Universitat Ramon Llull

DOCTORAL THESIS

Title	**INDIVIDUAL-LEVEL COLLABORATION AND FIRM-LEVEL INNOVATION IN THE BIOTECHNOLOGY INDUSTRY**
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1 INTRODUCTION

1.1 Relevance of the Research Topic

Modern economies are characterized by continuous and rapid innovation fuelled by technological and scientific advances. For firms competing in this environment, continuous access to new information, know-how, and ideas[1] is essential to innovate, which in turn, is necessary to achieve competitive advantage and organizational survival (Bierly and Chakrabarti, 1996; Davila, 2007). However, given the pace with which knowledge develops around the world and along numerous scientific and technological frontiers, no firm can internally develop all the expertise and capabilities needed to compete (Grindley and Teece, 1997). Firms must, therefore, continuously monitor and absorb knowledge from other organizations, including domestic and international firms, government laboratories, and universities (Arora and Gambardella, 1990; Powell et al., 1996; Liebeskind et al., 1996). One way in which a firm can access external knowledge is by engaging in inter-organizational alliances (Inkpen, 1998). Empirical research has confirmed that strategic alliances are an important source of scientific and technological knowledge which is a key input factor for innovation (Mowery et al., 1996; Ahuja, 2000) and firm performance (Stuart, 2000). This dissertation follows this logic and combines research on innovation and inter-organizational collaboration but broadens it to the level of individual collaborations.

[1] In the realm of this dissertation, "knowledge" is used as an umbrella term to cover data, information, ideas, know-how and expertise. Even though these concepts have significantly different meanings and properties (Boisot and Canals, 2004), their differences are hardly relevant for this dissertation.

1.1.1 Innovation

Innovation is a central human activity and is as old as mankind itself. It is an inherent characteristic of humans to think about new and better ways of doing something. The world we know today would not be possible without it. From the most simple human achievements and ideas (e.g., the wheel, the alphabet or printing) to the most sophisticated accomplishments (e.g., advanced medical treatments, Apollo 11 and modern information technology), nothing would exist without humanity's innovative drive (Fagerberg, 2005).

Despite its utmost importance, innovation has only been examined at the periphery of scholarly activities in the history of management and economic theory. With the notable exception of Schumpter (1939), Economics has long focused on other topics (e.g., optimal factor allocation and how markets work) while neglecting innovation-related issues (Fagerberg and Verspagen, 2009). However, this is changing, and research on innovation has flourished during the last few decades. More recent research has fostered our understanding of innovation, its general role in society and its economic consequences. Today, there is general consensus that:

- Innovation infuses novelty (and variety) in the economic and social arena and it is the main driver of economic progress.
- And, innovation is a powerful factor, explaining performance differences between firms, regions and countries. Innovative firms, regions and countries outperform less innovative firms, regions and countries and have higher productive volumes and income than less innovative ones.

Most of past research has focused (on the mostly positive) effects of innovation, while the actual processes underlying innovative activities have often been treated as a "black box" (particularly in Economics). This focus has begun to shift only gradually to encompass the various factors influencing and strengthening innovation, and researchers are now using a variety of different theoretical lenses to open the innovation "black box" and obtain a more fine-tuned picture of innovation activities (Rosenberg, 1994).

One widely accepted factor within more recent studies is that innovation, by its very fundamental nature, is the combination or recombination of existing ideas, skills, capabilities, resources or knowledge (Galunic and Rodan, 1998; Fleming, 2001; Henderson and Clark, 1990).[1] This means that the bigger the variety of input factors within a system, the greater the possible scope of combinations and the greater the resulting complexity of innovations. Thereby, it is generally assumed that this trend is progressive and that complexity increases (Fagerberg, 2005). The growing complexity of innovation implies that even large organizations are increasingly dependent on external inputs. Modern drug development illustrates this nicely. The pharmaceutical industry has always been characterized by its continuous scientific and technological change. However, the so-called molecular, biotech revolution (Malerba and Orsenigo, 2002) has increased this complexity even further in an already highly sophisticated industry. Compared to traditional pharmaceutical firms that have developed their competitive advantage through capabilities linked to medicinal chemistry, biotechnology firms are usually experts in the rapidly evolving field of molecular biology. Molecular biology has opened an array of new frontiers for research (including

[1] This idea can be traced back to Schumpeter's early work.

genomics, proteomics, genetic engineering, and gene therapy) and has also spawned hundreds of technologies (related to target identification, clinical trials, screening, and bioinformatics) that can be applied to research processes (Pisano, 2002). Thus, there is an ever-increasing number of 'locks and keys', particularly in pharmaceutical research and drug development, and no firm can master them all. In this environment, sources of new scientific and technological knowledge can come from an array of fields and a number of specialized firms, academic laboratories, and government institutions. In order to succeed in this industry, firms must reach across their organizational boundaries to sources of new knowledge and capabilities on both the scientific and technological fronts (Arora and Gambardella, 1990; Powell et al. 1996; Liebeskind et al. 1996).

This increasing complexity and need for boundary spanning activities leads directly to the second generally accepted finding regarding innovation research, namely, that innovation is hardly the activity of a single individual actor (Davila, 2007). Instead, innovation activities are embedded and interdependent in a wide network of relationships with various interconnected actors (Edquist, 2005). Several authors analyse innovation on the basis of sector and technological systems (Malerba, 2004; Malerba, 2002; Geels, 2004), while others focus on regional and national systems of innovation (Castellacci, 2009; Lundvall et al., 2002). Common to all these studies is their determination that innovation activities are embedded in a network of multiple actors crossing various organizational and institutional boundaries.

Both the increasing complexity within innovation and its systemic nature point directly to the increasing importance of inter-organizational relationships, the second key research tradition on which this dissertation is grounded.

1.1.2 Alliances[1]

During the last few decades alliances and organizational collaboration have become key issues for managers and researchers alike. Today, they are ubiquitous phenomena, crossing sectors, industries and countries (Gulati, 1998; Inkpen, 2002). The motives behind alliances encompass a wide range of reasons, including risk reduction, economies of scale and scope, access to complementary technology and resources, overcoming governmental barriers, international expansion, the search for legitimacy and blocking competition (Contractor and Lorange, 2004). Particularly, learning and knowledge-related advantages linked to innovation have been at the centre of recent alliance research (Inkpen, 2002).

However, alliances not only provide benefits for organizations. They come with a set of new problems and challenges, e.g., learning races (Hamel, 1991; Khanna et al. 1998), partner selection (Beckman et al. 2004; Mowery et al. 1998), and contract specification (Reuer and Arino, 2007). Additionally, alliances are organizational mechanisms that

[1] The terms "alliance" and "inter-organizational collaboration" are often used interchangeably to encompass a broad range of business activities. These activities can range from very short arms-length contracts to equity joint ventures, from informal agreements between firms in the same local cluster to highly structured contracts between international firms, and from small co-branding projects to the joint development of highly sophisticated and large-scale projects such as airplanes (Contractor and Lorange, 2004). Within this study, alliances are understood as a means for organizational collaboration between a firm and a second organization (another company, university, research institute, etc.) in order to access and develop knowledge and develop patents in the process of drug development The characterization as an organizational-level relationship is particularly relevant because the central theme of this dissertation is the contrast between "classical" organizational-level collaborations ("alliances") and individual-level collaborations.

take time to establish and, as they're costly in terms of managerial time and attention, they must be limited in number and targeted for specific needs. In an environment where the nature, location, and type of potential knowledge sources are continuously changing, firms may need to develop more flexible mechanisms for knowledge acquisition. In biotechnology, for instance, given the uncertainty associated to the scientific developmental process and the applicability and usefulness of knowledge absorbed from any particular target (whether a university or a firm), it is important that companies have some flexibility in setting up (and potentially dissolving) the inter-organizational mechanisms that will facilitate knowledge absorption.

1.2 Research Question

Despite the vast amount of research on collaborative arrangements for innovation, only a few studies examine the individual collaboration activities of members within an organization and their influence on firm innovation. This is surprising since several studies illustrate the important role individuals can play in knowledge acquisition and transfer processes. For instance, research on localized knowledge spillovers shows that individuals play an important role in the sharing of ideas and information between firms in regions (Saxenian, 1991; Almeida and Kogut, 1999). The role of the individual in creating knowledge bridges across organizations was highlighted in the early work on boundary spanners (Crane, 1972; Tushman, 1977). Additionally, several studies point to a connection between the acquisition of scientific knowledge through collaborative activities and patented innovations. Cockburn and Henderson (1998) found that collaborations between scientists in firms and universities (as indicated by the co-authorship of articles) increased the quality of the resulting patents. Zucker et al. (2002)

show that, specifically, “star scientists” affiliated to a company (whether as employees, board members, founders or those linked by co-authorship to the firm) enhance the company's innovativeness. Rothaermel and Hess (2007) have found that non star-scientists also have a positive influence on a firm’s innovation.

In addition to this initial evidence on the importance of individual activities in firms, little is known about the relationship between individual-level collaboration and firm-level characteristics. Previous studies do not clearly detangle individual collaborations with factors associated with individual and firm level expertise. To systematically evaluate whether individual (and often informal) collaborations can matter to a firm’s innovative output, the effects of individual collaborative activity have to be isolated by accounting for related factors, including the role of star scientists, the level of the firm’s intellectual capital, R&D investment, non-collaborative publications and strategic alliances. This leads to the first research question:

Research Question 1*: Do individual-level collaborations positively affect firm-level innovation and under what conditions are these collaborations important for the company’s innovativeness?*

Furthermore, keeping close to the cutting edge of technology is a daunting challenge, especially for small and often resource-constrained firms (Almeida and Kogut, 1997). Companies are faced with the challenge of not only innovating or even simply exploring new technological and scientific territories. They have to move beyond established practices and knowledge domains in order to keep close to the emerging frontiers of innovation. Prior research has shown that companies search for knowledge locally, i.e., in the neighborhood of their past practice and their current capabilities and expertise, and that it is very difficult to change their technological trajectories (Nelson and Winter, 1982). One solution might be found at the level of an individual member within the firm.

At the individual level, scientists can reach across organizational boundaries to collaborate with others scientists, and this can provide the firm with useful inputs for innovation (Gittelman and Kogut, 2003; Cockburn and Henderson, 1998; Murray, 2002; Tushman, 1977). Corporate scientists belong to both organizational and scientific communities and, hence, facilitate the flow of knowledge between the two (Tushman, 1977; Murray, 2002). Membership in scientific communities often gives rise to research collaborations between scientists (often informally) across organizational boundaries and results in the publication of co-authored scientific papers (Cockburn and Henderson, 1998). Scientists' collaborative activities often link firms and universities and can, therefore, offer access to not only additional knowledge but also unique and early developing knowledge (Liebeskind et al. 1996).

Individual-level scientific collaborations may not only lead to an increase in knowledge available to a firm, but, more importantly, they can facilitate insight and access to knowledge from a wider spectrum (geographically, organizationally, and scientifically) that would not be possible otherwise. Firms that have a large number of scientists engaged in external knowledge exchanges are, therefore, likely to be infused with a broad set of new ideas, decreasing the myopia (that is so often a part of the learning process) and consequently decreasing the resistance to change. Knowledge inputs and exchanges provide individuals with an early and clearer picture of the emerging scientific and technological landscape, and this expands the view of scientific and technological possibilities available to the firm. These collaborations can, therefore, broaden not just the spectrum of possible scientific advances within the firm, but, just as importantly, the perception of what is attractive (and unattractive) to them. This leads to the second research question:

Research Question 2: *Do individual collaborations across firms (as contrasted with internal collaborations and strategic alliances) encourage firms to innovate in the area of emerging innovation?*

1.3 Research Setting: Biotechnology

These hypotheses are tested in the context of the biotechnology industry because this sector stands out for three unique traits. First, the biotechnology industry is characterized by a high degree of knowledge intensity and its continuous development of new knowledge and innovation (Powell et al., 1996). Several studies show that the reliance on innovation in this industry is particularly elevated and that innovation ensures performance and long-term survival (Stuart, 2000; Zaheer and George, 2004; Shan et al., 1994; Baum et al., 2000).

Second, biotechnology firms are strongly embedded in networks of individual and organizational-level collaborations, including links to other firms, universities and research institutes (Powell et al., 1996; Arora and Gambardella, 1990; Liebeskind et al., 1996). The development and commercialization of new drugs require a range of capabilities, including those related to basic and applied research, clinical testing, production and manufacturing, marketing, distribution and managing the regulatory process (Powell et al., 1996). The complexity and diversity of the capabilities required to succeed create a division of labor between universities, pharmaceutical firms, and biotechnology firms. Universities and biotechnology firms tend to concentrate primarily on basic research and development, and pharmaceutical firms focus more on applied research, manufacturing, marketing and distribution (Arora and Gambardella, 1990; Rothaermel and Deeds, 2004). Biotechnology firms invest heavily in R&D, they often sponsor university research, create post-doctoral positions, and permit their scientists to work with relative autonomy and interact with others in the scientific community (Powell et al., 1996).

Finally, research in the realm of innovation, learning and knowledge often faces problems in developing valid and reliable means to measure outputs. However, during the last decades, patent data has shown its usefulness in many studies on innovation, knowledge flows, technological development and knowledge localization (Jaffe, 1989; Almeida and Kogut, 1999). Patent data has the advantage that it provides systematically compiled and detailed information and it is continuously available over time (Rosenkopf and Almeida, 2003). The same can be said for academic publications as a source to analyze collaboration and learning activities (Gittelman and Kogut, 2003). Like patents, articles provide researchers with a variety of information regarding a certain idea or innovation; this includes the authors, their organizational affiliation, organizational collaboration, the organization's/authors' address, references, and classification codes. Both data sources are subject to a critical review process, thus increasing their reliability. In terms of patents, this review is carried out by the patent officer, and, in the case of articles, they are approved through a peer-review process.

Additionally, in both cases, the information can be used to calculate advanced innovation and knowledge-oriented variables (e.g., patent value and technological scope). However, not all industries are suited to using patents (or publications) as the means of measurement because the propensity to use these and the motives behind their application vary significantly between industries (Mansfield, 1986; Cohen et al., 2000). Several cross-industry comparison studies reveal that drug development is among the industries with the highest reliance on patents. For example, in the pharmaceutical industry, on average, over 80% of patentable inventions are actually patented, while 60% of already developed or commercially-introduced inventions would not have been developed and 65% would not have been introduced if patent protection were not obtained (Mansfield, 1986). Similarly, 95.5% of firms related to drug development have applied for product-related patents within the last three years (Cohen et al., 2000). Even though these studies do not distinguish between drug development in pharmaceutical versus biotechnological firms, it can be assumed that the numbers are similar if not even higher among biotechnology firms. Biotechnology firms often don't have any products on the market, and their products' value depends on the patent pipeline (DeCarolis and Deeds, 1999). As a result, patents are an important instrument for these firms to protect and generate profits. This in turn makes the interpretation of patents more reliable in this industry than in others.

1.5 Dissertation Structure

The remainder of this dissertation is organized as follows. Chapter 2 provides a review of the relevant literature. This review is divided into three parts: First, the main theoretical lenses are discussed in detail, including (1) "A Behavioural Theory of the

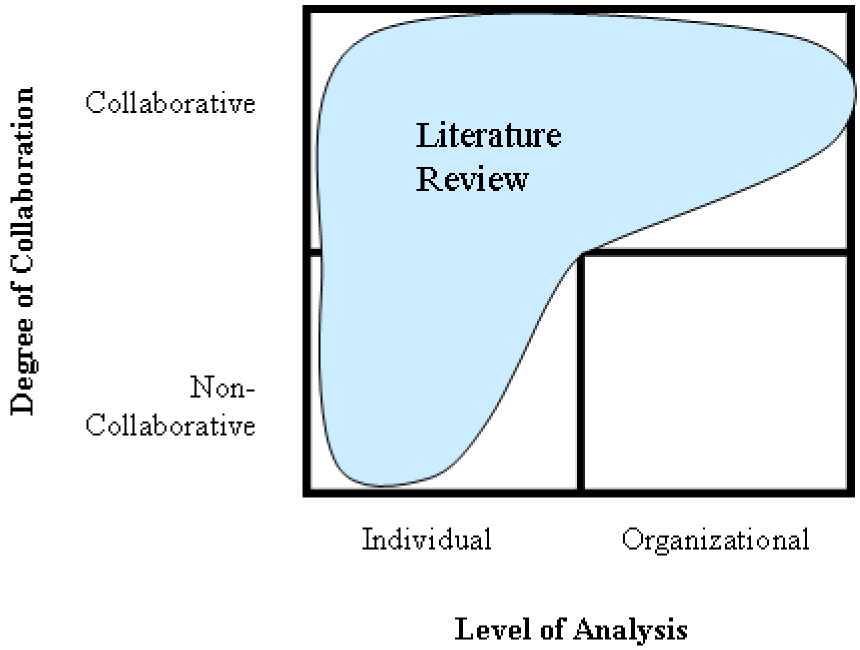
Firm", (2) Evolutionary Economics and (3) Organizational Learning. Second, the empirical literature on collaborative activities and innovation in regard to high technology industries is reviewed. Third, based on the previous literature review, the two research questions are derived. In Chapters 3 and 4, the two research questions are discussed in more detail. Chapter 3 focuses on the performance impact of individual collaboration, and Chapter 4 discusses how individual collaborations can influence corporate technological trajectories. Both of these chapters are structured like independent papers and include a section for hypothesis development, methodology, results and discussion. This separate discussion of the two research questions is justified for two reasons. First, even though hypothesis development addresses the logic found in A Behavioral Theory of the Firm (Cyert and March, 1963) the first draws more on arguments from Organizational Learning theories and the second from Evolutionary Economics (Nelson and Winter, 1982). Therefore, separate hypothesis development can better address the relevant theoretical issues. Second, although both questions are addressed in the same sample of firms, their operationalization requires the development of specific variables and the application of different statistical models. In the final chapter, the results of the two research questions are linked, and their common implications discussed.

2 LITERATURE REVIEW

This chapter reviews the relevant literature and is divided into two parts. The first part provides an overview of the main theoretical lenses of this dissertation. It describes the key aspects in A Behaviorial Theory of Firm (Cyert and March, 1963) and its two "offspring" research streams: Organizational Learning (Levitt and March, 1988; March, 1991; Huber, 1991) and Evolutionary Economics (Nelson and Winter, 1982). The second part discusses previous empirical research relevant to the underlying research questions. The review of empirical research focuses on collaborative mechanisms and makes the distinction between organizational and individual learning to systemize innovation literature. As such, the review of empirical literature can be grouped along two dimensions derived from the theoretical part of the literature review: (1) the level of analysis (the organizational vs. the individual level) and (2) whether or not an activity is collaborative (Figure 1).[1] Additionally, it is important to mention that the literature review in the following chapter is rather broad in its scope, referring to the general interest of this dissertation, the importance of individual collaboration. Chapters 3 and 4 review the previous literature specifically for the research questions at hand.

