037	0	0.6667	-								
2. Center size (count of current patients)	852	343.99	261.51	1	1467	0.270	-							
3. Age of clinic	852	9.10	5.1080	1	26	0.362	0.470	-						
4. (Log) Industry prior experience	852	11.51	1.0023	8.56	12.53	0.442	0.147	0.609	-					
5. Use of invasive technology (% ICSI)	852	0.21	0.2136	0	0.77	0.464	0.192	0.561	0.691	-				
6. Incidence of complex cases (% patients >35)	852	0.47	0.0986	0	0.8421	0.335	0.179	0.432	0.403	0.402	-			
7. (Log) Centre prior experience	852	6.77	1.8020	0	9.48	0.382	0.635	0.767	0.555	0.471	0.333	-		
8. Post 2001 (binary)	852	0.35	-	0	1	0.336	0.116	0.580	0.603	0.663	0.460	0.411	-	
9. Integrator (binary)	852	0.52	-	0	1	0.048	-0.076	-0.062	-0.012	-0.047	0.060	-0.097	-0.020	-
10. NHS affiliation (binary)	852	0.40	-	0	1	-0.198	0.191	-0.001	-0.008	-0.012	-0.223	0.099	0.004	-0.233

TABLE 2. OLS Regressions of the Success Rates for Standard Cases
(Fixed effects models with robust variance estimates)

DV = success rate in standard patient group (age<35)	Model 1 (Baseline)	Model 2 (H1)	Model 3 (H2)	Model 4	Model 5	Model 6
Centre size	-0.00001	-0.00001	-0.00002	-0.00002	-0.00002	-0.00002
	(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00002)
Age of centre	0.0081 ***	0.0080 ***	0.0082 ***	0.0078 **	0.0080 **	0.0081 ***
	(0.0031)	(0.0031)	(0.0031)	(0.0032)	(0.0032)	(0.0031)
(Log) Industry experience	0.0012	0.0028	0.0018	0.0013	0.0022	0.0026
	(0.0088)	(0.0089)	(0.0088)	(0.0089)	(0.0089)	(0.0089)
Use of invasive technology (% ICSI cycles)	0.0541 **	0.0583 **	0.0575 **	0.0534 **	0.0563 **	0.0589 **
	(0.0273)	(0.0270)	(0.0273)	(0.0270)	(0.0268)	(0.0271)
Incidence of complex cases (% patients over 35)	-0.0094	-0.0191	-0.0145	-0.0085	-0.0145	-0.0189
	(0.0587)	(0.0571)	(0.0583)	(0.0585)	(0.0572)	(0.0573)
(Log) Centre experience	0.0097 **	0.0051	0.0092 **	0.0104 **	0.0075	0.0064
	(0.0045)	(0.0048)	(0.0045)	(0.0047)	(0.0052)	(0.0049)
Post-2001	-0.0151 †	-0.0149 †	-0.0257 **	-0.0421	-0.1118 *	-0.0215 *
	(0.0103)	(0.0103)	(0.0111)	(0.0520)	(0.0628)	(0.0114)
Integrator X (Log) Centre Experience		0.0081 *			0.0042	0.0053
		(0.0041)			(0.0050)	(0.0050)
Integrator X Post-2001			0.0246 **		0.0656 †	0.0153
			(0.0107)		(0.0444)	(0.0130)
Centre Experience X Post-2001				0.0036	0.0111	
				(0.0066)	(0.0076)	
Integrator X Post-2001 X Centre Experience					-0.0033	
					(0.0032)	
Constant	0.1187 †	0.1137 †	0.1176 †	0.1164 †	0.1155 †	0.1147 †
	(0.0799)	(0.0811)	(0.0800)	(0.0802)	(0.0813)	(0.0809)
N_t (total centre-years)	852	852	852	852	852	852
N (total centres)	64	64	64	64	64	64
Log-likelihood	1132	1135	1135	1132	1138	1136
F statistic	68.19 ***	60.39 ***	59.61 ***	64.00 ***	48.63 ***	53.98 ***
Center fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

*** $p < .01$; ** $p < .05$; * $p < .10$; two-tailed tests.
† $p < 0.10$ one-tailed test

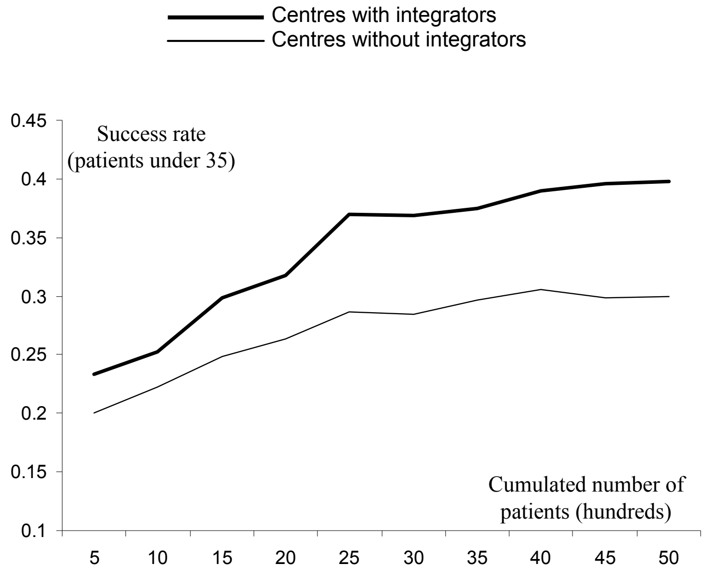
the fixed effect model does not permit the estimation of the impact for employing integrators, a Hausman test comparing fixed-effects and random-effects specifications indicated that the fixed-effects model is the appropriate specification (p-val <0.05).

Hypothesis 1a) states that the positive relationship between operational performance and experience is expected to be stronger for organizations employing integrators. The positive and significant coefficient of the interaction term in Model 2 supports this hypothesis and rejects hypothesis 1b). The findings show that IVF centres which coordinate the collective action of various contributors involved in treating a patient through a dedicated coordinator achieve better learning outcomes (i.e. higher learning rates).

This result supports the argument regarding the role of integrative structures in reducing the confounding effects of interdependence. Surprisingly, the significance of the experience measure disappears when its interaction with *integrator* is included. This is to be interpreted as evidence that centres without integrators are not generating productivity gains from experience. Yet again, this result is not due to the centres having superior capabilities – which is an alternative explanation ruled out by the significance of centre fixed effects, rather the results confirm the role of the integrator in enhancing the learning ability of these centres.

Figure 7 illustrates the pattern in the average yearly success rate for each of the two subpopulations in the sample – IVF centres which use integrators for coordination, and centres which do not. The plotted lines reinforce the finding of the analysis by displaying different degrees of steepness and a widening gap between them as experience accumulates.

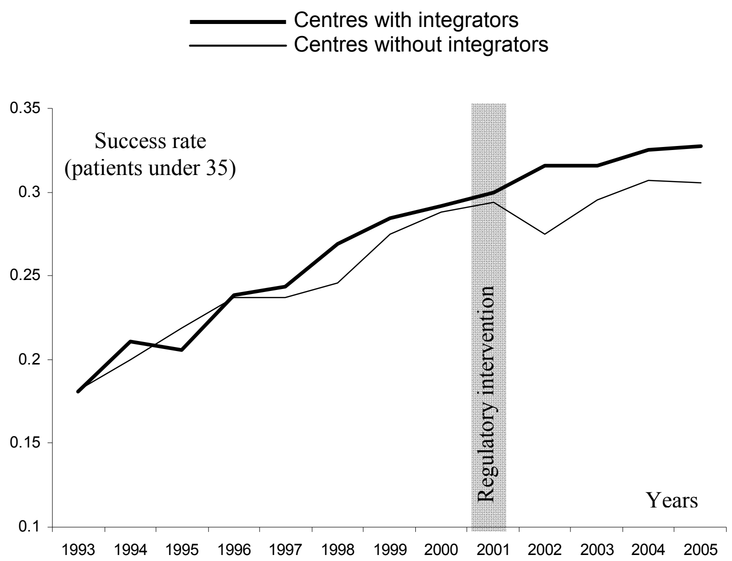
FIGURE 7. Performance improves faster with cumulated experience for IVF centres that use integrators



Hypothesis 2 states that the organizations which employ integrators are likely to have a less turbulent transition after a discontinuous technological change which changes the nature of task interdependence. As previously noted, the impact of the technological shock (*post2001*) is negative and becomes highly significant when the interaction between *post2001* and *integrator* is specified in Model 3. The positive coefficient of the interaction term estimates the difference in performance between centres with integrators in the post-shock period and all the other subsets (i.e., centres without integrators in the post-shock period; centres without integrators in the pre-shock period; and centres with integrators in the pre-shock period). Interestingly, the impact of the shock is offset by the benefits of having an integrator (i.e., the coefficients for the interaction term and *post2001* have the same size but opposite signs, thus cancelling each other out). Hence, contrary to the hypothesized effect of hypothesis 2b), integrators appear to be especially valuable for increasing the adaptive potential of organizations which employ them. This pattern of results is illustrated in

Figure 8 which plots the yearly success rates of the two groups of clinics for each year in the sample.

FIGURE 8. After the regulatory intervention limiting multiple embryo transfers, performance deteriorates more for IVF centres that do not use integrators.



Alternative explanations and further analysis

I performed three further analyses (Models 4 to 6) to explore the interaction effects between *centre prior experience*, *post2001* and *integrator* jointly. Due to the interacted variables being highly correlated, the interpretation of the results is problematical,[14] though the interaction between integrator and post2001 continues to be marginally significant in Model 5. Further analysis of the estimated centre fixed effects in Model 1 shows that having an integrator is positively associated with performance (Table 3). Interestingly, this additional analysis suggests that centres in the National Health System (NHS) tend to perform lower than their private counterparts.

[14] A Wald test for the two interaction terms in Model 6 rejects the hypothesis that coefficients are jointly equal to zero.

Although the natural experiment design rules out the possibility of centres selecting integrators in anticipation to the policy change, it doesn't exclude the possibility of unobserved characteristics of the IVF centre that might cause them to select integrators as well as respond better to change. However, this possibility is ruled out as the choice for employing integrators is made at founding and remains constant throughout the period of observation (i.e. the integrator status does not change within the interval of observation).

TABLE 3. OLS Regressions for the Centre Fixed Effects predicted for Model 1 (with robust estimators of variance)

DV = centre fixed effect	Model 7	Model 8
Integrator	0.0314 *	0.0257
	(0.0169)	(0.0211)
NHS	-0.0299 *	-0.0365 +
	(0.0172)	(0.0219)
Integrator X NHS		0.0149
		(0.0361)
Constant	-0.0013	0.0024
	(0.0138)	(0.0155)
N	64	64
Adjusted R square	0.096	.083
Prob > F	0.0173	0.0417
F statistic	4.34 **	2.91 **

*** p < .01; ** p < .05; * p < .10; two-tailed tests.
+ p < 0.10 one-tailed test

One alternative explanation for the results relate to the integrator possibly attracting additional resources for the clinic, such as an influx of additional cash which would allow centres to invest in better technology and hire versatile staff, and thus learn more effectively. I ruled out this alternative by performing two tests for the differences in the extent of invasive technology employed and research undertaken by the centres. If indeed the clinics charge a premium for cycles with integrators in order to reinvest the financial resources in better technology or in research that aids their capabilities, then the use of more invasive technology and higher involvement in research should be expected for centres with integrators. However, both tests found no significant difference between centres which employ integrators and centres which do not. In addition, the centre fixed effect specification accounts for other unobserved time-invariant characteristics (e.g., centre capability, intrinsic quality of management) which may vary across centres.