[1] Purely organizational and internal studies are not included in the literature review because the focus of this dissertation is on individual collaborative innovation mechanisms. Additionally, several previous studies have already focused specifically on this topic.

Figure 1: Literature Review: Structure



2.1 Theoretical Lenses

Researchers use a variety of theories to explain collaborative arrangements in firms, including Game Theory (Parkhe, 1993), Transaction Cost Theory (Oxley, 1997), Network Theory (Gulati, 1999), and a Resource-based View of the firm (Das and Teng, 2000; Eisenhardt and Schoonhoven, 1996). The same accounts for innovation research, where studies cover a wide range of fields including creativity (Amabile, 1988), regional or country-wide competitive advantage (Porter, 2000) and macroeconomic progress (Schumpeter, 1939), just to mention a few. However, when examining the combination or the intersection of the two research streams, two mainly dominant theoretical lines appear in the literature: Organizational Learning and Evolutionary Economics, both of which are based on the theoretical foundations outlined in A Behavioral Theory of the Firm (Cyert and March, 1963). Subsequently these three theories are explained in more detail.

2.1.1 *A Behavioral Theory of the Firm*

A Behavioral Theory of the Firm (Cyert and March, 1963) is one of the most influential theories on management and organizational theory (Ramos-Rodriguez and Ruiz-Navarro, 2004). It finds it origin in the seminal book by Cyert and March (1963), *A Behavioral Theory of the Firm*. Together with the two earlier and also very influencing books, *Organizations* (March and Simon, 1958) and *Administrative Behaviour* (Simon, 1947), it serves as the cornerstone for behavioural research in management and organizations. The so-called "Carnegie School" in organizational theory is largely defined by these three books (Augier and March, 2008; Gavetti et al., 2007).

The success of "*A Behavioral Theory of the Firm*" (Cyert and March, 1963) can be partly explained by the fact that it not only draws on tools, concepts and insights from economics and management, but also from anthropology, political science, psychology, and sociology to develop a realistic and applied theory of the firm. It refers to actual human behaviour and particularly to human decision-making in contrast to the (until then) idealistic view of human actions in economics and management. The key concepts and mechanisms it encompasses can be summarized in 7 main points (Argote and Greve, 2007):

1. Decisions are intentionally rational but bounded by human and institutional limitations (bounded rationality).
2. Organizations accumulate and use slack.
3. Problemistic search (search in response to problems).
4. Attention is a scarce resource.

5. Firms can be seen as coalitions of individuals and groups with conflicting goals in the search for dominant coalitions.
6. The use of standard operating procedures.
7. And firms satisfy in terms of aspiration levels and adjust these aspirations over time in response to experience.

Many of the ideas outlined in "*A Behavioral Theory of the firm*" (Cyert and March, 1963) were introduced in the earlier work by Simon and March. For example, "bounded rationality" was introduced earlier by March and Simon (1958) and the concept of a problemistic search was based on the model of individual motivation (March and Simon, 1958). However, the implications of these concepts for organizational decision-making were more fully developed by Cyert and March in 1963.

By questioning the main assumption of classical economics (e.g., rationality and profit maximization), *"A Behavioral Theory of the firm"* was and still is a direct challenge to classical economic theorizing. As Sidney Winter (1964) noted, *"this book delivers a major blow to that battered but hitherto unshaken intellectual construct, the theory of the profit-maximizing firm. Its importance derives from the fact that it presents a well-elaborated alternative theory that stands up well under the tests of both systematic and causal empiricism, rather than from any novelty in the criticisms it levels against orthodoxy. . . Those who have not heard the distant rumblings of the 'behavioural revolution' will be surprised at the momentum it has achieved. The final verdict cannot* *be predicted, but this book should at least convince most economists that the revolutionaries bear watching."* (p. 148)[1]

The degree to which *"A Behavioral Theory of the Firm*" has changed economic reasoning is still open to debate. However, elements of a behavioural view of the firm can now be found in many modern developments in Economics, e.g., Transaction Cost Economics (Williamson, 1979; Williamson, 2000), Evolutionary Economics (Nelson and Winter, 1982), and Organizational Economics (Gibbons, 2005).

Without doubt, the success of "*A Behavioral Theory of the firm*" can be found in management literature. The theory and some of its direct "offspring" continue to be among the most influential management books and articles of all time (Ramos-Rodriguez and Ruiz-Navarro, 2004). It has inspired and legitimated new approaches to studying organizations and it has become a foundational element in areas like population ecology, strategic management, and institutional theory and in related fields like political science, and sociology (Argote and Greve, 2007; Augier and March, 2008).

Argote Greve (2007) and Gavetti et al. (2007 argue that the success of "*A Behavioral Theory of the Firm*" is based on the fact that it doesn't propose a narrow paradigm with strong closure properties. Instead, it is based on closely related ideas which are applicable to different situations. Based on the usefulness and adaptability of this theory's basic assumption, its basic premises have been encompassed as foundational

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[1] As cited in Augier and March (2008).

principles in several research programs in organizational studies, sociology, economics, and strategy. However, on the downside, its influence has been more broad than deep (Gavetti et al. 2007).

The most direct descendents of *"A Behavioral Theory of the Firm"* are Organizational Learning Theories (Huber, 1991; March, 1991; Levitt and March, 1988) and Evolutionary Economics (Nelson and Winter, 1982; Nelson and Winter, 2002; Dosi and Marengo, 2007).[1] Both research streams keep closely to the basic assumptions, approaches, and research questions found in *"A Behavioral Theory of the Firm"*. (Gavetti et al., 2007; Argote and Greve, 2007). However, since most empirical research is embedded in either of these two research lines and does not fall under the "umbrella category" of the behavioural firm, they are explained in more detail below.

2.1.1.1 Evolutionary Economics

Evolutionary Economics itself has become one the most influential theory constructs in contemporary management and economic research (Ramos-Rodriguez and Ruiz-Navarro, 2004) and it is particularly salient with respect to innovation research (Fagerberg and Verpagen, 2009). As a direct descendent, it owes many of its concepts and most of its philosophy to *"A Behavioral Theory of the Firm"* (Cyert and March, 1963). Not only does Part II of Nelson and Winter's (1982) book, *Organization-Theoretic Foundations of Economic Evolutionary Theory*, cite many examples from the work carried out by Cyert, March, and Simon, but most of Evolutionary Theory concepts can be traced back to *"A Behavioral Theory of the Firm"* (Dosi and Marengo,

[1] It is important to note that there is no "single" Organizational Learning Theory. Organizational Learning research is more a collection of similar concepts and assumptions mostly related to "A Behavioral Theory of the Firm" (Cyert and March, 1963)

2007). For example, bounded rationality and problemistic search can be found within both theories. Probably the strongest link between both theories is the understanding of standard operating procedures or routines in order to use the language of Evolutionary Economics. Standard operating procedures can be seen as the predecessor of "routines" and thereby serve as the basis for Evolutionary Economics. Subsequently, routines became the foundational building blocks of research on capabilities, in general, and on dynamic capabilities. (Winter, 2003; Teece et al. 1997)

In short, "evolutionary economics examines organizational and industrial evolution processes based on a model of firms as routine-based agents that change incrementally through search rather than as a result of optimization" (Nelson and Winter, 1982). Sydney Winter identifies the ten basic propositions regarding the appropriate aim of economic theory, the nature of firms, and the process that leads to economic growth and change following the evolutionary logic as follows:[1]

1. Economic theory should reflect economic and organizational reality. Doing business research and doing business are not two completely different activities.
2. Instead of focusing primarily on static equilibrium analysis, economic theory has to take dynamic behaviour into account.
3. Processing information is costly. Organizations have limited time, resources and managerial attention.
4. Firms are profit seekers and not profit maximizers.

[1] The 10-point summary is based on the work by Cohen et al. (2001) which quotes a speech by Sydney Winter at a special conference to honour the co-author and co-founder of Evolutionary Economics, Richard Nelson (Cohen et al. 2001).

5. Firms are not limited by a fixed set of possibilities which they can optimize. They can innovate and create new opportunities and possibilities.
6. Firms are historical entities, based on stable practices (routines) which define their activities over time.
7. Firms are the holders of organizational and technological knowledge and the key agent of change.
8. Search processes are the basis for technological and organizational innovation. Therefore, the search is both internal and external, encompassing rivals, suppliers, customers, etc. Furthermore, the different search levels are interdependent.
9. Organizational search is affected by institutions and public policy and vice-versa, something which leads to a co-evolutionary process between both.
10. Market discipline and economic selection limit outcomes over time. However, over the short term, "anything goes".

Evolutionary Theory has a very active tradition of modelling the consequences of behavioural assumptions for industrial and firm evolution, and much research is directed to the issue of how organizations come to develop heterogeneous sets of capabilities and sustain (or modify) them over time (Argote and Greve, 2007). As such, the fundamental unit of analysis is often the routine. In the broadest sense, routines are "stable patterns of behaviour that characterize organizational reactions to variegated internal and external stimuli" (Zollo and Winter, 2002). They are the basis for behavioural continuity in Evolutionary Theory and led to the catch phrase, "routines as genes" (Nelson and Winter, 2002). Routines are the organizational analogue of skills at the individual level (Zollo and Winter, 2002).

Due to the fact that general capabilities and dynamic capabilities are based on the concept of organizational routine, routines are also central to research on strategic management. For Winter (2003), "an organizational capability is a high level routine (or collection of routines) that, together with its implementing input flows, confers upon an organization's management a set of decision options for producing significant outputs of a particular type." Dynamic capabilities are defined "as routinized activities directed to the development and adaptation of operating routines" (Zollo and Winter, 2002). Recent examples of capability-based research are: the development of dynamic capabilities in the Biotech industry (Rothaermel and Hess, 2007); its performance influence in the case of new ventures (Arthurs and Busenitz, 2006) and its development through alliances (Kale and Singh, 2007) and acquisitions (Ranft and Lord, 2002), just to name a few.

A central point in Evolutionary Theory, and one which is especially relevant for this dissertation, is the path-dependent nature of routines (Argote and Greve, 2007). This means that routines develop as a function of the past. They change and adapt but they do so through incremental changes based on experiences and in relation to the previous state (Becker, 2004). Research on innovation and organizational change particularly relies on path dependency in its reasoning (Helfat, 1994; Stuart and Podolny, 1996; Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002; Katila and Chen, 2008; Nerkar, 2003).

2.1.1.2 Organizational Learning

The second research stream which directly uses the concepts and mechanisms of *"A Behavioral Theory of the Firm"* is Organizational Learning (Argote and Greve, 2007). In their seminal work, March and Simon (1958) reject the claim of economic rationality and that organizational decisions are uniquely determined by environmental constraints. Instead, they argue that organizational behaviour depends on complex internal processes which add unpredictably into the decision-making process. The authors thus refer to several concepts which later became key to Organizational Learning (Schulz, 2002). Subsequently, *"A Behavioral Theory of the Firm"* (Cyert and March, 1963) sharpened the focus on organizational learning due to the authors' perception of the firm as a complex adaptive system which possesses considerable autonomy against external events. In particular, the role of search and aspiration levels and the importance of routine-based behaviour are central to Organizational Learning (Gavetti et al., 2007). The understanding that organizational learning is slow, complex and sensitive to small changes during the learning process and not always performance improvements is one of the clearest results of the behavioural research tradition.

During the last 40 years, research on organizational learning has produced an enormous amount of research. Some of it has become seminal in its own right and laid the foundation for independent research streams. For example, in his work on exploration and exploitation, March (1991) based his concepts directly on the work of Cyert and March (1963), leading to the creation of a flourishing new research stream. Similarly, the ideas of Communities of Practice (Brown and Duguid, 2001) and Absorptive Capacity (Cohen and Levinthal, 1990) build heavily on the foundation provided by *A Behavioral Theory of the Firm*. Additionally, a wide range of research on innovation, product development and organizational change uses concepts from Organizational Learning, but without clear references to it.

Several researchers have tried to systematize the vast amount of literature on Organizational Learning. For example, Huber (1991) tries to classify organizational learning in a hierarchical system with four main categories: (1) knowledge acquisition, (2) information distribution, (3) information interpretation and (4) organizational memory. Easterby-Smith et al. (2000) develop a framework for Organizational Learning which spans and connects the different types of learning, namely at the individual, group, and organizational levels. As such, Organizational Learning encompasses four factors: (1) processes-intuiting, (2) interpreting, (3) integrating, and (4) institutionalizing. Fiol and Lyles (1985) try to clarify the distinction between Organizational Learning and Organizational Adaptation and show that change does not necessarily imply learning. In a more recent review, Schultz (2002) outlines the history of the concept, reflects on the current debate and shows future lines of research.

Two conceptual distinctions in the literature are central to frame this dissertation and will be used for the subsequent, more detailed empirical literature review. First, many researchers discuss the differences between intra-organizational learning and inter-organizational learning (Schulz, 2002; Dosi and Marengo, 2007) because the two concepts most likely involve very different learning mechanisms and problems (e.g., the "not invented here" syndrome). [1]

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[1] However, Argote and Greve (2007) argue that, in certain circumstances, inter and intra-organizational learning can be discussed together. This is because similar learning mechanisms may be found at multiple levels of analysis (e.g., a myopic search may be behind imitation, and a single learning process can have consequences at multiple levels within organizations (Argote Greve, 2007).

Second, some agreement exists that Organizational Learning spans individual and organizational levels. However, various researchers have different views regarding the dominant level. It is generally accepted that individual learning is the micro unit of analysis for learning. As Simon (1991, p. 125) famously argues, organizational learning is only a metaphor because "all learning takes place inside individual human heads; an organisation learns in only two ways: (a) by the learning of its members, or (b) by ingesting new members who have knowledge the organisation previously did not have" (Simon, 1991). However, without denying the importance of individual learning, a number of authors have attempted to argue in favour of collective learning. According to the collective view, organizational knowledge is not only stored in the head of individual members within the organization but also in (1) routines, organizational practices, and shared representations and (2) a set of objects and artefacts that affect intra-organizational relations and behaviours (Gavetti et al., 2007). Organizational learning is not simply the sum of each member's learning. Even though all learning takes place inside the human brain, it cannot be abstracted from social influences, and knowledge generated by the individuals does not come to bear on the organization independently of other individuals (Easterby-Smith et al., 2000). It is an intrinsically social and collective phenomena (Teece et al., 1994), and its outcome is deeply linked to the conditions under which it takes place (Powell et al., 1996). Organizations, unlike individuals, develop and maintain learning systems that not only influence their immediate members but are transmitted to others through organizational histories and norms (Fiol and Lyles, 1985). Learning enables organizations to build an organizational understanding and interpretation of their environment and results in associations, cognitive systems, and memories that are developed and shared by members of an organization (Fiol and Lyles, 1985). Dosi and Marengo (2007) summarize the implication of the collective view of learning as follows:

- Organizational learning is linked to changes in organizational practices, but organizational practices are not always correlated to individual knowledge.
- Codification and interaction are the basis for all types of long-lasting organizational learning.
- Instead of seeing organizational learning as purely cognitive, it is much more a process of social adaptation, learning and modifying organizational rules, and developing shared interaction patterns.
- And organizational learning is characterized by path dependencies, whereby initial practices and routines shape and constrain the future activities and learning.

2.1.2 Related Theories

Even though Evolutionary Economics and Organizational Learning are probably the most dominant theory constructs to analyze collaborative activities and innovation at the firm level, by no means are they the only approaches. Previous research has used a variety of alternative theories to investigate similar research topics, including Transaction Cost Theory, Game Theory, and Institutional Theory. However, the most relevant alternative theories in regard to the underlying research question probably include the Resource-Based View of the Firm (Barney, 1991; Wernerfelt, 1984), the Knowledge-Based View of the Firm (Grant, 1996; Kogut and Zander, 1992), and Network Theory (Granovetter, 1985; Gulati, 1998). The Knowledge-Based View of the

Firm has a particularly strong link to Organizational Learning and Evolutionary Economics (Kogut and Zander, 1992). It is also important to mention that these theories are often used simultaneously and in a complementary manner to Evolutionary Economics and Organizational Learning to explain empirical phenomena (Gulati, 1999; Brass et al., 2004; Tsai, 2001).

2.2 Empirical Research on Innovation

The second part of this literature review discusses the empirical research carried out on collaborative activities and innovation with a special focus on high technology industries. As argued in the previous section, distinctions are made between organizational-level and individual-level behaviour.

2.2.1 Organizational Level

To structure the vast amount of research regarding organizational-level collaborations and innovation, the literature is grouped into four areas: (1) research on inter-organizational collaboration at a dyadic level (Strategic Alliances), (2) studies examining organizational networks, (3) research on the absorptive capacity with respect to inter-organizational collaboration or networks, and (4) company-university collaborations as a particularly important example of organizational collaboration with regard to innovation in high tech industries.

2.2.1.1 Inter-organizational Collaboration

Much of recent management literature focus on the learning advantages offered by alliances (Ahuja, 2000; Liebeskind et al., 1996; Shan et al., 1994; Shan et al., 1994). For example, early on Hamel et al. (1989) explained that alliances can be used as part of a learning strategy, and Kogut (1988) argued that alliances are formed because they help transfer tacit knowledge that is not easily transferred in arms-length relationships. Tacit knowledge is more easily transferred in alliances because the latter foster intense personal interaction. Grant and Baden-Fuller (2004) suggest that strategic alliances may be useful not just to acquire knowledge from partners, but also to exploit complementarities or access partner advantages. Thus, alliances may not only serve as a source of knowledge but also enhance the efficiency with which knowledge is applied in the firm. Additionally, alliances provide a platform not only to learn from partners' complementary knowledge, but also to learn about the partner and the knowledge exchange process itself (Inkpen and Dinur, 1998).

Particularly in knowledge intensive industries, such as biotechnology, companies apply strategies that use alliances to acquire knowledge and to keep up with rapid innovations on a number of fronts (Powell et al., 1996). This is because knowledge components and parts are seen as the building blocks for innovation (Fleming, 2001; Galunic and Rodan, 1998). Given the technological and scientific changes taking place in these industries, and given the resource limitations of firms, these organizations may need to follow a broad-based alliance strategy to avoid mediocrity.

One of the first authors in the field, Arora and Gambardella (1990), explored organizational collaboration between firms in the biotechnology industry. They demonstrated that a variety of collaborative formulas are correlated to each other and the authors argue that these collaborations are ways to collect distinct and complementary resources and capabilities. They also argue that the locus of innovation is in the network of inter-organizational relations and not within firms (Arora and Gambardella, 1990). Similar arguments are made by Rothaermel and Deeds (2004) who claim that the relationship between corporate alliances and new product development in the biotechnology field depends on a sequence of explorative and exploitative alliances. The development of a new product (a new drug in this case), begins with explorative alliances which predict the products to be developed. These explorative alliances subsequently predict exploitative alliances which lead to products in the market. Rothaermel and Deeds (2004) also show that this sequential product development process is moderated negatively by firm size. As firms grow, they tend to withdraw from product development and focus more on the discovery, development, and commercialization of potential projects through vertical integration (Rothaermel and Deeds, 2004).

Investigating the relationship between technological alliances and firm performance, Stuart (2000) argues that alliances are “access relationships” and that their advantage depends on the resource profiles of the alliance partners. He shows that firms with large and innovative alliance partners perform better than firms without such types of partners and that particularly young and small firms benefit more from large and innovative strategic alliance partners than old and big organizations (Stuart, 2000). Similarly, Zaheer and George (2004) relate biotech company performance to the fact of their being members of an alliance cluster, but the authors also add a geographical dimension to their investigation. They examine to what extent it matters whether or not firms form alliances with companies within their geographical proximity or if they do better by building alliances beyond their immediate geographical area. Their results suggest that a combination of both drives organizational performance. Being part of regional clusters is not enough; nor is it sufficient for firms to join alliance clusters. Firms gain most by a diversity of relationships within and beyond their geographical network (Zaheer and George, 2004).

Focusing particularly on the effect of collaborations on new and young firms, Stuart et al. (2007) show that a diverse set of up and downstream alliances is particularly important to new and small biotech firms. Firms with multiple in-licensing agreements are more likely to attract alliances with downstream partners; however, the positive relationship between up and downstream links diminishes as firms mature (Stuart et al., 2007).

An interesting issue is the causality between performance and collaboration, since not only can collaboration lead to better performance but, also, firms with high performance can attract more and better alliance partners. This question was central to the early work of Shan et al. (1994) who show that even though both relationships can be hypothesized, empirically, only the direction from collaboration to innovation yields significant results.

2.2.1.2 Inter-organizational Networks

To broaden the understanding of collaboration activities, several studies have extended the dyadic view of collaborations to a more network-based logic and methodology. In one of the most cited studies, Powell et al. (1996) demonstrate that, in fields characterized by rapid technological developments (like biotechnology), the centre of innovation is located within the network of inter-organizational relationships. Similarly, Liebeskind et al. (1996) argue that biotechnology firms rely heavily on a diverse set of network partners. Several authors have started to examine network properties to predict innovation performance (Ahuja, 2000; Schilling and Phelps, 2007). Ahuja (2000) analyses corporate alliance networks and their influence on firm innovation in the chemical industry. He finds that direct and indirect ties have a positive influence on innovation output while structural holes have a negative one. Schilling and Phelps (2007) find that a dense local clustering of firms enables communication and collaboration between companies. Therefore, alliance networks characterized by dense clustering and reach increase the innovative output of firms included in these networks. Looking particularly at the situation of young biotech firms, Baum et al. (2000) show that the number of alliances and their diversity increase the initial performance of start-ups. However, alliances with potential rivals can be harmful depending on the partners' relative scope and innovativeness (Baum et al., 2000).

2.2.1.3 Absorptive Capacity

Most of the previous studies analysed the effect of collaboration independently of organizational factors. However, this results in an incomplete picture because several organizational factors might influence the innovative effect of collaborative activities.

As such, absorptive capacity is probably the most prominent factor investigated in current empirical research.[1]

The term absorptive capacity was coined and popularized by Cohen and Levinthal (1990). They argue theoretically and illustrate empirically that the ability of a firm to recognize, assimilate and apply external knowledge is a function of the firm's prior knowledge base and that the development of this knowledge base is a cumulative and path-dependent process. Subsequently, absorptive capacity has been used in several studies. For example Mowery et al. (1996) show that a firm's ability to absorb capabilities from its alliance partners depends on the relatedness of the firms' respective knowledge bases prior to their alliance. In a later study Mowery et al. (1998) demonstrate that partner selection is also related to absorptive capacity. The authors use patent citations to measure the technological overlap between firms before and after alliance formation to demonstrate partner selection and organizational change processes throughout the alliance.

Drawing on Network Theory and the absorptive capacity concept, Tsai (2001) found that units within a firm improve their innovation performance if they occupy central network positions that provide access to knowledge developed within the firm. However, the positive effect depends on the organizational level of absorptive capacity. Without absorptive capacity firms cannot utilize the gain from their central network position (Tsai, 2001). Veugelers (1997) examines the two-way relationship between external R&D activities and internal R&D expenditures on a cross-section of Flemish

[1] Several other factors are shown to be important and are often used in empirical research, e.g., company age and size (Sorensen and Stuart, 2000; Schumpeter, 1939; Cohen and Klepper, 1996); however, absorptive capacity is the most important factor within the realm of this study.

companies. The author’s analysis boradens classical explanatory variables like size, diversification, ownership structure and technological opportunities to include the impact of various external sourcing strategies. She finds that research collaboration and, to a lesser extent, outsourced research have a significant positive effect on internal research. However, this relationship only holds if the companies have absorptive capacity in the form of a full-time, staffed research department. Simultaneously, the level of firms engaged in research collaborative efforts increases with internal research investments (Veugelers, 1997).

Lane and Lubatkin (1998) criticize the initial conceptualisation of absorptive capacity because it implies that firms have an equal capacity to learn from all other organizations. Therefore, they extend the firm-level construct of absorptive capacity to the dyad-level construct of relative absorptive capacity. They argue that a firm’s ability to learn from another company depends on three points: the similarity of both firms' respective knowledge bases, their organizational structures and compensation policies, and the dominant logics. They show empirically that the similarity of the partners' basic knowledge, lower management formalization, research centralization, compensation practices, and research communities are positively related to inter-organizational learning. Furthermore, relative absorptive capacity shows a greater explanatory power than the previous measure of absorptive capacity (Lane and Lubatkin, 1998). Investigating degrees of similarity between partnering firms' knowledge bases, Sampson (2007) argues that the positive effect of alliances on innovation performance depends on the level of technological diversity between the two partnering companies. Alliances increase firms' innovative performance when technological diversity between partners is moderate, rather than low or high. Even though this relationship holds irrespective of the alliance's organization, the author demonstrates that hierarchical alliance structures (e.g., equity joint ventures) increase the benefits from alliances with high levels of technological diversity (Sampson, 2007).

A very different approach to investigate the different roles of internal and external innovation mechanisms is applied by Almeida et al. (2002). Instead of looking at the effect of internal capabilities on external sourcing, these authors compare both internal and external knowledge transfers. In a sample of patent citations in the semiconductor industry, they show the relative superiority of intra-organizational knowledge transfers as compared to alliances (and markets) in cross-border knowledge-building. Building on a qualitative research study, they highlight the complex interplay between codified and tacit knowledge and the need to use different formal and informal mechanisms to build knowledge successfully across boarders (Almeida et al., 2002).

2.2.1.4 Company-University Collaboration

Corporate–university ventures represent a special type of organizational collaboration. These types of relationships have been analysed in innovation literature, particularly in science and technology-driven sectors. For example, several studies examine which firm characteristics influence the likelihood of engaging in company-university collaborative projects. Analysing Finnish firms, Leiponen (2001) shows that firm size and research skills have a positive effect on collaborations with universities (Leiponen, 2001). In a slightly different context Adams et al. (2000) illustrate that size and research activities influence whether a firm engages in relationships with federal research institutions. Santoro and Chakrabarti (2002) investigate the formation of corporate-university collaboration projects and reveal that particularly large firms from industrial sectors engage in firm-university collaborations to build their competencies in non-core technological areas. In contrast, small firms from high tech industries concentrate more on problem-solving in core technological areas through technology transfers and collaborative research with universities (Santoro and Chakrabarti, 2002). In one of the most methodologically advanced studies in this area, Veugelers and Cassiman (2005) use instrumental variable techniques to isolate the firm's decision to engage in collaborative projects with universities from the company's overall innovation strategy. Their analysis shows that large firms are more likely to be actively involved in industry science links. Additionally, the authors illustrate that these collaborations are used to share costs and are formed when the innovation process is not too risky. Furthermore, the capacity to appropriate returns from the innovation does not explain collaboration activities with universities (Veugelers and Cassiman, 2005).

Looking directly at the benefits of firm-university collaboration Cassiman et al. (2008) analyse the effect of science linkages to innovation performance at the patent level. The authors demonstrate that citations in scientific publications are not the main driver to explain forward citations, but they are positively related to their generality and geographical dispersion. Moreover, Cassiman et al. (2008) illustrate that science linkages at the firm level matter more for forward citations with the exception of emerging technologies. Particularly, non-science related patents which have no scientific linkage are less frequently and less easily cited than comparable patents of firms with science linkages (Cassiman et al., 2008). When looking at the impact of high level scientific output on patents, Gittleman and Kogut (2003) find that publications, collaborations, and science intensity are associated to patented innovations; however, important scientific papers are negatively associated to high-impact innovations. The authors conclude that scientific and marketable innovations follow a different underlying logic and that the direct move from science to patent is more difficult and complex than previously assumed (Gittelman and Kogut, 2003). George et al. (2002a) examine the effect of science linkages on patent variables and show that firms (in the Biotech sector) with university linkages have lower research and development expenses though they have higher levels of innovative output. However, they do not find support for the proposition that companies with university linkages show greater financial performance than similar firms without such linkages (George et al., 2002a).

2.2.2 Individual Level

The role of individual activities was already highlighted in early innovation literature[1] (Crane, 1972; Tushman, 1977; Allen and Cohen, 1969). However, within the last 15 years this topic has received more and more attention (Zucker et al., 2002; Zucker and Darby, 1997; Almeida and Kogut, 1999; Song et al., 2003; Rothaermel and Hess, 2007). This surge might be explained by the development of better databases which enable researchers to investigate on a more precise level. The three main areas discussed subsequently are boundary spanning activities, engineer mobility and the role of "Star Scientists".

[1] As in the previous section, the focus lies on collaborative mechanisms; the internal factors are not discussed in detail.

2.2.2.1 Boundary Spanners

Several of the early studies in this area could be included under the boundary spanning category. For example, Crane (1972) investigated the importance of individuals in creating knowledge bridges across organizations and the 'invisible college of scientists' that helps to diffuse knowledge within scientific communities. Her work is similar to related studies by Tushman (1977) and Allen and Cohen (1969) who argue about the positive effects of 'boundary spanning" activities by certain individuals who are well-connected internally and externally. "Boundary spanning" scientists can use their social ties to develop links to scientists in other firms, universities, and research institutions and thereby act as informal bridges across firm and geographic boundaries.

2.2.2.2 Mobility

A second research stream focusing on the external activities of individuals is work on engineer and scientist mobility as a conduit for inter-firm knowledge flows. For example, Almeida and Kogut (1999) show the importance individuals have for the exchange of knowledge between firms within regions. By analyzing data on the inter-firm mobility of patent-holders, the authors illustrate that the inter-firm mobility of engineers influences the local transfer of knowledge and that the flow of knowledge is embedded in regional labour networks (Almeida and Kogut, 1999). In a related study, Song et al. (2003) examine under what conditions learning-by-hiring is more likely to be successful. Using patent applications from software engineers who moved from US firms to non-US firms, the authors demonstrate that mobility is more likely to result in inter-firm knowledge transfers if the hiring firm is less path dependent, if the hired engineers possess technological expertise distinct from that found in the hiring firm, and if the hired engineers work in non-core technological areas in their new firm. They also demonstrate that domestic mobility and international mobility are similarly beneficial to learning-by-hiring (Song et al., 2003). In a very recent study Corredoira and Rosenkopf (2010) show that not only does the hiring firm gain access to knowledge in the firm from which it hired the employee, but, also, the firm losing the employee is more likely to access knowledge from their former employee's new employer. They find that firms losing employees are more likely to subsequently cite patents from firms hiring their old employees, thus suggesting that mobility-driven knowledge flows are bi-directional. Furthermore, outbound mobility is a particularly relevant knowledge channel between geographically distant firms, but its importance decreases for geographically proximate firms since other knowledge channels exist within regions (Corredoira and Rosenkopf, 2010).

2.2.2.3 Star Scientists

Similarly, though not explicitly, work on "star scientists" in the biotechnology field (and in other industries) makes several references to individual collaboration because these "stars" are often located in universities. In a series of papers, Lynne Zucker and Michael Darby together with other colleagues examine the importance star scientists have for innovation in firms. These stars are seen as a particularly important group of individuals. They show that collaborative activities with star scientists have a significant, positive effect on a wide range of performance measures, e.g., newly generated patents and products (Zucker et al., 1998; Zucker et al., 2002). The location of star scientists also predicts the location of firms which enter into new technology fields (both new and existing firms), as shown in studies on US and Japanese biotechnology firms (Zucker et al., 1998). Additionally, the quality of an academic researcher's scholarly output positively predicts his/her relevance to commercialization, to the number of collaborative projects with firms and the probability that another star will begin working with the firm (Zucker et al., 2002). The relationship between star scientists and innovation performance has also been successfully replicated for the semiconductor industry in the US (Torero et al., 2001).

However, Rothaermel and Hess (2007) argue in a recent study that the positive effect of star scientists on patenting can be primarily attributed to non-star scientists and that star scientists do not have a significant effect on patenting. This is determined when both types of scientists are included in the same regression model (something not done by Zucker and colleagues). However, Rothaermel and Hess argue that the tension can be reconciled by the finding that non-star star scientists fully mediate the effect of star scientists on innovative performance. Baba et al. (2009) obtain similar results in the photo catalysis industry in Japan by differentiating between four types of researchers in company-university collaborative initiatives (Edison, Pasteur, Star and Bohr type scientists). Only research collaborations with "Pasteur type scientists" increase a firms' R&D productivity. Contrarily, collaborations with "Star scientists" have little impact on companies' innovative output (Baba et al., 2009).

An explanation to the at best mixed findings regarding the performance implication of Firm university collaborations of the previous studies is provided by Murry (2002). Similar to others (Gittelman and Kogut, 2003) she argues that the underlying social structures are very different between "science" and "technology, but that both co-evolve and advance. Furthermore, she shows empirically that neither co-publishing nor citation as predicted from current literature drives performance, it is rather the co-mingling through founding, licensing and consulting (Murray, 2002).

2.2.3 Combination of Individual and Organizational Levels

The previous section shows that individual and organizational factors are primarily discussed separately in the literature. However, recent theoretical contributions (Felin and Hesterly, 2007; Hagedoorn, 2006; Brass et al., 2004) argue in favour of the simultaneous research of different organizational levels. All these studies identify two serious problems with the dominant single-level research approach. First, focusing on only one level of analysis implicitly assumes that most of the heterogeneity is located at the level of research, while alternative levels of analysis are considered to be relatively more homogeneous. Second, by focusing on only one level of analysis, researchers implicitly assume that the different levels of analysis are independent of each other. Both assumptions (homogeneity in, and independence of alternative levels of analysis) present serious problems which can lead to spurious empirical findings (Felin and Hesterly, 2007; Rothaermel and Hess, 2007).

A limited number of studies have started to address this issue. In two related papers Lori Rosenkopf and Paul Almeida compare the effect of individual mobility and organizational alliances. Rosenkopf and Almeida (2003) demonstrate how the mobility of inventors and alliances in the semiconductor industry can be used to facilitate inter-firm knowledge flows. The authors find that the usefulness of mobility and alliances increases with technological distance and that mobility specifically increases inter-firm knowledge flows regardless of geographic proximity (Rosenkopf and Almeida, 2003).

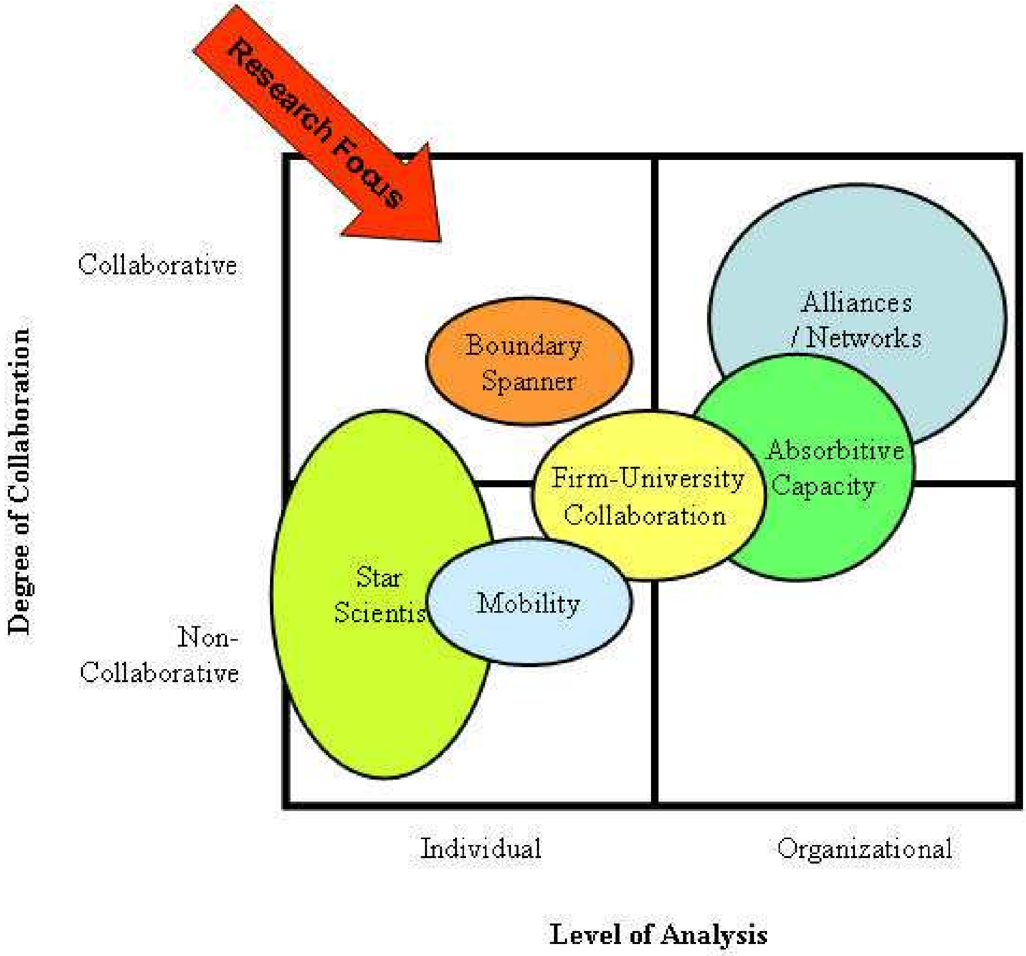
In a related study using a similar dataset, Almeida et al. (2003) show that the effectiveness of external learning increases with start-up sized companies; however, differences exist between formal and informal mechanisms. Firms learn from alliances regardless of their size. However, for more informal mechanisms, like mobility and geographic co-location, learning decreases with firm size (Almeida et al., 2003).