Another alternative explanation was suggested during interviews with IVF practitioners and relates to the integrator representing a comfort factors for the patient. It is commonly accepted in fertility that the psychological disposition of the parents-to-be influences their hormonal responses, with consequences for the outcome of their fertility treatments (Campagne 2006). In most interviews, IVF practitioners have suggested that having the same doctor or nurse throughout treatment may positively impact the chances of success. However, none of the claims for the psychological impact of the integrator on the patient's wellbeing can explain how it could also lead to better team learning for the specialists treating the patient. At best, the comfort factor generated by the integrator is captured in the constant term. Also, even if this comfort factor might impact *incremental* learning through an unknown mechanism, it shouldn't make a difference for *radical* learning after the occurrence of the exogenous shock because all centres maintained their design choice unchanged and the patient's comfort levels could not shift on the basis of the technological shock.

In combination, the additional analyses undertaken as part of this investigation offer more convincing evidence of the role played by the integrators as elements of organizational structure in shaping learning outcomes and enabling adaptation.

DISCUSSION

This chapter builds on the research traditions of organizational learning and organizational design to investigate an understudied implication of organizational structure for collective learning. Drawing on ideas raised in the literature, I suggest several mechanisms through which integrators impact organizational learning, and I distinguish between learning that is incremental and learning resulting from radical change in the environment. Uniquely, I examine the impact of integrators, as structural add-ons to the functional forms, on collective learning as evidenced both by learning rates and adaptation to a discontinuous technological change. Finally, I use the healthcare domain of *in-vitro* fertilization in the UK to examine the hypothesized relationships between organizational structure, learning processes and subsequent operational performance.

I found that in addition to improving the learning ability of organizations engaged in repetitive operations within stable paradigm, integrators also enable firms to withstand the vagaries of technological change better. The positive effect of integrators on radical and incremental learning was largely attributable to their role of managing the interdependence that arises between specialists coming from different domains of action. By lessening the confounding effects of learning in an ecology of other learners, these forms of lateral coordination enhance the reciprocal predictability of action which in turn enables better mapping of actions and outcomes and more effective system level learning. I provide both factual and empirical support for these mechanisms. Further, I take advantage of a systemic shock in IVF practice to study the relative importance of integrative structures in producing an appropriate response to an external shock which imposed restrictions on productive inputs. I find that the use of integrators aids adaptation.

The results substantiate existing theory that effective organizational action requires an accommodating organizational environment, not only task mastery achieved through experiential learning alone (Edmondson, Bohmer et al. 2001; Pisano, Bohmer et al. 2001; Edmondson 2003). Therefore, the way interdependence is managed affects the rate of improvement and adaptation. The study demonstrates this on a unique dataset by providing compelling evidence for a neglected dimension characterizing the macro-organizational context – the structure within which interactions among interdependent agents take place.

While I have attempted to overcome many limitations in the analyses, a few remain. Because the data for the study were from a single industry, a potential limitation relates to the generalizability of the findings to other industries. Research indicates that many manufacturing industries share similar characteristics and norms regarding structural mechanisms for coordination with healthcare, the setting for this study. For example, Wheelwright and Clark (1992) identified the presence of integrators (i.e. "heavyweight" team managers) while studying cross-functional teamwork at Motorola; similarly, TATA Motors and other car manufacturers specifically employ engineers to fulfil the role of *vehicle-integration managers* to coordinate the contributions of various functional departments to a focal car model (Shelton 2003). Therefore, although the generalizability of the study is somewhat limited, I expect that the use of integrators would affect learning dynamics of cross-functional teams in industries with similar concerns for coordination across distinct domains of knowledge.

Another potential limitation relates to the stable measure that captures organizational structure, thus preventing accurate estimations for the cross-sectional effect of the integrator and masking the nature of structure as also evolving with and being changed by experience. Moreover, and as suggested by qualitative data collected during field interviews, the role of the integrator may at times be filled by a nurse instead of a doctor, which provides an illustration for how the levels of authority exercised by the integrator could vary, possibly affecting the learning dynamics differently. This poses an interesting question for further exploration, namely how the learning outcomes of firms using integrators with authority differ from the learning outcomes achieved when integrators possess less or no authority over interdependent contributors.

As is usually the case for learning studies which employ quantitative methods, one must be extremely cautious about interpreting efficiency improvement as a measure of learning. This research utilizes panel data to examine the relationship between operational effectiveness and cumulated experience over an extended period of time (i.e. learning rates), and does not study the learning dynamics but rather the outcomes of these dynamics as they unfold. While this is a partial representation of how learning occurs in organizations, this limitation is partly compensated by the fact that the measure of cumulative experience employed in the analyses is capturing, albeit imperfectly, the extent to which knowledge is updated and accumulated through prior iterations of IVF treatments.

Finally, some measures employed in the analyses may not adequately account for the constructs intended – for example, centre capacity (measured as the number of patients treated in the current year) imperfectly approximates the size of scale economies achieved by some centres. Similarly, while centre fixed effects account for the time-invariant component of differences across centres, the lack of data on turnover rates and experience of staff (useful to account for the individual learning of integrators) restricts the ability to control for possibly relevant time-variant components.

Collectively, the findings inform an understanding of the processes by which organizational-level learning and adaptation occur in the presence or absence of integrative structures. More broadly, the results also point to the fact that features of organizational design relate to why some firms may learn and adapt faster than others. In addition to documenting the role of the integrator, this chapter also raises interesting questions about the role of other organizational structures in shaping collective action. Together, these results enable a further refinement of our understanding of the factors that enhance firms' abilities to learn from their experience and to adapt to change, and thus offer novel contribution to the strategy and organization field.

CHAPTER 4: THE IMPACT OF TASK COMPLEXITY ON ORGANIZATIONAL LEARNING

Research on organizational learning has documented learning curves for various industries (e.g., Dutton and Thomas 1984; Argote, Beckman et al. 1990; Darr, Argote et al. 1995; Mihm, Loch et al. 2003), it has transferred this analysis from studying production processes to more complex experiences such as acquisitions (Haleblian and Finkelstein 1999; Vermeulen and Barkema 2001; Hayward 2002) and alliances (Barkema, Shenkar et al. 1997; Hoang and Rothaermel 2005), and it has begun to study what type of macro-contextual factors are most beneficial for firms (Haunschild and Sullivan 2002; Schilling, Vidal et al. 2003; Wiersma 2007). In this chapter I pursue this line of research by explicitly examining an important moderator at the level of the firm, namely the composition of the firm's portfolio in terms of the complexity of its cases. Hence, I focus on the complexity dimension of the task environment as one reason why some firms learn quicker than others – a topic which is relevant for this dissertation as it explores the relationship between the macro context and organizational learning.

The earliest indication of the benefits entailed by taking on more complex tasks is found in Cohen and Levinthal (1990)'s seminal paper on absorptive capacity. Building on earlier findings from the psychology of human information processing, the authors suggest that deeper processing of information and increased efforts to make associations between what is being learned and the knowledge already possessed by the firm, improves assimilation and later retrieval of the information processed (Cohen and Levinthal 1990:131). A similar idea is found in Kim (1997)'s study of how Samsung developed the capabilities required to produce semiconductors, where he suggests that the energy expended by the organization in solving complex problems (Kim 1997:88), enables firms to build requisite capabilities more quickly. In a subsequent study of Hyundai's effort to develop absorptive capacity Kim (1998) also investigated how organizations can proactively construct crises by taking on more complex projects as strategic means to acquire new knowledge and expand their prior knowledge base. Unlike externally evoked crises, proactively constructed internal crises such as those triggered by the admittance of a difficult task, are galvanizing devices which increase the involvement in learning activities.

More recent research has begun to test empirically these claims. For example, Haunschild and Sullivan (2002)'s study on learning from heterogeneous experience provides a valuable insight into how airlines can benefit from experiences with more complex malfunctions. They argue that the high intensity of in-house efforts reflected in the repeated checks of elements characterizing failures with heterogeneous causes enhance the information processing of firms along with their learning abilities. Similarly, in a study of Dutch post offices, Wiersma (2007) finds that some level of diversity in the product portfolio (i.e. related heterogeneity) has a positive impact on the learning rate, while Weigelt (2009) demonstrates that the outsourcing of new technology projects, as opposed to developing them in-house, reduces a firm's learning by doing, internal investment, and tacit knowledge applications.

In the following sections I expand on the insight that the more challenging cases might have positive ramifications for the production process of the standard products. I argue that although at first sight (e.g. based on directly measurable figures such as margins) the cases may seem less attractive and less rewarding, due to their spill-over benefits, they might form a valuable element of a firm's portfolio after all. Building on qualitative data from the interviews, I describe how by confronting a higher proportion of complex problems, firms tend to perform better situational analyses and more thorough checks of the causal paths, with positive consequences not only for the resolution of complex cases, but also for sets of problems with lower levels of difficulty. Thus, I argue that it is important to take the indirect benefits of performing complex tasks into account.

In this chapter, I present theory and research on how task complexity as a factor in the organizational environment promotes or hinders organizational learning. I predict that learning curves are less steep for IVF centres performing relatively few difficult cases, and I test the hypothesis by employing three different measures of task complexity: 1) proportion of IVF patients that have a relatively poor prognosis because they produce few eggs, 2) proportion of IVF patients who have a relatively poor prognosis because they have failed to conceive through IVF before, and 3) IVF patients over 35 years old (i.e. the industry's standard cut-off rate), who are known to have significantly lower chances of success. All three variables support the study's prediction: they moderate an organization's learning curve, so that firms that perform more difficult cases improved their success rate quicker.

THEORY AND HYPOTHESES

Sources of Complexity

The learning processes within and among the constituent units that make up the firm are influenced by attributes of the portfolio of activities that the firm pursues. An important attribute is how complex are the tasks that enter in the composition of a firm's portfolio. Any new idea, technology, or decision process may be classified on a simplicity–complexity continuum (March and Simon 1958; Payne 1976; Campbell

1988). In this study, I focus on the relative impact of tasks which do not align themselves with a single technology, function, or the existing knowledge base of the firm, but which are characterized by higher interdependence among their subcomponents, higher number of functions embodied in the task, and/or an increased degree of difficulty in achieving the task's objectives. This conceptualization of task complexity follows the lines of Simon (1969)'s definition of complexity as stemming from "*a large number of parts that interact in non-simple ways,…* [such that] *given the properties of the parts and the laws of their interactions, it is not a trivial matter to infer the properties of the whole*" (Simon 1969, p.195). Similarly, Aldrich defines complexity as describing the number of units with which interaction is required and the extent to which an organization or subunit must have a great deal of sophisticated knowledge about products, technologies, customers and so on (Aldrich 1979, p.74).