Regardless, even though these two studies compare different levels, they still do not interact them. This is done by Rothaermel and Hess (2007) who simultaneously assess the effects of antecedents at the individual, firm, and network levels on innovation output. First, they look at the direct effect of these different levels and, second, they look at the interaction between the different levels. In general, they find evidence that innovation antecedents can be found across different levels and that they can have compensating or reinforcing effects on firm-level innovative output. The authors show that the individual-level antecedents of innovation are substitutes for firm- and network-level antecedents and that the firm-level and network-level antecedents serve as complements to each other (Rothaermel and Hess, 2007). Rothaermel and Hess (2007), Rosenkopf and Almeida (2003), and Almeida et al. (2003) clearly show that the combined investigation of individual and organizational-level factors is important when attempting to explain innovation within firms.

2.4 Research Gap

The previous literature review represents a summary of the most important studies in the field of inter-organizational collaboration and individual activities with respect to innovation. This review is structured along two dimensions_ (1) the level of analysis (the organizational vs. the individual level) and (2) whether or not an activity is collaborative. The previous literature reviewed can be added to a matrix consisting of both dimensions (Figure 2).

Figure 2: Literature Review: Overview



Compared to the organizational level, only very few studies address the question of individual collaborative activities and their influence on organizational-level innovation, and even less examine collaborative activities with respect to firm-level innovation. For example, though the research on engineer mobility focuses on external individual activities and links it to firm-level outcomes, this does not represent a collaborative activity *per se*. Research on star scientists, for example, often assumes that these researchers are located in external institutions but these studies seldom directly test this assumption in their operationalization. Even if this factor is considered, most studies do not examine the role of non-star scientist collaboration and thereby offer an underspecified model (Rothaermel and Hess, 2007; Zucker et al., 2002). Therefore, the effect of individual collaboration is not isolated. Research on boundary spanners is probably mostly closely related to the direct investigation of individual collaboration. However, it often focuses on the role and characteristics of these boundary spanners (Tushman and Scanlan, 1981), their influence and knowledge diffusion (Tushman, 1977) and less on firm-level performance. Additionally, these studies could be greatly enriched by a more fine-tuned empirical analysis which is now possible due to new databases on innovation related activities.

The study which probably most closely examines individual collaboration and firm-level outcomes with respect to innovation is Cockburn and Henderson's work (1998). These authors analyse the link between for-profit and publicly funded research in pharmaceuticals via the co-authorship of scientific papers between company scientists and publicly funded researchers, demonstrating that these relationships increased the quality of the firm's resulting patents (Cockburn and Henderson, 1998). However, and despite the great contribution of this study, several questions have not been addressed. Besides using a very small sample, the study does not control for several important factors (e.g., star scientists and strategic alliances), and it does not examine any contingencies of individual collaboration. Modern patent and article databases provide access to new data and allow handling previously unmanageable amounts of data. Therefore, the objective of this dissertation is to follow up this initial attempt to explore individual collaboration and further explore the relationships between individual collaborations and firm performance by addressing two related questions:

Research Question 1: *Do individual-level collaborations positively affect firm-level innovation and under what conditions are these collaborations important for the company's innovativeness?*

Research Question 2: *Do individual collaborations across firms (as contrasted with internal collaborations and strategic alliances) encourage firms to innovate in the area of emerging innovation?*

While the first question focuses on the quantitative generation of innovation, the second examines whether the generated innovation is qualitatively different from that produced by other innovation mechanisms. When responding to both questions, it is important to consider the alternative innovation activities identified in the previous literature review, including internal R&D and the role of star scientists and organizational alliances to isolate the affect of individual collaboration. Despite the relatedness of both research questions, they are discussed independently below. This is done for two reasons: First, even though hypothesis development is in line in both cases with the logic found in *"A behaviour theory of the firm"* (Cyert and March, 1963), the first research question draws more on arguments from Organizational Learning Theory while the second from Evolutionary Economics. A separate hypothesis development can better address the relevant theoretical issues at hand. Second, although both questions are focused on the biotech industry, their empirical operationalization requires developing specific variables which require different statistical models. The sequential and independent discussion offered by this methodology ensures a strong link between the theoretical model and empirical testing.

3 RESEARCH QUESTION 1: INDIVIDUAL COLLABORATION AND INNOVATION PERFORMANCE

One way in which a firm can access external knowledge is by engaging in inter-organizational alliances (Inkpen, 1998).[1] Empirical research has confirmed that strategic alliances are an important source of scientific and technological knowledge (Mowery et al., 1996; Powell et al., 1996; Ahuja, 2000) and contribute to firm success (Stuart, 2000). Yet, alliances are difficult to form and manage (Park and Ungson, 2001). Alliances are formal, legal entities that take time to establish and, being costly in terms of managerial time and attention, must be limited in their number, and targeted to specific needs. In an environment where the nature, location, and type of potential knowledge sources are continuously changing, firms need to develop flexible mechanisms of knowledge acquisition. In biotechnology, for instance, given the uncertainty associated with the scientific development process and the applicability and usefulness of knowledge absorbed from any particular target (whether university or firm), it is important that firms have some flexibility in setting up, and potentially dissolving, the inter-organizational mechanisms that facilitate knowledge absorption.

Recent research, both conceptual and empirical, suggests that knowledge flows facilitated by individuals are an important form of firm learning. For instance, research on localized knowledge spillovers shows that individuals play an important role in the

[1] Even though there are several possible benefits to alliance formation including gaining legitimacy or facilitating internationalization, I focus on their role related to knowledge acquisition.

sharing of ideas and information between firms (Saxenian, 1991). The role of the individual in creating knowledge bridges across organizations was highlighted in the early work of Diana Crane (1972) where she described the 'invisible college of scientists' that helped diffuse knowledge within scientific communities. This individual-level exchange of knowledge can be expected to be particularly important in knowledge intensive industries. The focus on the individual as a conduit for inter-firm knowledge flows is also evident from the work on mobile engineers and innovation in semiconductors (Almeida and Kogut, 1999).

In biotechnology, prior research has highlighted the role played by individuals (mostly scientists) in facilitating knowledge flows across organizations. These studies point to a connection between the acquisition of scientific knowledge (sometimes through collaborative activities on papers) and patented innovations. In an important paper, Cockburn and Henderson (1998), examining a sample of ten pharmaceutical firms, found that collaborations between scientists in firms and universities (as indicated by co-authorship of articles) increased the quality of the resultant patents. This finding suggested a link between science and innovation and also pointed to the potential innovative benefits of scientific collaborations. Building on this research, Gittelman and Kogut (2003) showed that, though scientific ideas are not usually inputs to patented innovation, a few scientists can enhance the value of their innovative outputs by drawing upon their scientific knowledge. In another influential study, Zucker *et al.* (2002) focused on the impact of star scientists in the biotechnology industry and examined their impact on innovation performance at the firm level. They found that star scientists affiliated with a firm (including employees, board members, founders and those linked by co-authorship to the firm) enhance the innovativeness of the firm.

Subsequently, Rothaermel and Hess (2007) found that only a very small percentage of researchers can be classified as star scientists (between 0.65% and 1.78%) and they produce about 15% of all articles. The paper went on to examine the role of both star and non-star scientists on firm innovativeness. Though they did not investigate the role of individual collaborations, they looked at individual, firm, and network level effects and found that non-star scientists matter even more than star scientists to firm innovation.

One of the many implications of the prior research is that scientific activity, does not always, but often can influence innovative output and that the intellectual capital of a firm's scientific workforce is an important influence on innovation. Less clear is the relationship between individual-level scientific collaborations and firm-level innovation, since the ability to form and utilize these collaborations is intertwined with factors associated with individual and firm level expertise. It is important to shed more light on these collaborations and their innovative effects since they are so pervasive – about 70% of all scientific articles are co-authored by researchers from different organizations (Gittelman, 2007) – and are potentially powerful knowledge sources. To systematically evaluate whether individual (and often informal) collaborations can matter to a firm's innovative output (critical to success in knowledge intensive industries), it is important to isolate the effects of collaborative activity by accounting for related factors including star scientists, the level of the firm's intellectual capital, R&D investment, non-collaborative publications and strategic alliances.

3.1 Theory and Hypothesis

3.1.1 Individual Collaboration and Innovation

Thus strategic alliances may be one way to access external knowledge (see Literature review), but they are difficult to manage and costly to maintain (Gulati and Singh, 1998). This is especially true for small biotechnology firms that are often constrained in terms of their managerial and financial resources. Further, the potential sources of useful information and knowledge are numerous and scattered and it may not be possible for even large firms to form alliances to access every possible source of relevant knowledge (Pisano, 2002). Most firms form only a limited number of strategic alliances in targeted areas. According to a 2004 study by Rothaermel and Deeds, biotechnology firms formed an average of 8 alliances each over a 25 year period.

Research suggests that an alternative mechanism of knowledge acquisition in biotechnology may be through communities of practice to which scientists belong (Liebeskind et al. 1996). These communities have a strong social dimension (common language and norms) that governs the flow of knowledge between researchers. Scientist's in biotechnology firms can use these social communities to develop links to scientists in other firms, universities, and research institutions. These links act as informal bridges across firm and geographic boundaries (Allen and Cohen, 1969). Biotechnology firms usually grant their scientists a degree of autonomy to engage with members of the scientific community (Powell et al. 1996). Thus, most scientists simultaneously belong to both organizational and scientific communities (Brown and Duguid, 2001) and often facilitate the flow of knowledge between the two. In biotechnology, these communities often give rise to research collaborations of scientists across firm boundaries. The product of these collaborations is often the publication of scientific papers. Why do scientists publish their research arising from individual or collaborative activities? Stephan (1996) points to the importance of 'priority' in scientific discovery suggesting that published papers establish the link between the individual and the discovery. Though organizations may or may not always incentivize their scientists to collaborate across firm boundaries, these collaborations provide individuals (and hence their organizations) with an additional source of knowledge and expertise, and allow insights and access to the knowledge from a wider spectrum (geographically, organizationally, and scientifically) than may otherwise be possible. Cockburn and Henderson (1998) find that in the pharmaceutical industry, 'connectedness' between for-profit firms and publicly funded research increases their performance in drug discovery.

Firms whose employees have engaged in a larger number of collaborations can be seen to have greater access to a common stock of community knowledge that sets the foundation for further knowledge development. These individual collaborations can be expected to enhance in-house innovative capabilities along developing technological or scientific trajectories, help monitor collaborative R&D processes elsewhere, and point the firm in the direction of future scientific research.

Hypothesis 1: The innovative output of biotechnology firms increases with the total number of individual-level collaborations of the firm.

3.1.2 Individual Collaborations and Technological Alliances

The idea that alliances can lead to inter-firm learning is well documented in the strategic management literature. Hamel, Doz and Prahalad (1989) explained that alliances can be used as part of a learning strategy. Subsequently, empirical and conceptual studies have supported this idea (Inkpen, 2000; Dussauge et al. 2000; Lyles and Salk, 1996). For example, Rosenkopf and Almeida (2003) and Mowery *et al.* (1996) use patent data to show that alliances facilitate inter-firm knowledge flows. Grant and Baden-Fuller (2004) suggest that strategic alliances may be useful not just for acquiring knowledge from partners but also for exploiting complementarities or accessing partners' advantages. Thus, alliances may not only serve as a source of knowledge but also as a way to enhance the efficiency with which knowledge is applied within a firm. In biotechnology, it can be argued that strategic alliances are extremely important to the innovative processes of a firm. Given the rate of change in the industry and the resource limitations of most stand-alone biotechnology firms, biotechnology firms appear to follow strategies that use external alliances for knowledge acquisition to keep up with rapid changes in technology on a number of fronts as well as to access partners' capabilities (Powell et al. 1996). Rothaermel and Deeds (2004) suggest that in biotechnology, alliances can play the role of enhancing exploration and exploitation[1] (the emphasis changes to the latter with increases in firm size). Baum *et al.* (2000) looked at strategic alliances formed by biotechnology start-ups in Canada and find that alliances provide early access to information and enhance innovative performance.

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[1] I focus on strategic alliances linked to R&D and production activities since the emphasis is on product or process innovation.

The previous hypothesised that individual collaborations enhance the innovative output of the firm leads to questions regarding the relative roles that individual collaborations and strategic alliances play with respect to firm innovativeness. One line of argumentation could be that the two types of collaborative activities act as complements. The informal collaboration of scientists across organizations could serve to enhance the formation and exploitation of formal strategic alliances or vice versa. Stuart *et al.* (2007) find that, for biotechnology firms, the external networks of scientists of a firm facilitate the organizations' ability to identify and absorb university research. Scientists' connections within the research community permit them to evaluate the quality and potential fit of research conducted in other organizations and hence allow them to play a key role in evaluating biotechnology firms as potential alliance partners (Liebeskind et al. 1996). The trust and understanding (Zaheer et al. 1998; Brass et al. 2004) built through informal collaborations could also enhance the management of these alliances making them more useful as knowledge sharing mechanisms. Further, individual collaborations could help a firm's scientists scan and search the market of ideas and technologies beyond the firm's reach and this knowledge combined with the knowledge sourced through strategic alliances[1] could enhance the innovativeness of the firm. Rosenkopf and Almeida (2003) show that firms use informal means such as hiring of experts to fill gaps in their knowledge base. Perhaps informal collaborations could be used to complement the knowledge base acquired by more formal means.

An opposing argument could be that firms may not be able to effectively employ two very different mechanisms for external sourcing, as they are dependent on

[1] Since the focus is on technological alliances, I use the terms strategic alliances and technological alliances interchangeably.

fundamentally distinct organizational capabilities and routines. Various organizational attributes (structure, systems, processes, culture and leadership) may align the organization more towards formal (strategic alliances) or informal (individual collaborations) forms of learning. After all, individual collaborations rise out of scientific communities that are characterized by unique norms and rules that are very different from those that lead to the formation of strategic alliances between firms (Gittelman and Kogut, 2003). By concentrating on one learning mechanism, firms build competences in one area and lose the ability to benefit from alternative forms of learning (Levitt and March, 1988). Proficiency in one innovation mechanism could impede them from developing expertise in alternative ones and therefore create competency traps (Levinthal and March, 1993). These arguments suggest that strategic alliances and individual collaborations may not play complementary roles and may in fact have a negative joint effect on firm innovativeness. Given the arguments, two competing hypotheses regarding the relationship between strategic alliances and individual collaborations are developed.

Hypothesis 2a: The impact of individual-level collaborations on innovative output of the firm increases with the number of technological alliances of the firm.

Hypothesis 2b: The impact of individual-level collaborations on innovative output of the firm decreases with the number of technological alliances of the firm.

3.1.3 Individual Collaborations and Regions

The father of neo-classical economics, Alfred Marshall (1920), explained the agglomeration of firms in geographical space, in part, by the presence of the 'atmosphere' of knowledge'. He suggested that firms are drawn to knowledge-rich regions and this clustering, in turn, increases the knowledge intensity of the region. More recently, case studies of regional clusters in Italy (Karim and Mitchell, 2000), Baden-Wuerttemberg in Germany (Herrigel, 1993) and Silicon Valley in the US (Saxenian, 1991) describe extensive intra-regional knowledge flows. In their seminal paper Jaffe et al. (1993) use patent citation data to show that knowledge tends to remain localized within geographic regions. Saxenian (1991) relates the dynamism of regions to the extensive networking and knowledge sharing both at the organizational level (between firms, universities, buyers, suppliers, and venture capitalists) and the individual level within the region. In general, locational proximity reduces the cost and increases the frequency of personal contacts, which serves to build social relationships between players in the region. A common thread amongst these studies is that individuals belonging to different institutions interact with each other locally in meaningful ways and hence enhance the flow of productive knowledge across regional organizations.

Social interaction between professionals in a region may lead to formal and informal collaborative activity across regional organizations and may also enhance the quality of these collaborations. The importance of proximity to inter-organizational collaborative activity is highlighted by Mansfield and Lee (1996). They find that the smaller the distance between a firm and university, the greater is the probability that the firm and the individuals therein will support R&D at the university. The study suggests that firms are relatively indifferent to the quality or prestige of the faculty when they fund university research in applied fields, so long as the university is located close to the firm. The importance of location to collaborative activity is not just relevant at the firm level but at the individual level as well. Gittelman (2007) shows that probability that scientists would engage in collaborations on scientific articles, decreases with geographic distance. The preponderance of collaborations that are regional may be explained by the fact that co-location helps with the frequent exchange of sensitive and often tacit knowledge (Maskell and Malmberg, 1999).

Co-location could have a secondary benefit for collaborations – it could help regional scientists identify potential partners. Only individuals who are aware of the current and future knowledge trends will be able to select the most valuable partners. Being located in knowledge intensive regions exposes firms to a larger pool of potential partner and increases the likelihood of finding a partner that best fits their needs. Belonging to a knowledge intensive region also serves to increase the legitimacy and reputation of a scientist to potential partners. For example, Cohen and Fields (1999) commented that Silicon Valley's reputation as a center of high-technology research and development attracts a broad variety of human and financial investment. Since one of the strongest advantages of regional clusters is that they permit a higher level of trust between individual players and build personal ties that facilitate the flow of tacit knowledge, being located in a knowledge-intensive region is likely to make collaborative activity more efficient. These arguments suggest that co-location in knowledge rich regions provides scientists with two collaborative advantages – first, the individuals are more likely to find quality research partners and second, the quality of the collaboration will be enhanced by local proximity.

Hypothesis 3: The impact of individual-level collaborations on innovative output of the firm increase with the strength of the regional knowledge.