To allow for a more straightforward discussion of the mosaic of factors that affect the degree of complexity – such as size, numbers, interactions, intricacy, difficulty, newness, and uncertainty – I argue that task complexity comes from two broad sources: 1) the newness and ambiguity surrounding task inputs and 2) the number and interactions among the inputs necessary to accomplish the desired result. Before I discuss each aspect, it is important to note that by relating task complexity "*directly to the task attributes that increase information load, diversity, or rate of change*" (Campbell 1988, p. 43), this definition allows for complexity to be determined independent of the agents performing the task.

Newness and ambiguity concerning task inputs. Though there is close relationship between complexity and newness, these are different concepts which are strongly interrelated. A poor understanding of the technology required for a challenging task, or the difficulty to identify the underlying aetiology of the problem, is likely to result in ambiguity about how best to solve technical problems. For example, combining existing technologies in novel ways to address idiosyncrasies of the problem at hand, as in the case of customized treatment plans for IVF patients, can lead to technological complexity. Similarly, the development or involvement in an entirely new activity, such as the use of new cryopreservation techniques or innovative hormonal therapies for ovarian stimulation in idiosyncratic cases, can also create complexity because of incompatibilities with existing technology systems. Therefore, I posit that the newness of a task element can increase the complexity encountered by firms.

Number and interactions among task components. Organizational tasks are typically composed of discrete components performed in sequence, with successful execution of each subtask determining the overall outcome. Some tasks are complex due to the number of distinct acts and the number of distinct information cues involved in accomplishing them, and because the effective integration of each act can create high degrees of complexity. In a similar vein, products may require the integration of hardware and software components, where each is being developed concurrently and is dependent on the other for the "system" as a whole to operate effectively. In another example, performing IVF on patients with several medical disorders requires more interventions than what is commonly performed to address sub-fertility problems, with many of the decisions taken without the knowledge of how downstream subtasks might be affected. Thus, when a task is undergoing a larger number development stages, organizational members must deal with the added complexity resulting from interactions across decisions taken at each stage. This is particularly relevant in the IVF domain, when the patient is over the age 35, has a history of prior IVF failure or did not produce enough egg cells following stimulation.

Task complexity and learning sub-processes

Varying the context of a task by increasing its complexity may enhance the development of implicit learning (Wulf and Schmidt 1997), or forms of passive learning whereby the learner picks up "critical covariations in the environment" (Reber 2003, p.233). Studies have shown that if a concept is presented in varied contexts, it gives the learner more possible associations for the concept, thereby improving understanding and recall (Maskarinec and Thompson 1976). Tyre and Von Hippel (1997) make note of this phenomenon within organizations when they find that engineers often need to explore a problem in multiple settings (e.g., plant and lab) before they are able to understand and resolve the problem.

Psychology studies of individual learning have demonstrated that *related* task variation (varying the content or context of the task) may enhance the learning process through facilitating the development of more abstract principles (or “schema”) related to a general class of tasks (Schmidt 1975; Paas and Van Merrienboer 1994). For this study I treat the increase in the level of task complexity as a type of “related variation” and I argue that the cognitive structures developed in such conditions at the individual level contain more cognitive nodes of knowledge as well as more links between them. Such network links may promote rapid assimilation and processing of new information as well as faster retrieval of stored information. Yet, while these mechanims have been confirmed at the individual level, the knowledge of how complexity impacts learning at group and organizational level remains somewhat speculative at present.

A major research stream in the organizational learning literature examines the process of learning. It is often viewed that the process of learning consists of multiple, interdependent stages, because solutions have to be searched for, chosen, and implemented. This notion has led several authors to describe it as a cycle of activities in which the organization engages to process knowledge that allows it to adapt and improve (Agyris and Schön 1978; Kolb 1984; Edmondson 1999; Gibson and Vermeulen 2003). For example, regarding team learning, Gibson and Vermeulen (2003) described the process as a cycle of experimentation, reflective communication, and knowledge codification. Following this vein, I posit that the process of organizational learning also captures the subprocesses of joint learning described in Chapter 3, which refers to individual contributors to a group task learning their way toward coordinated action when the knowledge stored in routines, technologies, and procedures is not sufficient to complete a complex task.

The levels of task complexity experienced by the firm impact the progression and depth of the learning subprocesses. Consider the stage of experimentation. When organizations undertake more complex tasks, novel challenges and opportunities are likely to be encountered. The firm's general competence in addressing these new sets of problems increases with each unfamiliar case. As the stock of experience with complex problems increases, the learner will experiment with and evaluate solutions which may not have been considered before. Dealing with more challenging cases will increase the skill level of the individuals involved. Evidence in human information processing suggests that task complexity requires the learner to generate a more elaborate mental model (Wilson and Rutherford 1989; Bannert 2002) and enhances the ability to carry an increased cognitive load (Sweller 1989).

First, individuals within the organization need to generate ideas on how to improve work through exploration or experimentation (Argyris 1976; Levitt and March 1988; March 1991). Second, a common understanding about a proposed solution needs to develop. When having engaged in experimentation, different members of the organization may have developed different mental schemas concerning the experience. To come to a common understanding of what the experience or information means, members transfer and combine insights through a process of reflection, coordination and joint learning (Jelinek 1979; Walsh, Henderson et al. 1988; Puranam and Swamy 2008). Finally, the knowledge needs to be translated into concrete, generalized concepts, decisions, or work methods (Agyris and Schön 1978; Kolb 1984). Together, these stages form the learning cycle.

Some of the centres where I conducted interviews seemed to deliberately use such complex cases for training purposes – see Table 4 for quotes. The complex cases were described as pushing people to experience new situations and new ways of doing things. Hence, dealing with complex cases enhances the general ability and skill level of the people involved. They lead to a deeper understanding, which aides the development of new solutions. These new solutions may also improve the success rate among more simple cases. As the quotes indicate, finding solutions to complex cases prevents a firm from becoming inert and over-reliant on a standard set of operating procedures.

Haunschild and Sullivan (2002) also suggested that the attention of the organizational members involved in dealing with a complex problem forces situational analyses which may go beyond simple responses and leads to a deeper analysis of the situation at hand. This is in line with Ocasio's (1997) principle of situated attention, which emphasizes that ventures requiring greater attention also require greater cognitive resources and higher levels of concern and participation from the organizational members involved. Since organizational members work in a multi-task environment, the experimentation triggered by experience with complex cases and the knowledge acquired while performing more demanding tasks may very likely lead to learning effects that also benefit the execution of simpler cases.

Difficult cases stimulate learning by heightening interaction between the various parties in an organization that contribute to the problem solving. Because they necessitate a departure from the standard procedure, it requires members of the organization to communicate and coordinate. Increased coordination will also bring out problems in standard cases, fine-tune solutions, and aid the transfer of knowledge and routines (Henderson and Cockburn 1996; Hargadon and Sutton 1997). The increased interaction will also aid processes of sensemaking (Weick, Sutcliffe et al. 2005), from which also standard cases will benefit. Accordingly, in the IVF setting, various interviewees indicated (see Table 4) that dealing with complex cases triggered renewed coordination between doctors, embryologists, and nurses, and collective reflection on how to deal with the problem at hand.

Finally, the newly developed insights and solutions will need to be translated into formal and informal processes, in the form of procedures, technologies, and routines – the third stage of the learning process. Methods and procedures, developed under difficult circumstances trying to solve a complex problem, may also improve performance when dealing with standard cases. Schilling and colleagues (2003), for example, found that experiences in a related setting also benefited learning relating to the focal task. The international business literature has also posited that competencies developed in a difficult market can be transferred back to the firm and also benefit its subsidiaries in other markets (Birkinshaw 1997; Barkema and Vermeulen 1998). Similarly, the interviewees contended that protocols, checklists, technological devices, and informal procedures developed when dealing with complex cases were often transferred to also be applied to standard cases – see Table 4 for quotes.

TABLE 4: Qualitative Evidence of how Difficult Cases Enhance the Process of Learning

Subprocesses of learning	**How they enhance the firm's success rate**	**Interview quotes**
Exploration / experimentation	Leads to improved skill levels in individuals	One interviewee described how her clinic "*has a system in place for nurses and junior doctors, and the way this has been done seems to work better than giving them only easy jobs… For example, Gina has now received a case with poly-cystic ovarian syndrome, which is one of the toughest diagnostics to work with; all her previous patients were young, straightforward cases which responded well [to drugs]. She's got the hang of it from those simple cases, but she needs the challenge to perfect her skill, to understand the various nuances and the subtleties of this job.*"
	What is learned from difficult cases aides the relatively simple cases	A doctor explained, "*What you see in the textbook or in the code of practice are treatment coordinates for standard cases, the typical patients showing up for consultation, young couples under 35, with good egg reserve, good sperm and good health… We have a lot of experience with them and they're easy cases where we rarely deviate from the standard procedure. And that's all fine, but when you get a difficult case, with complex pathology, and the standard procedure simply doesn't fit, what do you do? You change the practice, you start tinkering with the parameters, adding new things, adjusting doses and sequences so that it fits. And is that all? No, it isn't; you start tinkering with the procedure for the easy case as well; you take what you've learned from that difficult case to the easy case.*"
	Difficult cases deepen understanding	One IVF consultant stated, "*I think those difficult cases teach us much better how to do our job, how to understand the real depth of infertility as a medical condition, how to acknowledge our ignorance in order to overcome it. If you don't let the bad cases in, to teach you failure, to teach you pressure, you'll oversimplify, you'll miss many of the underlying causes.*"
	Focuses attention and solution finding	A doctor in a clinic which sees a high proportion of patients with advanced maternal age, and thus with lower chances of successful treatment, stated: "*Treating older women who constantly remind their doctors that they are running out of time builds a feeling of urgency, a feeling of*

		purpose in all those that enter in contact with them; they need the treatment fast and they need it done well!"
Reflection & coordination	Difficult cases lead to new solutions and improve coordination	"C*linics which admit more older women tend to be more experimental in the therapies that they offer. The effort of treating such patients –and patients with poor prognosis in general– intensifies the interaction among our doctors, embryologists and nurses.*"
	Improved coordination also aides the more simple cases	*"Clinics which admit more difficult cases tend to be more disciplined and more thorough in their work. And of course, even for us, the effort of treating [difficult patients] intensifies the interaction among our doctors, embryologists and nurses. And we tend to take that with us, and to do it for the next patient which enters our office."*
	Reflection and interaction leads to enhanced understanding	One of the doctors working at an clinic in London contrasted the nature of the clinic's patient base to his prior experience at a clinic in a provincial area: "*There I had mostly Caucasian patients, with less health issues than our patients here in [East London], where I see much more Africans than I ever saw in [Yorkshire]… also patients from the young urban population here are more likely to have pelvic infections, not using condoms, having unprotected sex, are more likely to get Chlamydia and all those things with tubal problems… So I see more pathologies, more problems and so on… but all these problematic cases add to our experience as doctors, it makes us talk to embryologists, to pharmacists; it matures us, it keeps us understand things, the physiology of different races and diseases, how drugs work for them, what their medical predispositions are*".
The translation of what has been learned into processes and procedures	Knowledge capture	*"It's hard [to treat complications] but treating severe cases comes with its rewards. I'm not talking only about the thrill of cracking a difficult case, I'm talking about the careful checklists that you put together and the resilience that you develop as you do that. Baby or no baby, the checklists and the ideas you tried stay with you, you'll try them again for less complicated cases again and again. Anything that leaves less to chance is worth trying again".*
	Knowledge capture and transfer	Many of the interviewees referred to the regular updating of clinical protocols, departmental interfaces, and organizational as a result of encountering challenging cases. As one quality control manager described, "*Doctors have checklists; the more difficult their cases, the longer the checklists. And I am interested in their checklists because I want to revise mine and bring*

		the system up to date. Are we getting cases with a new bullet point? Then I want to know about it, the other doctors want to know about it, the nurses as well.”
	Knowledge capture in procedures and technology	In the interviews there were many examples of how spillovers occur from the more complex cases to the less problematic ones, with most of them emphasizing the transfer of knowledge, diagnostic tools and equipment use. Such an example was offered by an experienced doctor describing how the use of a catheter typically employed in difficult embryo transfers had become the tool of choice for most doctors in his clinic, regardless of the difficulty of the case: “*Because we have experienced many two-stage transfers in older age groups, our medical director has authorized the purchase of several Wallace Pro-Ultra catheters. These catheters made the two-stage procedure so much easier under ultrasound, that most of us are using it now for the ordinary single-stage transfers.*”
	Knowledge transfer to relatively simple cases	Another indication of knowledge transfer from difficult to simple cases emerged from an embryologist’s description of his involvement in a case with a history of treatment failure: “*She had beautiful embryos, symmetrical, with equally sized blastomeres, perfect for textbook illustrations… we couldn’t understand why they didn’t implant… but then we did the PGD test and discovered chromosomal abnormalities in three of them… Now when I see perfectly symmetrical embryos I don’t get as excited as I used to. I always think ‘they should do a PGD on those!’*”

Therefore, I predict that the learning curves displayed by the firms in the sample will be steeper when the proportion of difficult cases that they deal with is higher; that is, the relationship between accumulated experience and the firm's success rate will be more positive for firms that deal with more difficult cases.

Hypothesis 3: *The organization's proportion of difficult cases will positively moderate the relation between its experience and rate of success, so that the success rate of organizations with a higher proportion of difficult cases increases more quickly with experience than the success rate of organizations that largely deal with standard cases.*

Consequently, organizations which deal with fewer difficult cases, will learn more slowly than organizations that take on more complex activities. Firms that admit a relatively high proportion of complex cases will likely, initially, display a lower success rate. However, if their rate of learning is substantially higher than firms with less complex cases in their portfolio – as I predict – their learning curves should at some point cross, so that the firms with a higher share of difficult cases actually begin to display higher success figures. I will test for this possibility directly in the models.

METHODS

The medical field of IVF provides another opportunity to untangle the relationship between organizational context and learning outcomes, by enabling a more direct observation of the levels of task complexity encountered by the IVF centres. In IVF, there are some clear indicators for whether a patient is a "difficult case" or not, due to a poor prognosis, prior failure, or age. In addition, other variables relevant to the study have been tracked longitudinally since regulators publicly endorsed the treatment.

Sample

The IVF data is also very suitable for the longitudinal analysis of the relationship between learning rates and task complexity because it contains complete longitudinal data on 90% of the clinics in the population (11 clinic display left-censored spells), and hence nearly complete data on these clinics' prior experience.[15] Finally, the fact that about half of the centres in the sample are private clinics, while the other half concern government hospitals (which cannot restrict access to treatment), offered a valuable control group to rule out some possible alternative explanations (e.g. reverse causality).

During the period 1991 – 2006, there were in total 116 IVF centres founded, of which 100 fertility centres by the end of the sample period had more than 2 years of data, with an average number of 9.3 years of observation per clinic. The oldest centres had provided IVF for 15 years while the youngest for just one year. The largest centre had treated over 13,000 patients during the window of observation, whereas the average prior number of cases was approximately 2,000 female patients. In total, these centres performed nearly 400,000 IVF cycles on approximately 330,000 female patients, who had delivered over 75,000 IVF babies by the end of 2006.

The sample differs from the sample analysed in Chapter 3 by the inclusion of a small number of IVF centres whose structural characteristics could not be determined based on the information provided in the Patient Guides. Similar to the previous sample, the success rate is presented separately for patients in six age-groups: below

[15] Preliminary analyses on the full sample and the sample of clinics which do not exhibit left-censoring lead to similar results.

35, 35-37, 38-39, 40-42, and over 43. In line with prior treatments, patients below 35 are as the primary base of comparison between centres (Sharif and Afnan 2003; Johnson, El-Toukhy et al. 2007).

Dependent and independent variables

Success rate. Consistent with my field observations, the primary dependent variable is the success rate in standard cases, defined as the live-birth rate involving the use of the patient's own fresh eggs in the IVF patient group below the age of 35. It is calculated as the number of live-birth events per number of female patients under 35 who underwent one or more fresh IVF cycles in the year of observation. I chose standard cases (i.e. women < 35) as the dependent variable, rather than the success rate among women of all ages, because this is what is made public and hence forms the information about the performance of the clinic. However, repeating the analysis with the success rate across all cases (i.e. women of all ages) basically led to the same results as the ones displayed below.

Prior experience. Experience was measured by cumulating all the prior cases that involved one or more IVF cycles involving the patient's own fresh eggs. The number of patients treated by each centre in a given year is not subject to publication in the Patients' Guide but this information was provided directly from the HFEA. In line with prior research (e.g. Argote, 1999), I computed the natural log of experience. This assumes, for example, that the experiential difference between 100 and 200 cases is more impactful than the difference between 10,000 and 10,100 cases.

To measure the level of difficulty in a clinic's patient mix, I identified three factors which IVF practitioners regard as relevant dimensions for assessing the complexity of a case: patients with a poor prognosis, patients that have failed to conceive through IVF before, and patients over 35 years old. Cases which do not fall into any of these three categories are regarded standard cases.

Proportion of poor prognosis patients. The number of oocytes (egg cells) retrieved from a woman's ovaries is an early indication of the likely outcome of the treatment. For patients with higher egg counts, practitioners tend to have more optimistic prognoses because large numbers of retrieved oocytes increase the probability of obtaining valid embryos, from which the best candidates can be selected to be transferred back in the patient's womb. For these patients, the excess of eggs or embryos is cryopreserved in the event that subsequent frozen cycles may be necessary. If a patient does not produce excess number oocytes, which subsequently can be frozen, this is seen as indicative of an underlying, challenging aetiology. Therefore, the use of frozen cycles relative to the amount of fresh IVF cycles performed at a centre has been treated by sector analysts as an indication of the proportion of "good prognosis patients" in a clinic's patient mix (Abdalla 2008). The more frozen cycles are performed at a centre relative to the number of fresh IVF cycles, the higher its incidence of good prognosis cases among its patients. To make the interpretation of this ratio consistent with the hypothesis in the study – which refers to the efforts expended by centres in handling more demanding cases – I subtracted this ratio from one to obtain the proxy for the difficulty engendered by treating poor prognosis patients.

Cases with a history of prior failure. Prior IVF failure is also regarded as a possible signal of a challenging underlying aetiology, which may require a more complex form of IVF treatment. Patients who have previously undergone IVF treatments and failed to conceive, either may have health conditions that require further investigation and additional interventions, or may have developed a tolerance to the drugs used. I were able to proxy the incidence of patients who have had more than one IVF cycle performed by dividing the total number of IVF cycles by the total number of IVF patients treated in a centre in the same year of observation. Hence, this measure indicates the relative number of IVF cycles which were not the patients' first attempts at treatment.

Patients in older age groups. The division by age in reporting the results is consistent across centres and illustrates the strong belief that IVF practitioners have about the importance of age in setting the parameters of the treatment cycle and the expectations about the treatment outcome. As clearly stated by one of the interviewees, "*Age is the most important parameter, [and] the only thing that we know and that is true beyond any scientific doubt is that increasing age equals more difficult cases and poorer outcomes.*" The exact ages of all patients treated are unknown, so I could not compute the mean or median patient age. Yet, I do know how many of a clinic's patients fell within the age category of under 35 (the standard group) and how many are older than 35 years (considered more challenging cases). Therefore, I computed the proportion of older patients as the ratio of the number of IVF patients over the age of 35 to the total number of IVF patients which were treated each year by each clinic.

High proportions of each of these patient groups pose challenges to centres in the sense that both sources of complexity discussed in the theory section can be identified. For example, the *newness and ambiguity* surrounding treatment inputs is increasing with age, as patients tend to display different and often unusual combinations of symptoms and pathologies. This is because a person's reproductive system generally exhibits more constraints to successful pregnancy: the pituitary and thyroid functions deteriorate; the shapes of the ovaries and uterus change, affecting their function; the neurotransmitters in the body become less responsive; the morphology of the human gametes changes, etc. These elements and their complex relation to each other must be attended to by *adding additional procedures* in the treatment cycle (e.g., customization of the hormonal doses in order to insure ovarian response; performing micro-manipulation procedures in the lab to ensure that the best embryo is selected, etc.), often *without a priori knowledge of their interactions* with outputs and inputs of other stages in the treatment. Similarly, for patients who have failed the previous cycle and for patients with lower egg counts, the treatment cycles tend to involve not only more task elements, but *may also involve new technologies or novel combinations of existing knowledge* in order to address the medical complications behind such symptoms.

Control variables. I controlled for centre size using a commonly accepted measure of centre capacity, namely the count of all licensed treatments (including IVF cycles, donor insemination, frozen cycles, and cycles which involve donated eggs and embryos) performed by each centre during the prior year. I included the square term of centre size because prior research has suggested that the effect might be non-linear (e.g. Haveman 1993). Furthermore, through a dummy variable, I controlled for whether a centre had ICSI (intra-cytoplasmic sperm injection) technology available. ICSI was an innovation that was introduced in the IVF domain during the period of observation. ICSI enables embryologists to address the problem of low sperm count or poor sperm mobility by injecting a single sperm into the ovum.[16] This made a significant difference even for couples where male infertility wasn't an issue because it left less to chance (Takeuchi, Minoura et al. 2000). At the beginning of the

[16] In the field of human reproduction, it is generally accepted that one third of the root causes for failing to get pregnant relate to a male factor, another third is due to a female factor, and the last third could be a combination of both male and female factors.

observation period, no centre had ICSI available, where at the end of the observation period all centres used ICSI, yet not all centres gained access to this technology at the same time. Therefore, I control for it through this time-variant variable.