3.1.4 Individual Collaborations and Universities

Public science (emanating from government laboratories, universities, and non-profit research centers) play an important role in the development of scientific expertise in the life sciences. Narin et al.(1997) find that 73% of the scientific papers cited by US industrial patents are from public science sources. For biotechnology, firms depend on public science for basic scientific research and concentrate more on applications of this science (MacMillan et. al., 2002). Not surprisingly, the emergence of the biotechnology sector was fostered, in part, by the close linkages between start-up firms and universities (Owen-Smith et al. 2002). Many biotechnology firms were founded by scientists from local universities and consequently, are located in close proximity of these universities and research institutions. The association between universities and firms does not stop there. Founders keep in close contact with universities via research collaboration and sponsorship of research centers. It is not uncommon, in the biotechnology sector, for university professors to move to research positions in firms or even hold simultaneous positions in both a university and a firm (Cockburn and Henderson, 1998). Hence, collaborations of scientists in biotechnology firms often take place with scientists from universities.

Why are university researchers such attractive partners of scientists based in firms? First, companies with university linkages have lower research and development expenses (than those without these linkages) and yet have higher levels of innovative output (George et al. 2002b). Second, research carried out within universities is often complementary in nature to that in firms. Universities often focus on more risky, early stage research with uncertain commercial value. Firms, and the scientists working for them, are not incentivized to do so. Collaborating with universities is therefore one way of accessing knowledge on emerging technologies and scientific discoveries. Third, collaborating with university researchers is less risky than allying with scientists in competing firms. Though universities may take part in the commercialization of their research, the academic culture and incentives follow a very different logic than firms, and universities are not seen as competitive or intellectual threats to firms. Finally, since the publication of scientific papers offers both the individual and the firm enhanced prestige, scientists in firms are often encouraged, directly and indirectly, to collaborate with their counterparts in universities (Powell et al. 1996). The knowledge gained from scientific collaborations impacts not just the individual's productivity but can be passed on to others in the organization and can enhance the value of the firm's innovative processes.

Hypothesis 4: The innovative output of biotechnology firms increases with the total number of individual-level collaborations with universities.

3.2 Methodology

3.2.1 Sample

The sample consists of publicly traded, stand-alone biotechnology firms from the US and Europe for the years 1990 to 2003. The BioScan database is used to select the firms.

BioScan is an independent industry directory that provides a comprehensive range of company information (e.g. ownership, location, products, alliances, mergers and acquisitions) and is used frequently for research purposes.[1] Additional biotechnology directories (EuropaBio and BioCom) were consulted [2] to validate the sample. Private firms, biotechnology divisions of large pharmaceutical companies, and research institutes are not included in the sample, because of lack of availability of comparable data. Due to the different underlying business logics and technological foundations, biotechnology firm specializing in services and agro-environmental biotechnology are also excluded from the sample. Despite focusing only upon publicly traded biotechnology firms, the sample is quite representative of the industry for the following reasons. First, within the biotechnology industry, firms often become public when they are small and young. Second, since financial reports provide company information for up to three years before they go public, it is possible to incorporate data from firms when they were still private. Therefore, sample allows including firms in their early stages of development. The final sample includes 115 US firm and 34 European firms. [3]

3.2.2 Dependent Variables

The dependent variable - innovative output - is measured as the number of patent families per firm per year. In the biotechnology industry, patents are considered strong indicators of innovative performance both within the industry and by academics because they are highly correlated with other performance measures, such as new product

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[1] For example, Gittelman and Kogut (2003), Rothaermel and Hess, (2007), Zucker *et al.* (2002), Shan *et al.* (1994)

[2] BIOCOM is the largest regional life science association in the world, representing more than 575 member companies in Southern California. EuropaBio is the European Association for Bioindustries.

[3] The sample might appear small in comparison to the number of firms in the industry. However, the sample size is similar to that used in comparable studies (Rothhaermel and Hess, 2007).

development, profitability, and market value (Cockburn and Henderson, 1998) and are commonly used as measures of innovative output (Ahuja, 2000; Ahuja and Katila, 2001; Stuart, 2000; Rothaermel and Hess, 2007).

One of the challenges of looking at innovation using patent data is that patenting systems differ across countries and it is therefore difficult to combine patent information from different countries. Since one innovation can lead to several patents in the same country or across countries, it is challenging to accurately estimate firm innovative output. To deal with this issue, innovation are measured by looking at patent families (rather then individual patents) as provided by the Derwent Innovation Index database.[1] A patent family is a group of patents filed by the same assignee(s) based on the claim of an original or priority patent. It includes the original patent and every subsequent patent based on the original. A patent family may include multiple applications from several countries, since there are differences in national regulations defining the breadth of intellectual property (Michel and Bettels, 2001). The use of patent families allows to consolidate patent information across the US and Europe, reduces the noise in the patent data, and therefore increases the accuracy of the measurement of innovation.[2]

[1] DWI provides access to a comprehensive database of international patent information including more than 20 million patent documents from 41 worldwide patent-issuing authorities including USA, France, Germany, UK, Japan, Australia and Spain. This database has been used in other studies particularly those focusing on patent family investigations (Lanjouw and Schankerman, 2004; Harhoff et al. 2003).
[2] For a detailed description of patent family methodologies please see Dernis and Kahn (2004).

3.2.3 Independent Variables

The number of strategic alliances formed by each biotechnology firm between the years 1990 and 2002 is obtained from the BioScan database. BioScan provides detailed information of firm alliance activity including the name of partners, month and year of the collaboration announcement, and the functional area of the collaboration (e.g. R&D, manufacturing, marketing, clinical trails, distribution, among others). Strategic alliances are coded into two categories - upstream or technology oriented alliances (including basic research and drug discovery), and downstream or market oriented alliances (including those dealing with marketing, sales and distribution). To verify the coding procedure, a biotechnology expert independently coded a randomly selected subsample (15%) of alliances. The inter-rater reliability was 0.92 - well above the conventional cut-off point of 0.70. Of the 804 alliances in the sample 639 (79.5%) are R&D or manufacturing oriented and 165 (20.5%) are marketing oriented. Since only a few firms form more than two alliances in any given year, Marketing Alliances and Technological Alliances are included as dummy variables.

Individual Collaborations are captured by the extent to which a firm's researchers engage in collaborative research with scientists from other institutions and is measured as the total number of articles (in scientific journals) co-authored by employees of the focal firm with employees of another organization. Publications are frequently used to capture the scientific activities of individuals (Cockburn and Henderson, 1998; Gittelman and Kogut, 2003) and are seen as reliable sources of information since they are subject to the critical review of colleagues and have gained approval in a peer review process.[1] Co-authorship typically entails face-to-face interaction, including extensive discussions, exchange of ideas and joint problems solving, and represents a considerable investment for the participants.

The ISI Web of Science (ISI) is used to identify every publication authored by any employee (identified by the institutional affiliation of the author) of the sample firms from the period 1990 to 2002[2]. Every journal within the ISI is considered as a potential source of publication. Any restriction that limits the number of journals or fields could lead to a selection bias, since the biotechnology industry is not clearly defined - it spans several scientific and technological areas including human and veterinarian medicine, biology, physics, chemistry, and informatics. Every article is examined for co-authors with other institutions (firms, universities, government agencies, and hospitals). After ensuring that the co-authors' affiliated institution was not a subsidiary of the sample firm, each co-authored article is counted as an individual collaboration in the year of the publication.[3]

The total number of publications by a firm's employees is an indication of the scientific quality of the firm. However, the primary interest is in the collaborative activity of scientists. In order to distinguish between the effect of general publication activity and that of collaborative publications, the number of Non-Collaborative Publications is included in the model. These publications are articles produced by researchers from a firm that are not co-authored by scientists from any other organization. Using this

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[1] For more detailed information on the validity of author patterns in biotechnology, please see Rothaermel and Hess (2007).
[2] The SCI database records details of authors, sources, keywords, and other information relating to the article as well as the bibliographic references and is frequently used for research of bibliometric data.
[3] This procedure is very similar to Cockburn and Henderson (1998).

approach, approximately 24,000 collaborative articles and 8,500 non-collaborative articles were identified.

3.2.4 Control Variables

Several control variables were included to account for field effects and heterogeneity in the sample.[1] An important control in any study of innovation is R&D Investment by the focal firm. This is variable measured as the total R&D spending by each firm for the given year. Firm size has been shown to impact firm success in numerous previous studies (Cohen and Klepper, 1996; Rosenkopf and Almeida, 2003). Firm Size is measured as the mean number of firm employees in a given year. Sales and total assets data was also collected for all firms, but the number of employees is the best indicator of size in the biotechnology industry. Sales represent a poor measure of size as many small biotechnology firms do not have positive revenue streams (or have very volatile ones). Total assets, too, is not an ideal measure, because most valuable assets are intangible ones and are not captured by accounting variables.

In addition to controlling for the total number of employees, it is important to incorporate a measure of the intellectual strength and research quality of the scientific workforce. The quality of scientific research of a firm can be measured by the number of citations to the articles produced. Therefore, the control Intellectual Capital is included in the model. It measured the average number of article citations per year for each firm. Since older articles have a greater opportunity to be cited than recent ones, the citation count is standardized by the number of years for which the articles could be

[1] I used Datastream as a source of firm information and checked this information using annual reports.

cited. Since acquisitions can be used as a mode of accessing external knowledge (Vermeulen and Barkema, 2001), a Acquisitions dummy is include in cased the focal firm acquired another biotechnology firm in a given year.

Prior research has emphasized the role that star scientists play in innovation (Zucker et al. 2002; Zucker et al. 1998). I control for the number of Star Scientists for each firm in a given year. I followed the approach employed by Rothaermel and Hess (2007) to identify star scientists. I first identified every author of a published biotechnology article - the average article had 6.5 authors and was cited 38.3 times. Based on this information, I counted the number of citations received per researcher and defined star scientists as those scientists whose total number of citations were more than three standard deviations above the mean. I use the number of citations instead of the number of publications, because they are a better indicator of the quality. To improve the measure, I also made adjustments for the number of authors per article (since in biology articles often have a large number of co-authors). This procedure led to the identification of 906 star scientists (1.04% of the total). These scientists were involved in 30.9% of all publications and accounted for 30.8% of all citations.

The extent of regional knowledge spillovers is related to the total knowledge created in the region (Tallman and Phene, 2007). I measured Regional Knowledge by the total number of biotechnology patents developed in each region in the year. Regions were defined as countries in Europe and as states within the US. I standardized these values so that the value '1' represents the region richest in biotechnology knowledge and '0' represents the region with the least knowledge. Finally, in order to control for the increase of patent activity in biotechnology during the last two decades (Powell and

Snellman, 2004) and other time varying factors that affect all firms alike (e.g. macroeconomic conditions and external shocks), I controlled for temporal effects. In a first step, I included year dummies in the analysis. However, since the time effects turned out to be linear, I used a single time variable instead.

3.2.5 Model Specification

The patent measure is a non-negative count variable which can be estimated by a poison or negative binomial regression. Since negative binomial regression models have the advantage that they account for an omitted variable bias, while simultaneously estimating heterogeneity (Cameron and Trivedi, 1998) It is used instead of the poison regression. In order to verify the model selection I performed the likelihood-ratio test (of alpha) to compare the results of the negative binomial model to the poisson model. The test shows the appropriateness of the negative binomial model ($P > 0.01$). Since the data had an excessive number of zero values, I also assessed suitability of using a zero-inflated negative binomial model. However, the Vuong statistic, Akaike's information criterion (AIC), and Bayesian information criterion (BIC) did not indicate an advantage to using this type of model. I used a fixed effect specification to control for unobserved firm heterogeneity (Green, 2003). The Hausman test indicated that the fixed effects model is appropriate.

To account for the non-normal distribution of R&D expenses, publication activity, and firm size, I normalized these variables using a logarithmic scale. To ease the interpretation of the results and to reduce potential co-linearity, the variables were mean-centered. Additionally, to control for potential simultaneity bias and to enhance any causality claims, all variables were lagged by two years.[1]

3.3 Results

3.3.1 Descriptive Statistics

Figure 1 presents the descriptive statistics. The data reveal strong heterogeneity across firms. For example, the biggest firm in the sample has more then 10,000 employees whereas the smallest firm employs only 4 people. As expected the data show that individual collaborations are more numerous than strategic alliances and that firms engage in more technological alliances then marketing ones. On average a firm engages in one technological alliance every two years and one marketing alliance every 7 years.[2] In comparison, each firm engages in an average of 13 individual collaborations per year. In the case of individual collaborations, approximately nine out of ten (93.5%) partners are located in universities, hospitals, or research laboratories. The opposite is true for strategic alliances where only about one in eight partners (13.1%) is a university, hospital, or research laboratory.

[1] I also used lags of one, three and four years, but the results remained stable.
[2] This number is based on the actual alliance average and not on the dummies.

Figure 3: Descriptive Statistics

Variable	Mean	St.Dev.	Min	Max
Regional Knolwedge	0,444	0,367	0,000	1,000
Intellectual Capital	3,476	10,236	0,000	180,929
Star Scientist	5,579	19,428	0,000	257,000
Temporal Effects	8,503	2,888	0,000	12,000
Acquisitions	0,073	0,260	0,000	1,000
R&D investments (Ln)	9,727	1,403	0,000	13,926
Firm Size (Ln)	5,118	1,314	1,386	9,220
Marketing Alliances	0,082	0,274	0,000	1,000
Technology Alliances	0,254	0,435	0,000	1,000
Total Firm Publication (Ln)	1,734	1,454	0,000	5,991
Non Collaborative Publication (Ln)	0,808	1,033	0,000	4,477
Individual Collaboration (Ln)	1,554	1,382	0,000	5,775
Ind. Collaboration Firms (Ln)	1,158	1,231	0,000	4,997
Ind. Collaboration Univ. (Ln)	1,766	1,581	0,000	6,394

Figure 2 presents the correlation matrix. Most correlations are at a moderate level with the exception of the publication variables. However, not all the publication variables are enter in the same regression model. For example, Total Publications is not used together with Individual Collaborations or Non-collaborative Publications. [1]

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[1] I also examined the correlation matrix of the parameters of the model as obtained from the estimation procedure. This matrix fully determines the Variance Inflation Factor and other collinearity measures in linear regressions. All correlations between the parameters were at acceptable levels indicating that the correlations did not bias the results.

Figure 4: Correlation Matrix

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Regional Knolwedge	1,00													
2	Intellectual Capital	0,09	1,00												
3	Star Scientist	0,24	0,22	1,00											
4	Temporal Effects	-0,03	-0,40	-0,07	1,00										
5	Acquisitions	0,09	0,00	0,08	0,02	1,00									
6	R&D investments (Ln)	0,28	0,09	0,39	0,18	0,21	1,00								
7	Firm Size (Ln)	0,11	0,10	0,35	0,09	0,29	0,66	1,00							
8	Marketing Alliances	0,03	-0,01	0,11	-0,08	0,10	0,15	0,16	1,00						
9	Technology Alliances	0,08	0,09	0,18	-0,04	0,11	0,31	0,22	0,26	1,00					
10	Total Firm Publication (Ln)	0,19	0,25	0,53	0,04	0,16	0,54	0,43	0,13	0,30	1,00				
11	Non Collaborative Publication (Ln)	0,29	0,13	0,53	0,04	0,16	0,53	0,43	0,13	0,27	0,84	1,00			
12	Individual Collaboration (Ln)	0,17	0,27	0,55	0,01	0,17	0,54	0,43	0,13	0,29	0,98	0,76	1,00		
13	Ind. Collaboration Firms (Ln)	0,23	0,24	0,54	0,00	0,18	0,55	0,48	0,13	0,25	0,89	0,72	0,91	1,00	
14	Ind. Collaboration Univ. (Ln)	0,16	0,24	0,52	0,07	0,17	0,53	0,42	0,13	0,28	0,94	0,71	0,97	0,88	1,00

3.3.2 Regression Results

Figure 3 presents the first set of regression results. In model 1, a baseline model only including the control variables is estimated. Intellectual Capital, Temporal Effects, Firm Size, Star Scientists and Acquisitions have a positive influence on innovative output. Surprisingly R&D Investment does not impact innovative performance. This result may be driven by the fact that the time-invariant differences across firms are absorbed by the firm fixed effects and some part of the time variant differences is picked up by the Temporal Effects variable.

Figure 5: Fixed Effect Negative Binomial Regression I

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Intelectual Capital	0,004 **	0,004 **	0,004 **	0,004 *	0,003
	(0,002)	(0,002)	(0,002)	(0,002)	(0,002)
Star Scientists	0,003 **	0,003 **	0,002	0,002 *	0,003 **
	(0,001)	(0,001)	(0,001)	(0,001)	(0,001)
Temporal Effects	0,071 ***	0,074 ***	0,072 ***	0,074 ***	0,075 ***
	(0,013)	(0,013)	(0,012)	(0,012)	(0,012)
Acquisitions	0,133 *	0,122 *	0,108	0,108	0,114
	(0,074)	(0,074)	(0,073)	(0,073)	(0,074)
R&D Investments (Ln)	0,031	0,022	-0,004	0,001	0,020
	(0,048)	(0,048)	(0,048)	(0,049)	(0,048)
Firm Size (Ln)	0,206 ***	0,205 ***	0,195 ***	0,193 ***	0,195 ***
	(0,058)	(0,058)	(0,057)	(0,057)	(0,057)
Marketing Alliances		0,084	0,080	0,090	0,100
		(0,074)	(0,073)	(0,073)	(0,073)
Technology Alliances		0,105 **	0,084	0,089 *	0,099 *
		(0,052)	(0,052)	(0,052)	(0,052)
Total Firm Publication (Ln)			0,104 ***		
			(0,035)		
Non Collaboative Publication (Ln)				-0,041	
				(0,043)	
Individual Collaboration (Ln)				0,123 ***	
				(0,040)	
(Individual Collaboration/Non Collaborative Publicaton) (Ln)					0,139 ***
					(0,047)
Constant	-0,727 **	-0,679 **	-0,548 *	-0,575 *	-0,779 **
	(0,323)	(0,321)	(0,321)	(0,325)	(0,324)
AIC	34158	34155	34148	34149	34149
BIC	34192	34199	34197	34203	34197
N	971	971	971	971	971
log likelihood	-2072	-2069	-2064	-2064	-2064

p>0.1*; p>0.05**; p>0.01***
Standard Errors in brackets

Next I tested for the positive effect of technological alliances on innovation (Model 2). In this model I also included marketing alliances as a control. The variable Technological Alliances has a positive but weakly significant impact on innovation whereas Marketing Alliances is not significant. In model 3, the impact of Total Firm Publications examined the. As expected this variable is positive and strongly significant. Model 4 splits publication activity into non-collaborative publications and collaborative publications (or Individual Collaborations). Supporting Hypothesis 1, Individual

Collaborations has a strong positive influence on patented innovative output ($p<0.01$). The number of non-collaborative publications does not impact patenting. In order to further explore the relationship between the non-collaborative and collaborative publications, I replaced these variables in Model 5 with a ratio of the two.[1] Model 5 shows a positive and significant effect for the ratio suggesting that as firms emphasize publishing scientific articles through collaboration (as opposed to independently), their innovative output increases. These results show that even after controlling for the quality of a firm's scientists (Star Scientists and Intellectual Capital), non-collaborative publication activity, strategic alliances (both technology an market), and R&D - variables that previous research has suggested may impact innovative output - the extent to which a firm's scientists collaborate on articles positively influences innovative performance.