I also controlled for the industry experience in the field of IVF. The average success rate of IVF across all centres increases over the years. Hence, an IVF centre entering the business in for example 2005 is likely to enjoy a higher immediate success rate than a centre at its year of entry in 1995, purely because the field as a whole has progressed. Firms learn from the experience of others (Argote, Beckman et al. 1990; Ingram and Baum 1997), through medical training, employee mobility, conferences, and so forth. Therefore, I controlled for total industry experience, measured as the natural logarithm of the count of all IVF cycles performed in the UK to date. Alternatively, I also re-ran all the models controlling for the highest clinic-level success rate achieved for the standard patient group in each given year, to indicate the "state-of-the-art" in the field. Both measures led to identical results. I display the models with total industry experience. Finally, I ran fixed-effects models (i.e. included centre dummies), representing a shift in the intercept of a firm's learning curve, to control for any remaining unobserved clinic-specific characteristics that may affect their clinical performance.

Analysis

To assure the robustness of the models, various estimators have been compared. Below, I present the results of the OLS estimator with fixed effects (within and between) and heteroskedasticity robust standard errors. Models using a random-effects estimator produced nearly identical results. However, because the dependent variable is a fraction bounded between 0 and 1 (proportion of patients that gave birth), the predicted values of an OLS model cannot be guaranteed to lie within this interval. To correct for this, Papke and Wooldridge (1996) introduced the fractional logit estimator, which they later expanded to be used for panel data (Papke and Wooldridge 2008). This estimator produced highly similar results to the ones displayed below, be it that the second test (patients who had failed before) only supported the hypothesis at $p < .10$. In the remainder of the paper, I display and discuss the results of the OLS regression because the size of the coefficients is most easy to interpret for this estimator.

The following regression model was developed to test H3:

$$Y_{it} = \alpha + \beta_1 \, EXP_{it} + \beta_2 \, COMPLEX_{it} + \boldsymbol{\beta_3} \, EXP_{it} \times COMPLEX_{it} + \Sigma \, \eta_j Z_{ijt} + \nu_i + \varepsilon_{it}$$

Where Y_{it} is the annual success rate for the standard patient group (below 35) treated at centre i in year t, EXP_{it} is the prior experience of centre i, Z is a set of control variables, v_i the firm-specific residual, and ε_{it} is a standard residual (with mean zero, homoskedastic, and uncorrelated with itself, v_i and independent variables). Coefficient β_3 tests H3, as it relates to how the proportion of difficult cases moderates the relation between experience and rate of success. Also, as noted previously, the analyses use three different measures for the complexity variable.

RESULTS

Table 5 displays summary statistics for the variables included in the models. Table 6 displays the results of the regression analyses. The first column concerns the model with control variables only. The results show that, in general, if centres grow larger their success rate increases. The quadratic effect of size is negative but, because the overall relationship between size and success only turns negative at +1.35 standard deviations above the mean, the estimations suggest that centre size only has a negative influence on the success rate when centres become very large. The effect of size is relatively modest, but significant. For example, if the average centre increases in size with one standard deviation (i.e. from 581 to 1014 treatments per year), the probability of a woman becoming pregnant increases with 2%. The other two control variables show effects as expected. The use of the innovative ICSI technology increases the success rate with about 5%. Overall industry experiences – as a proxy for overall progress in the field – is also significantly positive.

In model 2, the predictor centre experience is added. It is positive and significant as expected: on average, IVF centres become better with experience. Models 3–6 display the incremental addition of the main effects of treating difficult, poor prognosis patients. What may seem puzzling at first sight, is that all three predictors are *positive* and significant, which indicates that centres that proportionally treat more patients with a difficult aetiology (such as a history of prior failure, poor prognosis, and age) actually display a higher success rate, in terms of the number of live births. This seems contrary to common sense, since difficult cases would be expected to decrease a clinic's overt success rate. Models 7–10, however, which include the interactions, shed more light on this seemingly paradoxical result.

Tests of the Hypothesis. When the interactions between centre experiences and the three measures of difficult cases (poor prognosis, prior failure, and age) are added incrementally – as displayed in models 7–10 – all three of them become positive and significant. This indicates that the positive relationship between centre experience and success is stronger for centres that deal with more difficult cases. Hence, all three tests strongly support the hypothesis: centres that deal with a larger proportion of difficult

TABLE 5. Descriptive Statistics and Correlations (1022 clinic-years)

Variable	*Mean*	*S.D.*	*Min*	*Max*	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1. Success rate for standard patient group (under 35s)	0.2584	0.1092	0	0.6434	-						
2. (Log) Prior IVF experience	6.64	1.67	0	9.48	0.4099	-					
3. Incidence of poor prognosis patients	0.7790	0.1709	0	1	0.097	-0.1482	-				
4. Incidence of reinitiating treatment after previous failure	1.1564	0.0817	0.8182	1.4948	0.0687	-0.0055	0.1965	-			
5. Proportion of patients in the age-group above 35	0.4666	0.1019	0	0.8171	0.3783	0.3232	-0.1309	0.0507	-		
6. Centre size (capacity)	597.50	433.53	1	2271	0.2022	0.5828	-0.1257	0.0995	0.1406	-	
7. ICSI Technology (binary)	0.5230	0.4997	0	1	0.4931	0.4758	-0.102	-0.0999	0.4195	0.0699	-
8. (Log) Industry experience	11.45	1.05	8.57	12.53	0.4827	0.5902	-0.1397	-0.0451	0.3855	0.0507	0.7316

TABLE 6. OLS Regressions of the Success Rates for Standard Cases (live-births per patient in the age-group under 35)

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Centre size	0.0002***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***
	(0.0003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)
Centre size – quadratic	-6.50e-08***	-5.34e-08***	-5.21e-08***	-4.87e-08***	-5.29e-08***	-4.82e-08***	-4.95e-08***	-5.01e-08***	-5.79e-08***	-5.28e-08***
	(1.68e-08)	(1.76e-08)	(1.75e-08)	(1.74e-08)	(1.65e-08)	(1.64e-08)	(1.78e-08)	(1.69e-08)	(1.61e-08)	(1.59e-08)
ICSI Technology	0.0499***	0.0469***	0.0473***	0.0481***	0.0426***	0.0438***	0.0476***	0.0494***	0.0380***	0.0410***
	(0.0065)	(0.0066)	(0.0066)	(0.0066)	(0.0069)	(0.0069)	(0.0066)	(0.0065)	(0.0070)	(0.0069)
Industry IVF experience	0.0211***	0.0112**	0.0112**	0.0115**	0.0114	0.0117**	0.0129**	0.0084	0.0093*	0.0080
	(0.0036)	(0.0050)	(0.0050)	(0.0050)	(0.0050)	(0.0050)	(0.0050)	(0.0052)	(0.0053)	(0.0056)
IVF Experience		0.0097**	0.0102**	0.0097**	0.0080*	0.0085**	-0.0004	-0.0525***	-0.0096	-0.0726***
		(0.0041)	(0.0041)	(0.0040)	(0.0042)	(0.0042)	(0.0061)	(0.0182)	(0.0079)	(0.0201)
Incidence of poor prognosis patients			0.0389**			0.0341**	-0.0225			-0.0173
			(0.0167)			(0.0164)	(0.0281)			(0.0257)
Incidence of reinitiating treatment after previous failure				0.0644*		0.0483		-0.2905***		-0.2669**
				(0.0353)		(0.0363)		(0.1105)		(0.1155)
Proportion of patients in the age-group above 35					0.0913*	0.0904*			-0.2081*	-0.2250*
					(0.0468)	(0.0467)			(0.1242)	(0.1195)
Incidence of poor prognosis patients X IVF Experience							0.0122**			0.0093*
							(0.0056)			(0.0054)
Incidence of reinitiating treatment after previous failure X IVF Experience								0.0562***		0.0498***
								(0.0160)		(0.0167)
Proportion of patients in the age-group above 35 X IVF Experience									0.0459***	0.0469***
									(0.0172)	(0.0163)
Constant	-0.063*	-0.0014	-0.0360	-0.0750	-0.0318	-0.1170*	0.0022	0.3536**	0.1056	0.4406***
	(0.0358)	(0.0412)	(0.0441)	(0.0609)	(0.0451)	(0.0641)	(0.0425)	(0.1427)	(0.0695)	(0.1642)
N_t (total centre-years)	1022	1022	1022	1022	1022	1022	1022	1022	1022	1022
N (total centre)	105	105	105	105	105	105	105	105	105	105
F statistic	102.75***	83.66***	71.77***	70.26***	70.57***	54.56***	62.45***	64.05***	62.27***	43.39***
Centre fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*** p < .01; ** p < .05; * p < .10; two-tailed tests. ┼ p < 0.10 one-tailed test.

cases have steeper learning curves. Note that the three main effects concerning difficult cases in these models are *negative*. Hence, the direct effect of admitting a higher proportion of difficult cases is negative, as common sense would suggest: they, by definition, have a higher ex-ante probability of failure.[17] However, because of the learning effects they entail, centres that admit more difficult cases end up increasing their success rates. This explains the seemingly paradoxical results of models 3 – 6.

Figure 8 displays the estimated relationship between centre experience and the success rate. The line labelled "low proportion of complex cases" represents the estimated relationship for centres that are one standard deviation below the mean on all three predictors for incidence of difficult cases; "high proportion of complex cases" represents the relationship for centres that are one standard deviation above the mean for the same predictors.

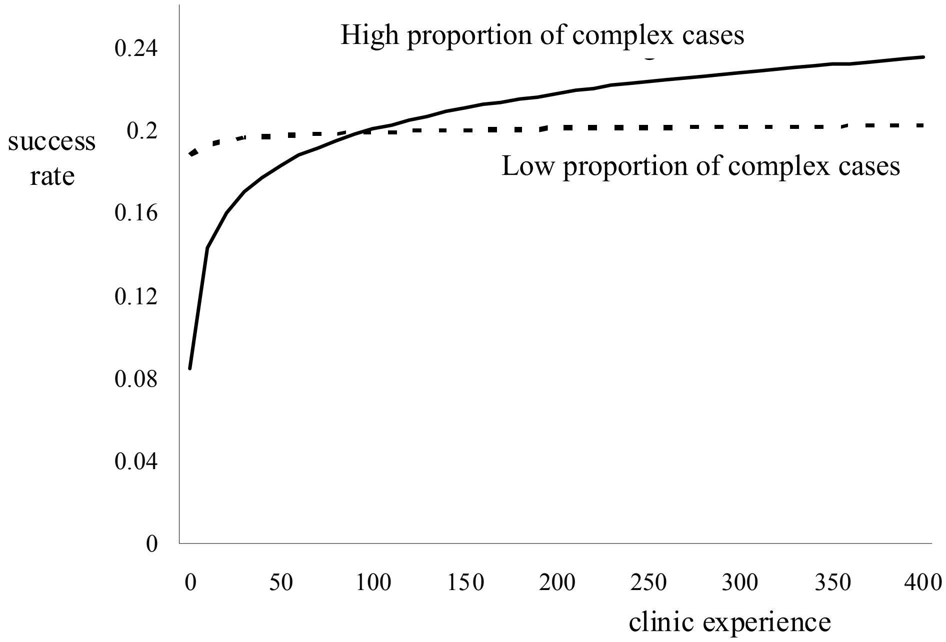
The results clearly show that treating difficult cases initially has a depressing effect on a clinic's success rate; a centre that admits more difficult cases has a success rate that is as much as 10% lower than centres that mainly treat more promising cases. However, as the graphs show, these centres start to catch up rapidly. After about a 100 cases their success rate already equals that of the centres that are treating less difficult sub-fertility cases.[18] Subsequently, they continue to improve their success rate quicker than their counterparts; after 400 cases, their overt success rate is already 3.3% higher than the centres that deal with few difficult patients.