Model 6 explores the interaction between the two collaborative modes studied - Individual Collaboration and Technological Alliances. The interaction term is not significant. Two competing arguments and hypotheses for the interaction term's effect on innovation performance were proposed, but both are not supported. Neither the argument on the complementarity of the two collaborative modes, nor the argument regarding different organizational capabilities is supported. I next look at the relationship between regional knowledge spillovers and individual collaboration (Model 7). The interaction variable is positive and significant ($p<01$) - Hypothesis 3 is supported.[2] In knowledge rich regions, the effect of collaborations on innovation is

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[1] The ratio was calculated as "ln (number of collaborative publications/non-collaborative publication)"
[2] It is important to remember that Regional Knowledge is a time-invariant variable that can not be included as a main effect in fixed effect regression models. However, time-invariant variables can be used for interaction effects in fixed effect models. This is also in line with the theoretical claim; I am interested

enhanced. The results for the interaction terms also hold for the fully specified model (model 8).

To test Hypothesis 4, I distinguished between the influences of collaborative publications with universities and those with firms. Model 9 shows that, as expected, only collaborations with universities has a positive and significant influence on innovation performance ($p<0.05$). Similar to the analysis of individual collaborative and non-collaborative publications, I use a ratio of university to firm publications to verify the results. The ratio variable does not support the findings of the individual effects (model 10). I therefore get partial support for the idea that collaborations with universities are more useful than collaborations with other firms.

in the joint effect of regional knowledge spillovers and individual collaborations on innovation performance and not on the direct effect, which is covered by the firm fixed effects.

Figure 6: Fixed Effect Negative Binomial Regression II

Variables	Model 6	Model 7	Model 8	Model 9	Model 10
Intelectual Capital	0,004 *	0,004 **	0,004 **	0,004 *	0,004 *
	(0,002)	(0,002)	(0,002)	(0,002)	(0,002)
Star Scientists	0,002 *	0,001	0,001	0,002 *	0,002 *
	(0,001)	(0,001)	(0,001)	(0,001)	(0,001)
Temporal Effects	0,073 ***	0,078 ***	0,077	0,069 ***	0,073 ***
	(0,012)	(0,012)	(0,012)	(0,013)	(0,012)
Acquisitions	0,108	0,101	0,104	0,112	0,106
	(0,073)	(0,072)	(0,072)	(0,073)	(0,073)
R&D Investments (Ln)	0,001	0,018	0,018	0,010	0,000
	(0,049)	(0,049)	(0,049)	(0,049)	(0,049)
Firm Size (Ln)	0,193 ***	0,155 ***	0,156 ***	0,194 ***	0,193 ***
	(0,057)	(0,058)	(0,058)	(0,058)	(0,057)
Marketing Alliances	0,092	0,091	0,096	0,087	0,092
	(0,074)	(0,071)	(0,072)	(0,073)	(0,072)
Technology Alliances	0,093	0,089 *	0,103 *	0,091 *	0,083
	(0,061)	(0,051)	(0,061)	(0,052)	(0,052)
Total Firm Publication (Ln)					
Non Collaboative Publication (Ln)	-0,041	-0,051	-0,052	-0,026	0,091 **
	(0,043)	(0,043)	(0,043)	(0,042)	(0,047)
Individual Collaboration (Ln)	0,125 ***	0,121 ***	0,125 ***		
	(0,041)	(0,040)	(0,041)		
(Individual Collaboration/Non Collaborative Publicaton) (Ln)					0,192 ***
					(0,057)
Technology Alliances x Individual Collaboration	-0,004		-0,013		
	(0,033)		(0,032)		
Regional Knowledge x Individual Collaboration		0,225 ***	0,230 ***		
		(0,086)	(0,087)		
Ind. Collaboration Firms (Ln)				0,006	
				(0,044)	
Ind. Collaboration Univ.(Ln)				0,081 **	
				(0,039)	
(Ind. Collaboration Univ./Ind. Collaboration Firms)(Ln)					0,019
					(0,038)
Constant	-0,577 *	-0,574 *	-0,585 *	-0,602 *	-0,710 **
	(0,326)	(0,325)	(0,327)	(0,327)	(0,323)
AIC	34151	34145	34146	34154	34148
BIC	34210	34203	34210	34212	34206
N	971	971	971	971	971
log likelihood	-2064	-2060	-2060	-2065	-2062

p>0.1*; p>0.05**; p>0.01***

Standard Errors in brackets

3.3.3 Robustness Checks

Stuart *et al.* (2007) showed that external scientific relationships can lead to more up-stream alliances. To evaluate the relationship between strategic alliances and individual scientific collaborations, I analyze the extent to which alliances lead to individual collaborations and vice-versa. To do this, I examined how many firms are linked to the same partner via both collaborative modes. Of the 14,482 inter-organizational linkages identified for individual collaborations, only 167 are also linked by strategic alliances (out of 804 alliances). This minimal overlap suggests that individual collaborations and strategic alliances are formed independently of each other. It also does not point to any relationship in the knowledge generation process for the two types of collaboration. Further, I examined whether the overlapping collaborations are the main drivers of innovation output by running a separate regression model excluding the overlapping collaborations from the sample. There are no substantial changes to the results indicating that overlapping collaborations did not drive the findings.

3.3.4 Field Research

To better understand the influence of individual collaborations on innovation and to check some of the underlying assumptions of the model, I conducted semi-structured phone interviews (of about 45 minutes) with 10 senior scientific officers from firms in the sample (2 European and 8 US firms). Every interviewee had a Ph.D. and three had previously had held leading positions in university laboratories. [1]

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[1] The interviews are not intended to formally test the ideas and measures, but are rather a tool to better understand and interpret the findings.

The interviews confirmed the fact that individual collaborations are indeed an important part of the research process of biotechnology firms. When researchers need additional insights or knowledge inputs in areas they are investigating, they identify potential collaborators based on their personal and professional networks or simply based on an internet search. As one researcher put it, they 'go down the list' until a suitable collaborator is found. The researchers in biotechnology firms and their academic partners have differing motivations for collaboration. For researchers within firms, these collaborations are usually targeted to fill a particular knowledge gap that emerges during the research process. While the immediate motivation for collaboration may be to successfully conduct research that leads to patentable inventions, this activity often leads to co-authored publications as well. This may explain why such a large percentage of publications in scientific journals have co-authors from different organizations. Small firms, particularly, use publications to gain legitimacy in the scientific and investment community. For university researchers, individual collaborations with firms are a source of funding, tools, and knowledge.

The interviewees suggested that firms need both individual collaborations and strategic alliances to enhance their knowledge. They also highlight differences between the two. Individual collaborations are strongly rooted in the scientific community whereas strategic alliances are often driven by non-scientific managers. Furthermore, researchers acknowledge that individual collaborations, usually with academic researchers, stand in contrast to strategic alliances that are organizational in nature. Individual collaborations are much more informal in nature and are usually and managed and initiated by an individual. Individual collaborations are based on personal relationships between researchers, whereas strategic alliances are more formal in nature and are planned and executed within the organizational bureaucracy. Individual collaborations are formed and managed based on the characteristics and knowledge of the individual researchers, while strategic alliances are based on broader organizational characteristics and capabilities. From the point of view of a scientist, the time and cost in building and maintaining strategic alliances often makes them unattractive. Scientists perceive individual collaborations to be faster and more flexible and hence they engage in them more actively.

One criticism of studies using patent and bibliometric data is that they do not appropriately capture innovative activity of firms. However, the interviewees confirm the belief that the use of both sets of data is appropriate for the sample of biotechnology firms. Firms need to patent and publish scientific articles to protect their intellectual property and gain legitimacy. Particularly for small biotechnology companies that often have no products and markets, patents are a good indicator of innovative output, and are often used by potential investors to gauge the success of firms. The publication of scientific articles is encouraged directly and indirectly by the firm. The researchers interviewed, all of whom have both co-authored publications and patents, also agreed that co-authored publications are a good measure of the extent of individual collaborations and suggest that there is a direct link between success of individual collaborations on scientific research and subsequent patents.

An interesting question is to what extent each type of collaborative relationship provides access to different types of knowledge. Conventional wisdom suggests that universities are the source of knowledge related to basic research, while firms are the source of more applied knowledge. The interviews suggest a muddier picture. Even though it is true that most basic advances in the field are derived from university research, they are also a source of applied knowledge. A number of interviewees suggest that firms gain substantial applied knowledge oriented towards the development of products through collaboration with universities.

3.4 Specific Discussion

The actions of individuals are often less observable than those of firms and are therefore hard to track. Fortunately, individual collaborations by biotechnology (and other) scientists do leave a paper trail. This trail has allowed us to evaluate and illustrate the extent of these collaborations and their positive impact on firm innovative output. The empirical tests confirm the central idea of this study – that scientific collaborations of researchers from different organizations have a positive effect on firm level innovative output. Though prior research has suggested that the actions of individual scientists and engineers play a role in the building and circulation of knowledge, and that collaborative actions across organizations enhance patenting quality, in these part of the thesis I did not aim to, and did not focus upon, the firm-level innovative implications of the combined collaborative activities of individual researchers. The results show that even after controlling for factors that have been previously suggested to impact the innovative output of a firm, including the quality of a firm's star and non-star scientists, individual-level scientific ability, strategic alliances (both technology an market), and R&D investment, the extent to which a firm's scientists collaborate on scientific articles positively influences the firm's innovative performance. The research thus isolates and highlights the role of individual level (and often informal) collaborative activity in enhancing a firm-level outcome - innovativeness - critical to an organization's success in high technology industries.

The research finds that firms use two modes of collaboration to source of knowledge for innovation. The two modes span levels of analysis (individual and organizational). By incorporating the influence of strategic alliances, I build on a well established stream of research that considers the effect of collaboration at the organizational level. I move beyond the emphasis on strategic alliances as collaborative mechanisms by highlighting the importance of individual collaborations on firm level innovation, thus highlighting the role of the underlying sociology of individuals in influencing observable organizational outcomes. In this way, I add to the growing body of research that focuses on the implications of phenomena such as mobility of engineers or hiring of star scientists. The research makes the point that it is necessary to move beyond the study of strategic alliances if I are to fully understand the impact of the range of collaborative arrangements on firm innovation.

The choice of learning mechanisms between strategic alliances and individual collaborations may have a strategic angle as well. If both mechanisms are useful for learning, the use of individual collaborations may have an advantage. They are less easily observable and therefore, due to the causal ambiguity associated with this mechanism of learning, are less likely to be imitable, suggesting implications for the sustainability of advantages obtained by employing this mechanism.

Though strategic alliances positively impact organizational innovativeness, research points out that these alliances are difficult to form and manage, and small firms may be limited in their ability to learn in this way. Managers often see formal alliances as strategic learning tools and yet have difficulty fully exploiting them for success (Gulati and Singh, 1998). The results suggest that managers have an additional tool in their managerial toolbox - collaborations conducted at the individual-level. This mode of knowledge acquisition can significantly enhance a firm's knowledge base and productivity. Individual collaborations are particularly important when they are regional in nature and when they link firms and universities. I do not suggest here that it is just easier or more likely to form individual collaborations when the scientists are co-located or when one belongs to a firm and the other works for a university. I suggest instead, that under these circumstances, collaborations once formed, are more valuable as learning tools and this provides an opportunity for managers of knowledge intensive firms.

An issue worth investigating is the relative role that strategic alliances and individual collaborations play in the innovative process. The data suggests that these two collaborative mechanisms provide access to distinct knowledge pools. Approximately 90% of strategic alliances are firm-to-firm linkages while a similar percentage of individual collaborations are firm-to-university (or research laboratory) linkages. This could suggest that these knowledge sources could play complementary roles. I attempted to probe this issue by investigating the interaction effect between strategic alliances and individual collaborations and the results reveal a non-significant value for this term on the dependent variable. Field research indicates that firms would like to tap into both sources of knowledge. Apparently firms are unable to use knowledge from these collaborative mechanisms in a complementary manner. An explanation to this conundrum may be that, given limited organizational resources for most small biotechnology firms, spreading resources too thinly across collaborative mechanisms results in both types of collaborations under-performing. A related explanation could be that firms need different capabilities and routines to harness each mechanism effectively. For example, strategic alliances are often supported by formal organizational processes and structures (Dyer and Singh, 1998), whereas the interviews indicate that individual collaborations are much more informal in nature and enhanced by organizational flexibility. It may be difficult for organizations to combine the organic approach to manage individual collaborations with a more structured approach for strategic alliances.

3.5 Specific Limitations

While I have used different sets of tests to ensure the robustness of the results, some limitations remain. The study is focused only on one industry, which raises question about the generalizability of the results. The biotechnology industry is special in its reliance upon basic scientific research and its unique product development and approval process. I intend to investigate whether the results can be generalized to other high-technology industries like the information technology and semiconductors. I also recognize that innovation output operationalized by patent counts is a one dimensional measure for innovation. However, patent counts have shown their usefulness in numerous previous studies and alternative innovation measures, including new products developed, correlate highly with the measure. Similar to patent information, article based measures are frequently used to measure individual collaboration. Nevertheless, they may under-represent the individual collaborative activity of companies, since they only measure the collaborations that lead to publication.

4 RESEARCH QUESTION 2: INDIVIDUAL COLLABORATION AND EMERGING INNOVATION

4.1 Theory and Hypothesis

The behavioral theory of the firm (Cyert and March, 1963; March and Simon, 1958) suggests that individuals are bounded rational. In the face of uncertainty and complexity, they do not consider, or rationally evaluate, the complete spectrum of choices before them. Rather, they are heavily influenced by current areas of practice and by historical actions when deciding on future approaches. Thus, these individual select actions that tend to be in the neighborhood of current practice rather than those that may be the most attractive in terms of future success. Nelson and Winter (1982) point out that organizations, like individuals, are bounded in their rationality and decision processes. Using this lens to explain the evolution of organizations, they suggest that firms are path dependent – actions (including technology development and innovation) tend to be along well established and familiar paths. They ascribe this to the formation of routines (organizational skills or habits) within the organization. These routines favor local search processes and make it difficult for the firm to adapt to any changes that are a departure from past practices and trajectories. In complex and dynamic environments, local search routines fail to identify the best new solution to a problem (Fleming and Sorenson, 2004). These insights suggest that firms may find it difficult to search for, and utilize knowledge in areas that are more distant from their existing areas of expertise and may find it challenging to move in new innovative directions.

A related idea that may explain why firms find it difficult to develop new areas of expertise comes from the knowledge based view of the firm (Grant, 1996; Kogut and Zander, 1992). This view suggests that firms develop expertise in many areas through experience. Grant (1996) defines capabilities as "a firm's ability to perform repeatedly a productive task". Capabilities are hard to develop and do not change easily. They arise from an interaction of people, structure, systems, processes and culture within the firm. Since the sources of capabilities are complex and diffused, and capabilities are built and reinforced by organizational systems over time, they are both difficult to identify and change (causal ambiguity). Leonard-Barton (1992) suggests that existing capabilities may become core rigidities that prevent firms from changing and adjusting to external needs. Levinthal and March (1992) point out that experiential learning within organizations is common but experience is a 'poor teacher' and may lead to myopia or the inability to absorb or acknowledge changes in the external environment. Therefore, even in a dynamic and rapidly evolving innovative environment, firms often tend to exploit existing capabilities and continue to innovate in areas close to their past expertise[1].

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[1] The idea of a routine, arising from evolutionary economics, is related to the concept of a capability associated with the knowledge based view of the firm. Winter (2000) argues "An organizational capability is a high level routine (or collection of routines) that, together with its implementing input flows, confers upon an organization's management a set of decision options for producing significant outputs of a particular type".

Empirical research in the form of in-depth case studies and large scale quantitative analyses supports the idea of local search even in the face of significant environmental change. Siggelkow (2001) uses a longitudinal case study of Liz Claiborne to show how coupling between units within the firm prevented it from adapting to environmental change. Grant and Baden-Fuller (2004) highlight the example of Kodak to show how existing capabilities led to a managerial reluctance to recognize the need for change in the area of technological innovation during the shift from chemical to electronic based technologies in the photography industry. In an early study, Helfat (1994) showed that R&D activity does not change significantly over time for firms in the petroleum industry and that differences in R&D persist across firms. In a study of medical imaging, Martin and Mitchell (1998) show that new entrants account for most new design introductions – existing players made mostly incremental changes to their products. Sorenson and Stuart (2000) demonstrate that in the high technology industries (biotechnology and semiconductors) older firms are more innovative but these innovations tend to be more inward looking and have less relevance to the external environment.

The above arguments suggest that firms may find it difficult to develop flexibility in their technological capabilities to innovate in new or emerging areas even if they see this as important to their success. So how can firms enhance their ability to stay abreast of new ideas and knowledge and, if necessary, innovate in emerging technological areas? Extant research gives us some hints about how firms may acquire and utilize the knowledge and capabilities to facilitate technological change. The evidence is that external mechanisms can be used to absorb knowledge distant from a firm's current expertise. Rosenkopf and Almeida (2003) show that firms can acquire knowledge from geographically or technologically distant domains through alliances and mobility and this knowledge helps them reach beyond the localness of search processes. At the individual level, Song et. al. (2003) highlight both the tendency towards local search and point to one way overcoming it – by hiring experts from other countries and firms. Hiring was only useful when the new engineers and scientists were employed outside a firm's core areas. At the organizational level, Karim and Mitchel (2000) show that acquisitions can reinforce previous business activities (resource deepening) or help them undertake new and 'path-breaking' activities (resource extending). Hence, existing evidence suggests that in some instances external sources may be useful in helping organizations adjust their technological trajectories. The studies however do not suggest that all mechanisms for acquiring external knowledge are useful to change a firm's technological trajectory or which if any mechanisms will give the firm the flexibility to move towards new innovative areas in the field.

The capability to move beyond a firm's current innovation trajectories and practices is especially important in biotechnology. Compared to traditional pharmaceutical firms that have developed their competitive advantage through capabilities linked to medicinal chemistry, biotechnology firms usually have expertise in the rapidly evolving field of molecular biology. Molecular biology has opened an array of new frontiers for research (including genomics, proteomics, genetic engineering, and gene therapy) and has also led to the development of numerous technologies related to target identification, clinical trials, screening and bioinformatics (Pisano, 2002). The sources of new scientific and technological knowledge come from an array of fields and from a number of specialized firms, academic laboratories, government institutions from around the globe (Powell et al. 1996). Success in this industry can be related to expertise in basic science and the development of associated technologies to test, develop, and commercialize scientific ideas (Bartholomew, 1997). Hence, firms need to gain insights and knowledge into future productive directions for research and continuously develop scientific, technological, and organizational capabilities to innovate successfully in new and emerging areas. Firms must therefore continuously reach across their organizational boundaries to source emerging expertise in science and technology to enhance the direction and quality of their innovative activities.

4.1.1 Individual Collaboration and the Frontier of Innovation

At the individual level, scientists can reach across organizational boundaries to collaborate with others on research activities and this can potentially provide the organization with useful inputs for innovation (Gittelman and Kogut, 2003; Cockburn and Henderson, 1998; Murray, 2002; Tushman, 1977). Since scientists belong to both organizational and scientific communities, they can facilitate the flow of knowledge between these communities (Murray, 2002). Membership in scientific communities often gives rise to research collaborations of scientists (often informal) across organizational boundaries and result in the publication of co-authored scientific papers (Cockburn and Henderson, 1998). Individual-level scientific collaborations do not just lead to an increase in knowledge available to a firm, but importantly facilitate insights and access to the knowledge from a wider spectrum (geographically, organizationally, and scientifically) than may otherwise be possible. Firms that have a large number of scientists engaged in external knowledge exchange are likely to be infused with a broad set of new ideas, decreasing myopia (that is so often a part of the learning process) and consequently decreasing the resistance to change. Since scientists themselves are at the core of the organization, collaborative activity with those outside the organization promotes the development of new capabilities at the individual level, and cumulatively at the organizational level, along directions of their emerging interest.

Knowledge inputs and exchanges provide individuals with an early and clearer picture of the emerging scientific and technological landscape and this expands the view of scientific and technological possibilities available to the firm. These external individual collaborations can therefore extend, not just the spectrum of possible scientific advances within the firm, but just as importantly, the perception of what is attractive (and unattractive) to them. Fleming and Sorenson (2004) point out that scientific investigation allows one to develop better maps of the landscape of (scientific and technological) possibilities being faced by an individual or organization. Additional scientific inputs, obtained and refined through external interaction and scientific collaboration allow a firm to perceive global (rather than just local) optima and hence broaden the search process.

Previous research has pointed to the special characteristics, values, and norms of the scientific community (Merton, 1973; Stephan, 1996). For example, for Merton (1973) the norms of science and scholarship are based on four principles: universalism, communalism, disinterestedness and organized skepticism. These norms of the science community explain relatively low levels of fraud and plagiarism as compared with other domains (Sztompka, 2007). Knowledge obtained from a trusted partner or collaborator is more likely acquire saliency, to be acted upon, and influence subsequent decision making. Since many scientific interactions center around emerging technologies, approaches and ideas, the flow of knowledge within the community itself influences the future innovations that will develop in the field. Membership in this community therefore allows for an understanding and movement towards, not just existing knowledge, but of future innovative areas.

In sum, firms whose employees engage in a larger number of external individual level collaborations can be seen to have a wider and more detailed view of possible avenues for research, a clearer idea of the relative merits of alternative search processes within the organization, and greater access to a stock of emerging insights, techniques, and knowledge that could enable them to pursue attractive options. These firms will therefore not just be better equipped to overcome some of the limitations of local search, but also are more likely to be able to innovate in emerging and developing areas.

Hypothesis 1: Firms with greater numbers of external individual collaborations are likely to grow more aligned to the frontier of innovation in the field.

4.1.2 Strategic Alliances and the Frontier of Innovation

The idea that alliances can lead to inter-firm learning is well documented in the strategic management literature. Hamel, Doz and Prahalad (1989) explained that alliances can be used as part of a learning strategy. Subsequently, empirical and conceptual studies have supported this idea (Inkpen, 2002; Doz, 1996; Stuart, 2000; Dussauge et al. 2000; Lyles and Salk, 1996). For example, Rosenkopf and Almeida (2003) and Mowery et al. (1996) use patent data to show that alliances facilitate inter-firm knowledge flows.

In biotechnology, it can be argued that strategic alliances are extremely important to the innovative processes of a firm. Given the rate of change in the industry and the resource limitations of most stand-alone biotechnology firms, these firms appear to follow strategies that use external alliances for knowledge acquisition to keep up with rapid changes in technology as well as to access partners' capabilities (Powell et al. 1996). Rothaermel and Deeds (2004) suggest that in biotechnology alliances can play the role of enhancing exploration and exploitation[1] (the emphasis changes to the latter with increases in firm size). Baum, Calabrese and Silverman (2000) look at strategic alliances formed by biotechnology start-ups in Canada and find that alliances provide access to information and enhance innovative performance.

Though strategic alliances have many potential benefits, there are several reasons to believe that these mechanisms are used by firms to enhance existing trajectories of research rather than explore emerging areas that may not be close to the firm's current expertise. First, alliances are difficult to manage and costly to maintain (Gulati and Singh, 1998). This fact is especially true for small biotechnology firms that are often constrained in terms of their managerial and financial resources. Since the potential sources of useful information and knowledge are numerous and scattered, it may not be possible for even large firms to form alliances to access every possible source of relevant knowledge (Pisano, 2002). As a result most firms form only a limited number of strategic alliances in targeted areas. According to a 2004 study by Rothaermel and Deeds, biotechnology firms formed an average of 8 alliances each over a 25 year period.

[1] I focus on strategic alliances linked to R&D and production activities since the emphasis is on product or process innovation.

Given that strategic alliances are relatively few, they are likely to be targeted towards areas of greatest perceived need.

A second, related point is that strategic alliances are indeed an organizational level mechanism (rather than an individual level action) where critical decisions are made often by senior management. These actors are more closely tied to the firm's past history and success and are most likely to be subject to path dependent thinking and decision making. As explained by behavioral theory, past success and actions are likely to greatly affect the decision making of these actors, making it more likely that the strategic direction of alliances formed will be to enhance and grow the firm along existing trajectories rather than exploring new fields and approaches. Strategic alliances so formed will not give scientists an opportunity to reassess and recalibrate mental maps and are instead likely to reinforce exiting innovation directions rather than transform them.

A third issue associated with alliances is that they are a part of an organizational and legal process that is time consuming and difficult to implement. Even once legally established, alliances formation is itself evolutionary (Doz, 1996) involving the gradual establishment of routines and trust across firms before they can be effective in knowledge sharing (Zollo et al. 2002). Hence, there is a significant time lag between the decision to form an alliance and the point at which they are useful in facilitating knowledge flows between firms. Given that (a) alliances are restricted in their number and breadth, (b) their formation is likely to be influenced by path-dependent processes, and (c) they are significant lags between the formation decision and the availability of knowledge form these collaborations, alliances may not be the best mechanism for keeping abreast of emerging innovations in a dynamic field where the sources of new science and technology are diverse and changing. While strategic alliances may enhance a firm's innovativeness and its ability to commercialize innovations, they are likely to reinforce the trajectories of existing innovation. Hence,

Hypothesis 2: Firms with greater numbers of strategic alliances are likely to grow less aligned to the frontier of innovation in the field.

4.1.3 Internal Individual Collaboration and the Frontier of Innovation

In addition, to the use of external collaborative mechanisms like strategic alliances and informal scientific collaborations, internal firm practices and characteristics are likely to affect the likelihood that a firm will innovate in new and emerging areas. I now explore the role of internal individual collaborations and firm specialization on the type of innovation for biotechnology firms.

Innovation has been described as the recombination of knowledge (Fleming and Sorenson, 2004). Hence, internal collaboration between members of any organization is likely to lead to better sharing and utilization of knowledge and more intra-firm learning. Collaboration of scientists within a biotechnology firm is likely to result in enhancing innovativeness. However, internal collaboration may also have a darker side to it. Individual collaboration amongst members of the same firm while leading to the efficient use of existing knowledge can also simultaneously decrease the salience and the utilization of external knowledge. Greater interaction and discussion between scientists of the same firm can lead to the reinforcement of existing mental models and world views and serve to enhance the value placed on what is already known within the firm. Further, internal collaborations are likely to positively build resources and capabilities along existing trajectories and hence serve to deepen the path dependence of the firm. Thus individual internal collaborations could consume resources and mindshare that could be otherwise be oriented to searching for knowledge beyond the boundaries of the firm. This would decrease the flexibility and motivation to explore new technological directions. In comparison to external scientific activities, which are the expression of emphasis on an external search process, internal collaborations are evidence of a search process based on the internal and existing knowledge base of the firm thereby reinforcing existing scientific processes and paths.

Hypothesis 3: Firms with greater numbers of internal individual collaborations are likely to grow less aligned to the frontier of innovation in the field.

4.1.4 Specialization and the Frontier of Innovation

A key firm characteristic that affects the innovation process is the extent to which the firm is technologically specialized (or diversified). Technological specialization (or focus on relatively few technologies areas) allows a firm to effectively utilize scarce resources and build capabilities in an efficient manner along well defined and narrow trajectories. Investment in a few related technological areas can enable firms to benefit from scale economies and to move quickly down the experience curve, permitting the development of expertise and technological outputs more quickly than may have been otherwise possible.

While specialization can enhance a firm's technological productivity along existing areas of expertise, it may also hamper a firm's ability to explore new territories or move in new technological directions should the need arise. Kogut and Kim (1994) use patent analysis to show that expertise in particular semiconductor technological field opens avenues for developing technological expertise in new fields. This implies that specialized firms that by definition have expertise in a narrow set of fields, have fewer technological platforms that aid diversification in to new and emerging fields.

One of the important insights arising from Cohen and Levinthal's (1990) seminal work on absorptive capacity is that investments in R&D influence an organization's ability to recognize potentially useful external knowledge, absorb it, and utilize this knowledge effectively in their own research processes. Technologically diversified firms should be able to recognize potentially useful knowledge pertaining to a wider range of fields than more specialized firms. They are also likely to have knowledge overlaps with a wider range of other organizations and a broader set of organizational capabilities and are therefore better equipped to absorb this knowledge effectively. Technologically diversified firms can also utilize external knowledge more effectively since they have greater opportunities to make knowledge combinations that allow them to innovate and develop expertise in new technological directions (Cohen and Levinthal, 1990). Since the extent of technological diversification is not just a function of technical knowledge but also dependent on an organization's human resources, structure and processes, it is not surprising that Cantwell and Andersen (1996) observe that the extent of specialization changes only gradually over time. However, technologically diverse firms have greater opportunities to move into emerging technological areas given the greater opportunities for cross-fertilization of knowledge (Granstrand, 1998; Suzuki and

Kodama, 2004) and they have an enhanced capability to avoid lock-in by absorbing and exploiting external knowledge from a variety of sources and fields (Garcia-Vega, 2006). Based on these arguments I suggest that specialized firms are likely to be more path dependent and find it more difficult to overcome local and narrow search.

Hypothesis 4: Firms that are more specialized are likely to grow less aligned to the frontier of innovation in the field.

4.1.5 Interaction Specialization and Collaborative Mechanisms

Our previous arguments on the relationship between specialization and absorptive capacity suggest that the degree to which a firm is specialized will moderate the relationship between the various collaborative mechanisms utilized by the firm and the organizations ability to move in to emerging technological areas. If specialization reduces a firm's ability to recognize and value external knowledge that is distant from current practice, it is also likely to have a negative effect on the utilization of knowledge absorbed from a wide variety of sources by informal scientific collaborations. The scientists of more specialized firms are likely to collaborate with colleagues from a narrower spectrum of technological areas and the resultant cumulative knowledge brought in by this mechanism is also likely to be less diverse (than it would be in a technologically diverse firm). Not only is the knowledge absorbed likely to be less diverse, the likelihood of its assimilation in the firm is lower since the narrower knowledge base of the firm, and the organization's systems and processes may be unable to fully incorporate this diverse knowledge.

I had argued earlier that strategic alliances and internal collaborations are a product of path dependent and often backward looking decisions within the firm. These modes of collaboration further enhance the lock-in of firms along fixed technological trajectories and reduce the chances of the firm moving in new technological areas as opportunities emerge in the field. I believe that in specialized firms, with narrow areas of technological expertise, these tendencies towards lock-in will be further enhanced.

Hypothesis 5a: Firm technological specialization dilutes the positive relationship between the number of external individual collaborations and alignment to the frontier of innovation in the field.

Hypothesis 5b: Firm technological specialization enhances the negative relationship between the number of strategic alliances and alignment to the frontier of innovation in the field.

Hypothesis 5c: Firm technological specialization enhances the negative relationship between the number of internal individual collaborations and alignment to the frontier of innovation in the field.

4.2 Methodology

The sample and some of the independent variables are the same as in the previous empirical investigation. However, the dependent variable, several specific independent variables and the model specification are quite different to the previous model.[1]

4.2.2 Dependent Variables

I use the international patent classifications codes (IPC) to capture the technological positions (and the change of position across time) of firms in the industry. Several studies have highlighted the usefulness of patent measures as indicators of innovative activity and capabilities (Hausman et al. 1984; Ahuja, 2000). In addition, IPC codes have been frequently used to assess firms' positions in technological space (Stuart and Podolny, 1996; Ahuja, 2000; Song et al. 2003; Rosenkopf and Almeida, 2003).

The IPC scheme is a hierarchical classification system used to classify and search patent documents. It is useful in assessing technological positions and distances (between firms) since the technological classes represent conceptually distinct groups(Zeebroeck et al. 2006). The codes are structured at three levels – classes representing broad technical fields, sub classes and finally, groups (Benner and Waldfogel, 2008). The study suggests that each firm occupies a position in technological space that emerges from a variety of decisions, actions, systems, and processes within the firm and this position can be observed from the technological areas in which the firm innovates in at any point in time. The pattern associated with the change in a firm's innovative (and

[1] All variables relevant for the second empirical investigation are explained in the this part of the dissertation. However, for the exact description of the sample please see "3.2.1 Sample" of the previous section

technological) position over time reveals the firm's technological trajectory. Like firms, the overall industry can also be seen to occupy a innovative position at a point in time and to follow a trajectory over time. An aggregation of the technological positions of all the firms in the industry (as revealed by the patented innovations) and the changes in these positions over time serves to indicate the industry's technological position and trajectory. I can therefore use data on patented innovations, to study the position of a firm relative to the industry at any point of time and compare the trajectory of the firm relative to the industry over time. The comparison of the relative technological position of the firm to the field across time allows us to observe whether a firm is moving towards (or away) from the innovative frontier of the field.

I use the Derwent Innovation Index database (DWI) to gather detailed patent information for the sample firms between the years 1990 and 2005.[1] I then use the IPC codes (at a sub-class level) to calculate the Euclidian (D_{it}) distance between a firm and the overall field at any point of time. This technological distance is measured as follows:

$$D_{it} = \sqrt{\sum (p_{kit} - p_{kt})2}$$

where p_{kit} represents the proportion of a patenting activity for a firm (i) in a given subclass (k) in year (t), and p_{kt} estimates the proportion of patenting activity in a given subclass (k) of the whole industry in the year (t). *K* is the number of dimensions (patent classes).

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[1] DWI provides access to a comprehensive database of international patent information comprising more than 20 million patent documents from 41 worldwide patent-issuing authorities including USA, France, Germany, UK, Japan, Australia and Spain.

The difference between the Euclidean distance between the firm and the field across two points in time (M) gives us an idea if a firm's innovative position is moving closer or further from the innovative core of the field. Hence, $M = D_t - D_{t+n}$ where D_t is the distance between the firm and the field in time t and D_{t+n} is the distance at time t+n. Since D_t and D_{t+n} can range from 0 to 1, M can range from -1 to 1 where high numbers indicate that the firm and the field are becoming more closely aligned. I used a three year time period to evaluate the changes in distance between the firm and the field (n=3).[1]

4.2.3 Independent Variables

Strategic (Technological) Alliances: I identified strategic alliances between two firms through the patent database by identifying every case where two or more organizations were listed as joint assignees (or owners) of the patent at the time it was granted. I took into account merger and acquisition activities, subsidiary relationships, and name changes which could have resulted in the listing of multiple assignees but did not represent alliances between independent firms. The use of co-patenting as definition for alliances has the disadvantage that it captures only a limited set of activities as collaborations, because not all collaborative activities lead to co-patenting. However, it has the advantage that it (1) focuses very precisely on innovation related alliances, (2) links the innovation generating activity accurately to the participants (authors, firms), (3) provides a finer grained picture of collaborations by including those not available

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[1] I use patent application dates to identify the date of the innovation. In addition to running the models for n=3, I performed a sensitivity analysis with n=2 and n=4.

from other sources, and (4) enables us to calculate input and performance measures of the collaborative innovation activity. I believe that the advantages of patent based alliances measure outweigh the disadvantages in this particularly study.[1]

External Individual Collaborations: This variable captures the extent to which scientists of a firm engage in collaborative activities with scientists from other organizations. It is measured as the number of articles (in scientific journals) co-authored by employees of the focal firm with employees of another organization. Archival data from publications is often used to estimate the scientific activities of individuals and is seen as a reliable source of information because they are subject to the critical review of colleagues and have gained approval in a peer review process (Gittelman and Kogut, 2003).[2] I use the ISI Science Citation Index (SCI) to identify all publications authored by at least one employee of the sample firms[3]. I include every journal listed in the SCI in the initial search for articles because any restriction could lead to a selection bias. This is particularly relevant for the biotechnology industry, since this field spans several scientific and technological areas.

Internal Publications: This variable measures the total number of articles published by individuals within the firm. External Individual Collaborations and Internal Publications together make up the complete set of publications of a firm. To distinguish between collaborative and non-collaborative internal publications, I introduce the variables

[1] Please see Schilling (2009) for a general discussion of the accuracy of different alliances databases.
[2] For more detailed information on the validity of author patterns in biotechnology, please see Rothaermel and Hess (2007), who discuss the publication time lag, mobility of authors, and the locus of intellectual property creation and appropriation. For a discussion of the drawbacks of co-author patterns see Katz and Martin, (1997).
[3] The SCI database records details of authors, source, keywords, and other information relating to the article as well as the bibliographic references and is frequently used for research purposes on bibliometric data (e.g. Gittelman and Kogut, 2003; Ramos-Rodriguez and Ruiz-Navarro, 2004).