[17] The negative main effect of treating a higher proportion of older patients (> 35 years) is somewhat surprising, since the dependent variable concerns the success rate among patients less than 35 years. Probably, centres that are lenient in admitting older patients are also more lenient admitting patients who have a lower ex-ante success rate for other reasons (unobserved in the models), which would explain the overall negative effect.

[18] Note that, on average, centres treat 116 cases in their first year of operation. Hence, it takes the centres with "high proportion of complex cases" about a year to catch up with the centres that have "low proportion of complex cases".

FIGURE 9. The influence of treating difficult cases on a clinic's success rate.

* Note: The graphs plotted are based on the results as estimated in model 10. Low/high is one standard deviation above/below the mean. All other variables are included at their mean.



Alternative explanations and further analysis

The results presented are potentially open to an alternative explanation, namely reverse causality. It seems possible that (prospective) patients with a relatively poor prognosis, who can access and observe all clinics' success rates, may be more inclined to select and visit a centre with a higher overall success rate. If so, centres with a higher (ex-ante) success rate would attract more difficult cases, rather than the other way around. To test for this possible effect directly, I estimated the models on the subsample of national health service (NHS) centres only.

NHS centres cannot select which patients they can treat; they have to admit all patients assigned to them. As one doctor working in an NHS centre explained, "*I can't pick and choose here at all. I have to see everyone who comes to the door… I can't turn down someone who has bad endometriosis or poor egg reserve, I can't say 'sorry I can't* *treat you' because it's their right, they're NHS. In a private centre I can, oh yes, I can tell them 'look, I don't want to include you in my statistics.*' *Or I can stimulate them with a bit of medication to see how they respond, and if they don't respond, I won't start them through a treatment cycle… So there is much more independence as to what some doctors can do in private clinics*." Patients, however, cannot select their own NHS centre either; they are assigned to a particular centre randomly (i.e. based on their home address' postal code). Therefore, poor prognosis patients cannot choose a centre with a higher success rate; there is no possibility of a reverse causality effect.

Our longitudinal data included 39 NHS clinics, which together comprised 406 clinic-year observations (see Table 7). I estimated the effect of the three predictors on these clinics' success rates through the same models, as displayed in Table 6. In spite of the smaller sample size, the coefficients on all three predicted interactions still confirmed the hypothesis (poor prognosis = .0096, $p<.05$; prior failure = .0371, $p<.10$; patients above 35 = .0444, $p<.05$); only marginally smaller than in the full model. To conclude, there is very little reverse causality going on, if any, and the results still fully support the prediction made in this study.

TABLE 7. OLS Regressions of the NHS Success Rates for Standard Cases (live-births per patient in the age-group under 35)

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Centre size	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Centre size – quadratic	-1.03e-07***	1.06e-07***	-1.05e-07***	-1.04e-07***	-1.06e-07***	-1.03e-07***	-1.02e-07***	-1.07e-07***	-1.05e-07***	-5.28e-08***
	(2.68e-08)	(2.77e-08)	(2.75e-08)	(2.91e-08)	(2.79e-08)	(2.93e-08)	(2.79e-08)	(2.85e-08)	(2.81e-08)	(1.59e-08)
ICSI Technology	0.0466***	0.0472***	0.0493***	0.0485***	0.0460***	0.0491***	0.0506***	0.0494***	0.0416***	0.0463***
	(0.0099)	(0.0101)	(0.0105)	(0.0087)	(0.0117)	(0.0105)	(0.0107)	(0.0093)	(0.0107)	(0.0105)
Industry IVF experience	0.0098†	0.0127†	0.0129†	0.0130†	0.0121†	0.0125†	0.0139†	0.0111	0.0146†	0.0144†
	(0.0058)	(0.0088)	(0.0088)	(0.0090)	(0.0087)	(0.0090)	(0.0089)	(0.0096)	(0.0090)	(0.0099)
IVF Experience		-0.0029	-0.0029	-0.0030	-0.0034	-0.0034	-0.0109†	-0.0440†	-0.0233*	-0.0638**
		(0.0070)	(0.0071)	(0.0069)	(0.0070)	(0.0070)	(0.0076)	(0.0280)	(0.0117)	(0.0311)
Incidence of poor prognosis patients			0.0257†			0.0233†	-0.0172			-0.0130
			(0.0159)			(0.0173)	(0.0205)			(0.0203)
Incidence of reinitiating treatment after previous failure				0.0464		0.0358		-0.1921		-0.1555
				(0.0992)		(0.1002)		(0.2110)		(0.2324)
Proportion of patients in the age-group above 35					0.0439	0.0402			-0.2489	-0.2688†
					(0.0824)	(0.0802)			(0.1980)	(0.1984)
Incidence of poor prognosis patients X IVF Experience							0.0096*			0.0080†
							(0.0053)			(0.0053)
Incidence of reinitiating treatment after previous failure X IVF Experience								0.0371†		0.0299
								(0.0246)		(0.0274)
Proportion of patients in the age-group above 35 X IVF Experience									0.0444*	0.0463*
									(0.0242)	(0.0236)
Constant	0.0086	-0.0085	-0.0339	-0.0621	-0.0167	-0.0805	-0.0075	0.2211	0.0872	0.2784
	(0.0579)	(0.0682)	(0.0657)	(0.1561)	(0.0763)	(0.1596)	(0.0620)	(0.2865)	(0.1070)	(0.3168)
N_t (total centre-years)	406	406	406	406	406	406	406	406	406	406
N (total NHS centres)	39	39	39	39	39	39	39	39	39	39
F statistic	22.43***	18.12***	15.93***	16.92***	15.36***	13.12***	14.41***	17.95***	12.77***	12.35***
Centre fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*** p < .01; ** p < .05; * p < .10; two-tailed tests. † p < 0.10 one-tailed test

DISCUSSION

In this chapter, I showed that higher levels of overall task complexity eventually lead to long term advantages for firms. The British IVF centres in this study that admitted fewer difficult cases initially enjoyed higher success, in the form of more live births per patient treated. However, this advantage fairly quickly vanished because the centres treating significantly more difficult cases learned quicker from their prior IVF experiences. Hence, even though some centres mainly treated patients with a relatively simple aetiology, their number of live births per patient ended up being lower.

This study serves as a complement to organizational learning studies that have examined the relationship between prior experience and performance (e.g. Argote and Ophir 2002), by exploring how performing more complex tasks affects learning from experience. This approach is consistent with theory on organizational learning proposing that variation in learning rates across organizations has various sources which await further investigation by researchers (Argote 1999). While work in this new research stream has been able to identify the dimensions of the task environment that are more likely to promote intra-organizational learning (Haunschild and Sullivan 2002; Schilling, Vidal et al. 2003; Wiersma 2007) we still lack an understanding of how task complexity might influence the knowledge processes associated with organizational learning. Building on these theoretical priors, I found that centres benefit more from their own experience when they undertake more difficult cases. In many cases organizations have control over the proportion of complex tasks that they could perform, thus suggesting that strategies which encourage firms to undertake more complex tasks in their area of expertise may allow them to reap performance benefits from such activities.

The analysis presented provides a number of insights into the relationship between prior experience and task complexity and highlights the importance of complex tasks for the development of knowledge and the competitive advantage of firms. In doing so, the paper adds to the literature that examines knowledge development, knowledge management and its implications for performance in settings where firms undertake repetitive operations. Theoretical linkages can be made with research in project management (Hobday 1998; Hobday 2000; Tatikonda and Rosenthal 2000; Pich, Loch et al. 2002) and the knowledge-based view of the firm (Wernerfelt 1984; Hamel and Prahalad 1990; Teece and Pisano 1994; Teece, Pisano et al. 1997).

The project management literature has hinted at the importance of considering the role of task complexity in project-based learning while research adopting a knowledge-based view has focused on the role of knowledge in generating competitive advantage. However, both streams have focused on group or organization-level outcomes without adequately exploring how the knowledge generated through prior experience interacts with task complexity, and especially how the latter factor conditions the benefits gained from prior experience. One central reason for these limitations is that many of the factors that are central to firm learning and complexity are not observable in publicly available, aggregate data (Pich, Loch et al. 2002). This paper overcomes these shortcomings by utilizing a unique dataset containing firm-level information to more accurately measure firm experience and complexity of firm-level activities.

The implications of the results are substantial. They suggest that difficult activities, that seemingly are not very attractive for a firm to perform, may have indirect and long-term benefits in the form of learning effects. This can make performing these activities worth their while. Such learning effects could pertain to many kinds of products or services in an organization's portfolio, whether it concerns types of treatments, industrial projects, or relatively complex variants of a firm's existing product line. Doing so, the study contributes to a broader line of research that examines the unanticipated effects of seizing to perform certain activities – for instance due to outsourcing – on the development of an organization's capabilities (Cohen and Levinthal 1990; Macher and Boerner 2006; Weigelt 2009).

The chapter also provides insights for researchers and practitioners in the medical domain. Medical professionals often assume that it is the skill of the individual doctor or the team of doctors that determines a patient's chances of success. This study shows that, also in the medical domain, pushing the frontiers of knowledge matters. It is not only the individual physician that matters – the cumulative experience of the institution and the composition of its portfolio have significant ramifications for individual patients. If one considers the scale of the probability for a successful IVF cycle, which is about 25 percent nation-wide, shifts as documented by this study of as much as 15% (e.g. due to learning effects in centres that admit more complex cases; see Figure 8) are not trivial.

Similar to the analysis in the previous chapter, this investigation does not systematically document what is being learned as a result of experience. Apart from the qualitative illustrations, this chapter does not expose what changes in the knowledge base or in the administration of the observed organizations as a result of their experience. The chapter examines a particular aspect of the composition of an organization's portfolio, in terms of the balance between its standard and difficult cases, but many other characteristics of portfolios potentially influence the extent to which an organization is able to reap the benefits of a learning opportunity. Aspects relating to personnel turnover, remuneration systems, research and development issues, quality management, and so on have a potential impact on these issues. Future research may be able to reveal and unravel their impact.

Finally, like any industry, the field of fertility centres has its idiosyncrasies and I cannot make normative judgements on how well the findings can be generalized to other settings. It is plausible that a similar relationship between learning rates and complexity levels may exist in other contexts outside the medical field. The findings may be relevant to settings where firms produce the same type of product or serve the same category of clients but require different levels of cognitive resources across them, and where intra-firm knowledge spillovers occur between more complex tasks and less demanding tasks. A useful analogy can be offered in the context of acquisitions and joint ventures where expectations about the performance of the inter-organizational relationship are based on a priori characteristics of the partnership. For example, it is expected that an acquisition which requires high integration or a joint venture with a culturally-distant partner may ask for more managerial may require more due diligence than partnerships with lower resource requirements. However, the effort intensity engendered by managing such complex inter-firm relationships may stimulate organizational learning and may have spillover benefits for parts of the organization or other inter-organizational relationships which do not require the same amount of attention or intensity of effort.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

In this dissertation, I began an exploration of the question - under what conditions of the organizational context can a firm achieve more effective learning and adaptation? To address this question, I focused on two key dimensions that characterize the organizational context: the formal structure of the organization and the nature of the tasks that are undertaken by the firm. I examined the effect of two factors corresponding to each dimension – the use of *integrators* and the levels of *task complexity* – on a sample of medical centres which provided fertility treatments in the United Kingdom.

In the first study, I explore the question of how the presence of an integrator might alleviate the challenges of team learning when the nature of the task interdependence is not perfectly known. To address this question, I drew on recent research in the stream organizational design and on studies which have begun to unpack the learning dynamics within teams. These studies suggest that in general integrators enable better communication across functional departments, better reciprocal predictability of action among task contributors, less ambiguous intermediate feedback and more effective joint learning, further leading to a better use of prior experience at both individual and group levels. Though there have been some indications that some forms of organizational integration may hinder learning (Chesbrough and Teece 1998; Sorenson 2003), I found that the use of integrators enhances the *incremental learning* of organizations, as reflected in the positive moderating effect on the relationship between IVF success rates and the prior experience of the IVF centre. The implication of this finding is that, when considering the learning outcomes achieved by firms, formal structures which increase coordination at the lower levels of the organization also enable firms to benefit more from prior experience than firms which do not use these structural mechanisms of integration.

I then examined the impact of integrators on the *radical learning* attained in response to an external shock in the environment. Consistent with the literature reviewed, I argued that by providing exception management and interpretations (albeit imperfect) of the shift in the underlying task interdependence, integrators provide a platform for joint contributors to learn more effectively how their actions interact in the new environment. The implication of this finding is that integrators are beneficial for firms when volatile environments introduce noise in group learning dynamics, and that in the aftermath of a disruptive shock in the environment, firms with integrators will perform better than those where integrators are absent.

In the second study, I explored the relationship between task complexity and the effectiveness of learning. Building on prior literature on task structure and the role of task variety in learning, I discussed the mechanisms by which firms that undertake more complex tasks may gain long-term benefits from such experiences in the form of learning effects. Further, I provided qualitative evidence from interviews that these mechanisms are present in the IVF centres that studied. Finally, I developed three measures for the incidence of complex cases in the portfolio of IVF centres, with the results supporting the hypothesis that task complexity has a positive moderating effect on the relationship between prior experience and clinical performance. While undertaking complex projects in the early years of a firm's life does appear to be detrimental to performance, such experiences enable firms to make better use of their prior experience and to catch up and even outperform firms engaging in less complex activities.

Overall, through both the formal integrator analyses and task complexity analyses, I have tried to develop a more nuanced understanding of the effects of these factors on the ability of firms to learn from experience and adapt to shifts in their underlying conditions. In doing so, this dissertation contributes to a broader line of research that examines how features of the organizational context can impact learning processes and learning outcomes. While there are several limitations to the methodology and analyses in this dissertation, the pattern of results is intriguing and merits further exploration.

The relationship between organizational structure and task attributes

Though it was not the main focus of this dissertation, the relationship between the use of integrators and task complexity also needs to be addressed. This is necessary in order to addresses issues of correlation-causation and model specification (e.g. omitted variable bias).

As a preliminary step to investigate the nature of the association between the two main constructs, it was necessary to merge the data used for each study. Because the datasets analysed in each chapter have been obtained separately and at different points in time from the Human Fertilization and Embryology Authority, they did not overlap perfectly and contained different numbers of observations (i.e. the centres in the sample analysed in Chapter 3 are a subsample of the centers analyzed in Chapter 4). Some inconsistencies arise from the fact that the smaller dataset contained recently updated information on organizational structure which could not be obtained for the larger dataset which was obtained previously to the smaller dataset. Also, measurements for a number of centre-year observations included in the analysis of Chapter 4 display missing or different values than the measurements recorded in the dataset used in Chapter 3. Thus, in the process of merging the datasets, some of the data was lost and the analysis of the merged sample includes only 64 IVF centres and 826 centre-years. Further work will be undertaken to reconcile the discrepancies and assess the potential of a sample selection bias.

As a first attempt to address to test the intuition that there might be a positive association between the use of integrators and the complexity of the cases treated at the IVF centre, I performed a pairwise correlation of the measures for each construct (see Appendix, Table 8). The correlations between the measure recording whether the IVF centre uses integrators and the measures for the three dimensions of task complexity exhibit values under 20 %, suggesting that the association, though positive, is not very strong.

The analysis presented in Table 9 of the Appendix provides further insights by testing the impact of integrative structures and task complexity simultaneously on the merged dataset. Despite the reduction in statistical power as a result of the small sample size, the coefficients for the interactions are largely consistent with the main analyses presented in Chapter 3 and Chapter 4, and maintain the hypothesized signs. The only exception applies to the interaction between prior experience and the use of integrators which is not significant in either of the models and exhibits a negative sign in Model 4. Finally, the high correlations among the interacted terms used to test the hypotheses (i.e. experience – integrator, shock – integrator, and experience – complexity), suggest that that caution should be used in discarding the possibility that these effects exist (see Table 10 of the Appendix for the values of pairwise correlations among interacted terms). Intuitively, because these interaction terms are correlated, they explain the same part of the variation in treatment success rates, so their explanatory power and the significance level of their coefficients is "divided up" between them.

Boundary conditions and limitations

Although I have tried to address various conditions that would affect the relationships in the main propositions, the findings are subject to a few boundary conditions and limitations. First, a central premise of this research concerns the nature of interdependencies between differentiated and specialized contributors to a group task. An important boundary condition of the findings relates to the fact that structural mechanisms of coordination enable better learning when ignorance about the underlying interdependencies and difficulty of communication between specialists are prevailing. It may well be the case that when contributors have perfect knowledge about which combination of their actions lead to enhanced performance of the system, and when there are no costs or boundaries to communication, the use of integrators may be redundant or even detrimental.

A second important limitation is that the study does not address the extent to which integrators represent a cost to the IVF centres that employ them (e.g. managers filling the integrator roles may need to be incentivized with higher salaries), or whether those entrusted with this role face additional pressures (e.g. extended hours, job stress, etc.), and therefore, I have not directly addressed the disadvantages that may emerge from such structural arrangements. I nevertheless recognize that such organizational structures are costly to maintain and that the extent of firm resources necessary to ensure their effectiveness remains a critical factor which future developments of the study must consider.

The current study is limited in that it relies on a binary measure of structure which doesn't capture whether some IVF centres make more intensive uses of integrators than others. Furthermore, the study does not tease apart the specific mechanisms through which integrators work. For example, in arguments about the role of the integrator for team learning I have not distinguished between integrators with authority over individual contributors and integrators with little status or influence in the organization. While it would be possible to make this distinction in the IVF setting by comparing the learning rates of centres where the integrators are doctors to those where nurses fulfil the integrative role, data about the use of nurses as integrators is not available for all the years in the sample and will require further investigation. Thus, for time being, a potential limitation to these arguments is that they apply only to integrators with authority.

Another boundary condition of this research relates to the fact that IVF continues to be a highly uncertain treatment, and thus provides a setting where the environmental volatility is always high. As suggested by Sorenson (2003), in more stable environments, the expected impact of integration on learning is negative. The lack of support for the alternative hypotheses concerning the negative impact of integrators on learning may be explained by the fact that the field of IVF has not yet reached the state at which accurate predictions of the outcomes can be expected.

As the discussions of the empirical results for both analyses have emphasized, these investigations do not systematically document what is being learned as a result of experience. For example, I was not able to observe behavioural differences at the team level between centres employing integrators and centres which do not, or changes that occurred over time in the administrative structures of the centres as result of their experiences. Similarly, I could not assess the nature and amount of new knowledge gained by centres which tend to undertake more complex cases. Nonetheless, qualitative data from interviews and secondary sources offered many illustrations of how organizational learning manifests itself within IVF centres.

Another further limitation relates to the inability to account for other aspects of the organizational environment, individual learning, organizational design, coordination mechanisms, remuneration systems, and so on that may have a potential impact on issues of organizational learning and adaptation. Future research may be able to reveal their dynamics and unravel their impact. Finally, like any industry, the medical field of human sub-fertility has its idiosyncrasies and I cannot make normatively strong statements or generalizations of the findings to other settings. I do hope that these findings will spur further interest and research into this domain of considerable importance to organizational scholars and practitioners alike.

Implications for research

This dissertation has implications for the literature on organizational learning, especially the tradition that examines the relation between cumulative experience and success. This literature has made much progress, in terms of determining learning curves for various industries and processes (see, Argote 1999; Argote and Ingram 2000). Moreover, studies in this tradition have begun to untangle what underlies the transfer of knowledge (Szulanski 1996; Almeida and Kogut 1999; Argote and Ingram 2000), examine inter-organizational learning (Ingram and Baum 1997; Argote and Ophir 2002), and the diversity and type of experiences that lead to learning (Haunschild and Sullivan 2002; Hoang and Rothaermel 2005; Baum and Dahlin 2007). However, very little is known about moderators of the learning curve, especially moderators that are under control of the firm's management. The moderators examined in this dissertation – pertaining to the organizational structure and the composition of a firm's portfolio of activities – represent genuine choices for the people that govern the organization. Thus, this dissertation provides insight into why some firms learn quicker than others.

For research on organizational design, an implication of my arguments is the need to consider the dynamic effects of organizational structure in terms of the benefits that certain organizational setups entail for learning, over and above their associated coordination benefits (Levinthal and Warglien 1999; Rivkin and Siggelkow 2003; Ethiraj and Levinthal 2004; Siggelkow and Rivkin 2006; Knudsen and Levinthal 2007). Thus, in addition to improving the learning ability of organizations engaged in repetitive operations within stable paradigms, integrators also enable organizations to withstand the vagaries of technological change better. The positive effect of integrators on radical and incremental learning is largely attributable to their role in managing the interdependence that arises between specialists from different domains of action.

By lessening the confounding effects of learning in an ecology of other learners, other forms of lateral coordination should be expected to enhance organizational learning. Further research studying the relative importance of integrative structures for learning at individual and collective levels could shed light into the mechanisms that generate not only coordinated action, but more efficient use of prior experience and more effective adaptation. Empowered teams, liaisons, or technologies allowing real-time surveillance of other's actions could provide further areas of study.

The findings concerning task complexity also have implications for research on organizational capabilities. To achieve short term gains, many organizations adopt "low-hanging fruit" strategies and avoid risky or complex undertakings. However, the strategy of selecting promising cases as inputs to maximize outputs, comes at the expense of lower learning rates in the long term. As of yet, we know very little about the impact of selection at the gate for firms employing such practices, in spite of the prevalence of this societal phenomena (Stan and Vermeulen 2010). My findings suggest that the benefits of selecting only promising cases may be short-lived, and that firms may shoot themselves in the foot by staying away from complexity. Further research may offer more insight into the consequences of selection at the gate.

Implications for practice

Regarding the implications to practice, these findings call attention to the limits imposed on value creation by features of organizational structure and task environment. The main constructs in my arguments – the use of integrators to coordinate work at lower levels in the organization, and the complexity pertaining to the composition of a firm's portfolio of activities – are likely to be relevant to other organizational settings, in service sectors and in industries such as manufacturing rather than only in healthcare.

More generally this study highlights the need for managers to consider the potentially constraining effect of their firm's structural features and portfolio composition on the ability to enhance future performance and remain sustainable in volatile environments. For example, the findings concerning the impact of integrators have practical significance because they raise attention to their value-creating role and the how they enable superior learning outcomes at the organizational level. If integrators are creating value for the IVF centres, then why aren't more IVF centres or firms in other industries adopting this organizational arrangement? In considering the difficulties of managing work across functional boundaries, top managers in firms which must bridge several domains of action would do best to mandate and empower integrators in addition to the formal communication channels.

The study also provides insights for practitioners concerned with effective practices for portfolio management. The study suggests that actively managing the types of projects undertaken by the firm, such that they enable more exploratory learning behaviours, significantly enhances organizational capabilities. Many firms have to make important decisions regarding the composition of their product portfolio; whether to focus on a limited number of standard products or to include more challenging niche markets. This study provides the insight that the more challenging projects might have positive ramifications for the production process of the standard products. Hence, in healthcare, as in other industries, management matters and the way an organization is set up to tackle new challenges and tap into new sources of knowledge has a significant impact on the stock and application of its existing knowledge. These findings clearly show that issues of organizational administration heavily determine the abilities of firms to learn and adapt.

Contributions

With this dissertation I have attempted to make several contributions. First, this study explored a previously unaddressed area of organizational learning – the impact of structural features of organizations on the learning outcomes of firms. Existing research in organizational design has focused mainly on the coordination benefits of structure and, with the exception of some recent agent-based simulation studies, has predominantly looked at the impact on performance outcomes cross-sectionally while neglecting the dynamics that structures entail (Levinthal and Warglien 1999; Rivkin and Siggelkow 2003; Siggelkow and Rivkin 2005). By linking considerations of organizational structure to types of learning outcomes in real-world organizations, I offer an enriched understanding of the mechanisms through which attributes of the formal organization in general, and integrators in particular, affect collective learning dynamics. The results also substantiate existing theory that effective organizational action requires accommodating organizational structures, not only individual and group task mastery. Indeed, the investigations suggest that individual contributions and learning aggregate differently depending on the structural arrangements employed, further affecting the rate of improvement and adaptation at the organizational level.

Another contribution relates to the relationship between task complexity and organizational learning, as the nature of the task remains an understudied antecedent of learning. Though current research suggests that complexity might prompt learners to consider more possible associations for concepts underlying the task and to develop a more complex knowledge structure that benefits the standard tasks (Haunschild and Sullivan 2002; Schilling, Vidal et al. 2003), task complexity has been generally studied in relation with the fit between the task environment and organizational structure (i.e., building on the tradition of Tushman and Nadler 1978), leaving claims about its impact on learning effectiveness largely unexplored. Therefore this study represents a novel contribution to the strategy and organization literature by examining on how the benefits of experiential learning depend on the attributes of the portfolio of activities undertaken by firms.

The final two contributions of this dissertation are empirical. First, the study regarding the formal structure of IVF centres and their incremental and radical learning contains the first large sample test of the impact that integrators have on organizational outcomes. While several agent-based simulation studies have analyzed related structural factors, research employing quantitative methods to investigate the role of organizational structure has lacked a systematic measurement of structural attributes for real-world organizations. As a consequence, few studies have been able to empirically isolate the effect of structural features and to assess their impact on organizational outcomes longitudinally. In this dissertation I was able to reliably measure across organizational settings and time whether IVF centres displayed integrators. Moreover, the research design also benefited from the external shock which affected the production technology but was exogenous to the organizational structure.

The second empirical contribution relates to the problem of reverse causality that can arise in the study of task complexity, as some organizations (e.g. IVF clinics) might not be getting better *because* they deal with many difficult cases; instead, because they are better, they attract more challenging cases. Indeed, among for example cancer units, highly reputable institutions often display higher mortality rates; this is because patients with the most challenging aetiology (and hence lower ex-ante probability of survival) find or are referred to the best hospitals. Fortunately, the characteristics of the IVF data used in this study allowed for a direct test of reverse causality, due to the presence of a control group (i.e. NHS clinics where patients are assigned randomly, by postal code). Indeed, ruling out reverse causality and offering strong support for a theory of learning from complexity, the empirical effects in this group were virtually identical to the private clinics.

Conclusion

This exploration of experiential learning and adaptation in the medical field of IVF has demonstrated that two critical factors – integrators and task complexity – affect the learning processes and outcomes of firms. The use of integrators as choices of formal design shape collective outcomes in the long run; in particular they facilitate learning when underlying conditions remain stable and when they shift the nature of the task interdependence. Regarding task complexity, it appears that organizational contexts which permit participation in more complex tasks produce more learning than organizational contexts in which the tasks performed exhibit lower levels of complexity. The dimensions of formal organizational structure and task environment that I have identified in the context of IVF clinics revealed these effects, suggesting that coordination at the lower levels of the organization and the pressure induced by taking on more demanding tasks enhances the ability of organizations to learn from their experience.

One important conclusion can be derived from this dissertation. Though firms may share similar levels of prior experience and may face the same exogenous intervention on critical inputs, factors that relate to their organizational context enables them to learn at faster rates and adapt more effectively. To date, few researchers have explored how the cumulated experience of organizations, structural characteristics, attributes of the task undertaken, and their complex interactions affect performance. This dissertation extends this approach by providing evidence that variation in learning rates and adaptation across organizations has two important sources: organizational structure and task attributes.

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APPENDIX

TABLE 8. Descriptive statistics and correlations among variables in the merged dataset.
Note: Only 826 centre-years (64 IVF centres) have complete data.

Variable	*Obs*	*Mean*	*S.D.*	*Min*	*Max*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. Success rate for patients under 35	850	0.268	0.1041	0	0.67	-									
2. Centre size (patient count)	899	332	260.92	1	1467	0.2375	-								
3. Centre age	891	7.873	5.0670	0	26	0.3168	0.4800	-							
4. ICSI Technology (binary)	908	0.577	-	0	1	0.4560	0.1211	0.5631	-						
5. (Log) Industry experience	835	11.50	1.01	8.57	12.5	0.4636	0.1419	0.6157	0.7392	-					
6. (log) Centre prior experience	884	6.548	2.15	0	9.48	0.3536	0.6524	0.8080	0.4727	0.5857	-				
7. Integrator (binary)	915	0.425	-	0	1	0.1468	-0.2323	-0.1715	-0.0059	0.0306	-0.2359	-			
8. Post 2001 (binary)	914	0.327	-	0	1	0.3713	0.1108	0.5664	0.6414	0.6092	0.4012	0.0198	-		
9. Incidence of poor prognosis patients	844	0.779	0.1605	0.03	1	0.1212	0.0195	-0.1500	-0.1066	-0.1348	-0.1461	**0.1078**	-0.0506	-	
10. Incidence of previous treatment failure	846	1.157	0.0828	0.82	1.54	0.0006	0.0078	-0.0666	-0.1461	-0.0904	-0.0486	**0.1024**	-0.1122	0.2250	-
11. Incidence of patients above 35	899	0.464	0.1005	0	-0.84	0.3504	0.1773	0.4226	0.4319	0.4120	0.3439	**0.1565**	0.4671	-0.0859	0.0008

TABLE 9. OLS Regressions of the Success Rates for Standard Cases when accounting for both integrative structures and task complexity

Variable	*1*	*2*	*3*	*4*
Centre size (patient count)	-0.00001 (0.00002)	-0.00001 (0.00002)	-0.00002 (0.00002)	-0.00002 (0.00002)
Centre age	0.0079 ** (0.0031)	0.0080 ** (0.0032)	0.0067 * (0.0037)	0.0069 * (0.0038)
ICSI Technology	0.0247 * (0.0139)	0.0258 * (0.0145)	0.0261 * (0.0137)	0.0266 * (0.0141)
(Log) Industry experience	-0.0040 (0.0085)	-0.0027 (0.0089)	-0.0070 (0.0094)	-0.0064 (0.0100)
(Log) Centre prior experience	0.0148 ** (0.0067)	0.0132 † (0.0089)	-0.0658 ** (0.0287)	-0.0578 * (0.0289)
Post 2001	-0.0101 (0.0121)	-0.0216 † (0.0135)	-0.0108 (0.0119)	-0.0214 † (0.0133)
Incidence of poor prognosis patients	0.0538 ** (0.0246)	0.0449 * (0.0266)	-0.0115 (0.0882)	-0.0070 (0.0863)
Incidence of previous treatment failure	0.0334 (0.0521)	0.0325 (0.0509)	-0.3107 * (0.1689)	-0.2784 † (0.1734)
Incidence of patients above 35	-0.0401 (0.0740)	-0.0430 (0.0750)	-0.3105 † (0.2326)	-0.2970 (0.2549)
Integrator X Centre experience		0.00001 (0.0061)		-0.0017 (0.0061)
Integrator X Post 2001		0.0279 * (0.0156)		0.0253 † (0.0157)
Incidence poor prognosis patients X Centre experience			0.0092 (0.0134)	0.0076 (0.0132)
Incidence of previous treatment failure X Centre experience			0.0526 ** (0.0238)	0.0476 † (0.0243)
Incidence of patients over 35 X Centre experience			0.0412 † (0.0308)	0.0388 (0.0336)
Constant	0.0817 (0.1127)	0.0860 (0.1141)	0.6548 ** (0.2660)	0.6064 ** (0.2867)
N_t (centre-years)	826	826	826	826
N (centres)	64	64	64	64
F-Statistic	32.26 ***	26.83 ***	31.23 ***	34.17 ***
Centre fixed effects	Yes	Yes	Yes	Yes

*** p < .01; ** p < .05; * p < .10; two-tailed tests. † p < 0.10 one-tailed test.

TABLE 10. Correlations among the corresponding interactions for Integrative Structures and Task Complexity

Interacted terms	1	2	3	4
1. Integrator X Centre Experience	-			
2. Integrator X Post 2001	**0.5826**	-		
3. Incidence of poor prognosis patients X Centre Experience	0.1045	0.1908	-	
4. Incidence of prior failed treatments X Centre Experience	0.0278	0.1506	**0.7246**	-
5. Incidence of patients above 35 X Centre Experience	0.1398	0.3104	**0.5866**	**0.7948**