Internal Individual Collaborations and *Internal Individual Publications*. Internal Individual Publications measures the number of singled authored publication within the firm and Internal Individual Collaborations measures the number of publications co-authored by two or more scientists in the same organization.

Technological Specialization: I measure the technological specialization of the firm by calculating the Gini coefficient and using IPC technology sub-classes. Zeebroeck et al. (2006) show that the Gini coefficient is the most reliable measure when trying to capture technological specialization with patent data.

4.2.4 Control Variables

Control Variables: To control for the heterogeneity in the sample I include several control variables in the study.[1]

R&D Investment is an important variable in any study predicting innovation activities. This variable is particularly important in a study investigating the technological movement of firms because several studies showed the path dependency of R&D (Helfat, 1994; Cohen and Levinthal, 1990).

Similarly, Firm Size has been shown to impact firm innovation (Cohen and Klepper, 1996; Rosenkopf and Almeida, 2003) and can be directly linked to innovation search behavior (Sorensen and Stuart, 2000). Therefore, I control for size as number of

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[1] I used Datastream as a source of firm information for most of the control variables and double checked it with SEC-10K forms.

employees in a given year. The number of employees is preferable to alternative measures for size such as total assets or sales in this industry. Sales represent a poor measure because biotechnology firms often do not have positive revenue streams (or have very volatile ones) and accounting measures may not capture the real size of small firms in high technology industries.

Since acquisitions can be used as a mode of accessing external knowledge (Vermeulen and Barkema, 2001), I included a variable, Acquisitions, that indicates if the focal firm acquired another biotechnology firm in a given year. To capture the characteristics of firms that have previously been shown to be important to innovation, I introduce four additional controls - Intellectual Capital, Science Orientation, Relative Technological Advantage, and Star Scientists. The intellectual strength of the researchers involved in research activities could influence their capability to predict future directions of the field and so I control for Intellectual Capital measured as the average number of times the academic articles published by each firm has been cited. The Science Orientation of the firm could influence the direction and level of specialization of subsequent innovation, so I measure this as the ratio of the numbers of papers published to R&D Investments. The strength of a firm in a technological area could affect its subsequent technological trajectory, therefore I measure the Relative Technological Advantage (RTA) of each firm (Zhang et al. 2007). The RTA is defined as the sum of the ratios of the share of firm (i) patents falling in technology class k, over the share of all patents falling in that technology class, where P is the number of patents held by firm i in technology class k.

$$\mathrm{RTA}_{it} = \sum((p_{ikt} / \sum p_{ikt}) / (p_{kt} / \sum p_{kt}))$$

Several previous studies have highlighted the role that star scientists play in the innovation process (Zucker et al. 2002; Zucker et al. 1998). Therefore I control for the number of Star Scientists for each firm in a given year. Similar to Rothaermel and Hess (2007), I identify star scientists based on their publication activity. I first identified every author within the sample of publication and then counted the number of citations received per researcher. To account for the fact that in biotechnology, articles have a large number of authors, I adjusted for the number of authors per article. Finally, I defined star scientists as those scientists whose total number of citations were more than three standard deviations above the mean. The number of citations is a preferable measure to identify star researchers to pure publication counts because citations are a better indicator of the quality. The procedure identifies 906 star scientists (1.04% of the total scientists), who are involved in 30.9% of all publications and accounted for 30.8% of all citations. These ratios are comparable to previous studies (Zucker et al. 2002; Rothaermel and Hess, 2007).

4.2.5 Model Specification

The dependent variable is truncated at 1 and -1. This would suggest the application of a Tobit regression. However, Tobit models have the disadvantage of being sensitive to the violation of their underlying assumptions (particularly normality) and they also prevent the use of fix-effect models to control for unobserved heterogeneity (Greene, 2003). For this study, the truncation is may not be a critical issue because a large number of firms do not change their technological profile in a particular time period and the changes are nearly symmetrical in both directions (mean = 0.012; mode = 0.002; skewness = 0.650; kurtosis = 15.415). Based on the distribution of the dependent variable, the application of a Tobit regression is not advisable. Instead I apply an OLS panel regression with robust standard errors. This model has the advantage that I can control for unobserved heterogeneity via fixed effects[1].

To account for the non-normal distribution of R&D investment, firm size, star scientist and all publication variables I normalized these variables using a logarithmic scale. To ease the interpretation of the results and to reduce potential co-linearity, interaction effects are mean-centered. Additionally, since the calculation of the dependent variables, includes a lag of 3 years I reduce potential simultaneity bias.

4.3 Results

4.3.1 Descriptive Statistics

Figure 7 presents the descriptive statistics and the correlation matrix. The data reveal strong heterogeneity across firms. For example, the biggest firm in the sample has more then 10,000 employees whereas the smallest firm employs only 4 people. As expected the data show that individual collaborations are more numerous than strategic alliances and non-collaborative publications. The average number of external individual collaborations per firm per year is 13, compared to 4 internal publication and 0.6 strategic alliances. Of the internal publications, 26.9 percent are single authored and 73.1 percent are co-authored. In the case of external individual collaborations, approximately nine out of ten (93.5%) partners are working in universities, hospitals, or research laboratories. The opposite is true for strategic alliances where only about one

[1] The Hausman test rejects the use of random effects models.

out of eight partners (13.1%) is a university, hospital, or research laboratory. All correlations are at a moderate level with the exception of the External Individual Collaboration and the various types of Internal Publications measures. To further asses the problems of multi-collinearity I calculated the Variance Inflation Factor (VIF) for a pooled regression. All VIF's are at acceptable levels (<0.5) indicating that the multi-collinearity is not biasing the results.

Figure 7: Descriptive Statistics & Correlation Matrix

	Variable	Mean	Std. Dev.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Dependent Variable	0.007	0.145														
2	Time Trend	9.499	1.905	-0.076													
3	RD Investments (Ln)	9.939	1.245	-0.074	0.255												
4	Firm Size(Ln)	5.160	1.316	-0.102	0.081	0.663											
5	Aquisition	0.102	0.367	-0.021	0.098	0.194	0.287										
6	Science Intensity	0.001	0.001	-0.003	-0.124	-0.344	-0.102	-0.040									
7	Relative Technological Advantage	2.390	1.339	0.149	0.106	-0.262	-0.058	-0.017	-0.032								
8	Intellectual Capital	65.412	200.939	-0.029	-0.101	0.255	0.268	0.081	0.063	-0.185							
9	Star Scientist (Ln)	4.612	24.078	-0.026	0.035	0.238	0.268	0.074	0.065	-0.100	0.472						
10	External Individual Collaboration (Ln)	1.710	1.350	-0.070	0.338	0.542	0.424	0.195	0.168	-0.236	0.428	0.384					
11	Strategic Alliances (Ln)	0.576	0.676	-0.103	0.434	0.353	0.272	0.141	-0.002	-0.142	0.087	0.185	0.438				
12	Internal Publication (Ln)	0.909	1.059	-0.079	0.298	0.519	0.430	0.176	0.101	-0.184	0.345	0.333	0.763	0.421			
13	Internal Individual Collaboration (Ln)	0.763	1.002	-0.073	0.282	0.497	0.404	0.159	0.073	-0.179	0.272	0.299	0.688	0.400	0.959		
14	Internal Individual Publication (Ln)	0.401	0.640	-0.053	0.263	0.432	0.388	0.167	0.124	-0.111	0.401	0.348	0.696	0.416	0.755	0.598	
15	Technological Specialization	0.285	0.181	-0.185	-0.015	0.490	0.405	0.171	0.050	-0.183	0.294	0.216	0.526	0.311	0.477	0.436	0.316

4.3.2 Regression Results

Figure 8 (model 1 to 4) shows the results for the OLS firm fixed effects regression model. In model 1, I estimate a baseline model including the control variables only. As expected R&D Investment has a positive effect on the dependent variable while Firm Size has a negative effect. Intellectual Capital, Science Intensity, Temporal Effects, Scientists and Acquisitions have no effect. In model 2 I add the main variables of interest. Supporting Hypotheses 1, 2, and 3, Strategic Alliances ($p<0.001$) and Internal Individual Collaborations ($p<0.05$) are negative and significant while External Individual Collaborations has a positive and significant effect ($p<0.05$). These results indicate that informal collaborations with individuals from other organizations help guide firms towards the locus of future innovation in the field, while internal collaborations and strategic alliances have the opposite effect. Additionally, Science Intensity becomes significant ($p<0.01$). I next add the degree of technological specialization to the analysis (model 3). In line with Hypothesis 4, technological specialization decreases the alignment with the future locus of innovation ($p<0.01$). The incorporation of technological specialization reduces the level of significance of Strategic Alliances ($p<0.1$) and External Individual Collaborations ($p<0.1$). Finally, in model 4 I include the interaction effects between the three search mechanism and technological specialization. The results show that technological specialization increases the negative effect of Strategic Alliances ($p<0.05$) and Internal Individual Collaborations ($p<0.1$) but does not affect External Individual Collaborations. This provides support for Hypotheses 5a and 5b but not for 5c.

Figure 8: Firm Fixed Effect Panel Regression

Variables	Model 1 B /SE	Model 2 B /SE	Model 3 B /SE	Model 4 B /SE	Model 5 B /SE	Model 6 B /SE	Model 7 B /SE	Model 8 B /SE
Controls								
Time Trend	-0.002	0.000	0.002	0.001	0.002	0.002	0.002	0.001
	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
RD Investments (Ln)	-0.058 ***	-0.064 ***	-0.063 **	-0.054 ***	-0.062 ***	-0.059 ***	-0.063 **	-0.056 ***
	0.020	0.021	0.021	0.020	0.021	0.021	0.021	0.021
Firm Size(Ln)	0.041 *	0.040 *	0.042 *	0.038 *	0.041 *	0.040 *	0.043 *	0.039
	0.024	0.023	0.023	0.023	0.023	0.023	0.023	0.024
Aquisition	-0.013	-0.014	-0.013	-0.009	-0.013	-0.008	-0.013	-0.010
	0.012	0.012	0.012	0.012	0.012	0.012	0.014	0.014
Science Intensity	-10.188	-15.499 ***	-16.311 ***	-12.395 **	-16.151 ***	-14.173 **	-16.343 ***	-12.852 **
	6.412	5.954	6.077	6.097	6.207	6.319	6.232	6.243
Relative Technological Advantage	0.012	0.011	0.010	0.011	0.010	0.011	0.011	0.012
	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Intellectual Capital	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Star Scientist (Ln)	-0.002	-0.004	-0.004	-0.003	-0.004	-0.004	-0.003	-0.005
	0.004	0.005	0.005	0.004	0.005	0.004	0.006	0.006
Main Effects								
External Individual Collaboration (Ln)		0.031 **	0.033 **	0.027	0.033 **	0.035 **	0.035 **	0.026
		0.014	0.015	0.026	0.015	0.014	0.016	0.027
Strategic+B75 Alliances (Ln)		-0.032 ***	-0.021 *	-0.074 **	-0.021 *	-0.022 **	-0.018 *	-0.067 **
		0.010	0.011	0.034	0.011	0.011	0.011	0.034
Internal Publication (Ln)		-0.024 **	-0.023 *	-0.060 **			-0.024 *	-0.064 **
		0.012	0.013	0.025			0.013	0.025
Technological Specialization			-0.166 ***	-0.322 ***	-0.165 ***	-0.263 ***	-0.172 ***	-0.334 ***
			0.059	0.097	0.059	0.076	0.061	0.102
Internal Individual Collaboration (Ln)					-0.020 *	-0.068 **		
					0.012	0.029		
Internal Individual Publication (Ln)					-0.012	-0.041		
					0.014	0.038		
Interaction Effects								
Individual Collaboration (Ln) x Tech. Specialization				0.022				0.027
				0.054				0.056
Strategic Alliances (Ln) x Tech. Specialization				0.146 **				0.130 *
				0.074				0.076
Internal Publication (Ln) x Tech. Specialization				0.099 *				0.108 **
				0.052				0.053
Internal Individual Collaboration (Ln) x Tech. Specialization						0.134 **		
						0.061		
Internal Individual Publication (Ln) x Tech. Specialization						0.080		
						0.082		
Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.372 ***	0.414 ***	0.405 ***	0.387 ***	0.403 ***	0.401 ***	0.407 ***	0.394 ***
	0.139	0.138	0.140	0.138	0.141	0.138	0.142	0.139
	0.007	0.003	0.004	0.005	0.004	0.004	0.004	0.005
N	691	691	691	691	691	691	661	661

* p<0.1; **p<0.05; p<0.01

4.3.3 Robustness Checks

To examine alternative explanation and to check the robustness of the results I run further analyses. First, I investigate the difference between Internal Individual Collaborations and Internal Individual Publications. Model 5, which depicts the main effect of both variables, shows that only collaborative internal activities have a marginally significant effect on the dependent variable. Following the logic of the previous model, I also run a fully specified model (Model 6), which includes all the interaction effects. In line with the previous models, the interaction is significant ($p<0.05$). These results indicate that Internal Individual Collaborations are the main driver of Internal Publications. Next, I run a sensitivity model excluding the largest firm from the analysis. I do this for two reasons: First, Some of the large firm relatively much bigger and have much more collaboration and alliances. Even though I control for size and transform the independent variables, these firm could have an over proportional influence on the results. Second, the trajectory of the field is directly influences by the activities of the individual firm. Event though I believe this effect is small due to the sample size, a regression excluding the biggest firm provides a more conservative estimate of the effects, because the biggest firm should be the firm were the bias is most severe. Model 7 and 8 shows the results for models excluding firms with more than 3500 employees.[1] The results remain stable (in comparison to model 3 and 4), which strengthen the results.

Finally, Figure 9 presents the previous analysis in form of a firm fixed effect logit specification, where the dependent variable is specified as a dummy of increasing or

[1] I used different cut off criteria to reduce the sample but the results remained stable. The upper limit was calculated $(\mu + 3\sigma)$ and the lower limit (75th percentile+3x inter quartile range).

decreasing fit with the innovation frontier. This analysis is more conservative than the OLS model, because the specification of the dependent variables only measures the direction of change but not the magnitude of it. As expected the results broadly support the previous findings, with some exceptions. The three main effects are supported in model 6, but in contrast to the previous analysis technological specialization (model 7) is not significant. Of the three interactions terms, only the effect of strategic alliances and technological specialization ($p<0.05$) on the dependent variable is significant.

Figure 9: Firm fixed Effect Logit Regression

Variables	Model 1 B /SE	Model 2 B /SE	Model 3 B /SE	Model 4 B /SE	Model 5 B /SE	Model 6 B /SE	Model 7 B /SE	Model 8 B /SE
Controls								
Time Trend	-0.090	-0.087	-0.082	-0.099	-0.075	-0.081	-0.081	-0.096
	0.060	0.062	0.062	0.063	0.062	0.062	0.065	0.066
RD Investments (Ln)	-0.282	-0.350	-0.340	-0.233	-0.341	-0.323	-0.320	-0.221
	0.246	0.261	0.262	0.269	0.263	0.266	0.262	0.270
Firm Size(Ln)	0.131	0.145	0.162	0.104	0.147	0.154	0.119	0.080
	0.265	0.272	0.273	0.278	0.273	0.276	0.277	0.282
Aquisition	0.143	0.121	0.085	0.095	0.093	0.131	0.051	0.047
	0.250	0.251	0.253	0.252	0.251	0.254	0.269	0.269
Science Intensity	-30.420	-98.465	-93.864	-48.077	-98.472	-77.827	-88.718	-46.705
	127.722	142.081	141.495	141.192	145.770	141.603	141.824	142.683
Relative Technological Advantage	0.149 *	0.144	0.143	0.154 *	0.134	0.136	0.137	0.147
	0.090	0.091	0.091	0.092	0.091	0.092	0.093	0.094
Intellectual Capital	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.001
	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
Star Scientist (Ln)	-0.189	-0.225 *	-0.229 *	-0.220 *	-0.227 *	-0.239 *	-0.169	-0.185
	0.128	0.132	0.132	0.132	0.133	0.133	0.150	0.150
Main Effects								
External Individual Collaboration (Ln)		0.404 **	0.384 **	0.320	0.369 **	0.413 **	0.403 **	0.353
		0.171	0.176	0.254	0.176	0.179	0.180	0.263
Strategic Alliances (Ln)		-0.349 **	-0.346 *	-1.193 **	-0.351 **	-0.381 **	-0.304 *	-1.100 ***
		0.173	0.180	0.392	0.180	0.182	0.181	0.404
Internal Publication (Ln)		-0.318 *	-0.329 *	-0.716 **			-0.290	-0.841 **
		0.175	0.179	0.326			0.181	0.333
Technological Specialization			-0.137	-2.164 *	-0.149	-1.300	-0.137	-2.388 **
			0.821	1.164	0.824	0.944	0.828	1.204
Internal Individual Collaboration (Ln)					-0.395 **	-0.923 ***		
					0.171	0.328		
Internal Individual Publication (Ln)					0.156	-0.167		
					0.217	0.490		
Interaction Effects								
Individual Collaboration (Ln) x Tech. Specialization				0.290				0.224
				0.700				0.714
Strategic+B17 Alliances (Ln) x Tech. Specialization				2.321 **				2.167 **
				0.991				1.028
Internal Publication (Ln) x Tech. Specialization				0.951				1.485 *
				0.863				0.893
Internal Individual Collaboration (Ln) x Tech. Specialization						1.488 *		
						0.839		
Internal Individual Publication (Ln) x Tech. Specialization						0.875		
						1.248		
Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	679	679	679	679	679	679	645	645

* p<0.1; **p<0.05; p<0.01

4.4 Specific Discussion

This part of the dissertation examined the challenge faced by firms in dynamic and uncertain innovative environments to keep track of, and when strategically appropriate, move towards the emerging frontier of knowledge and innovation. It focuses on the issue of how firms can keep abreast of continuously evolving, complex, and dispersed knowledge, and when necessary, adjust or alter their technological and innovative trajectories and capabilities, to stay close to the cutting edge of the evolving field. Building upon concepts from evolutionary economics (Nelson and Winter, 1982) and the behavioral theory (Cyert and March, 1963) of the firm, I suggest that this process is not easily achieved, since individuals and firms alike have difficulties in rationally evaluating the environment and selecting the most appropriate future direction for the firm. Faced with uncertainty and complexity, they do not consider the complete spectrum of choices before them. Instead, they are heavily influenced by current areas of practice and by historical actions when deciding on future approaches. Thus, decisions and actions taken tend to be in the neighborhood of current practices and firms tend to move along existing paths even as new and possibly technologically distant avenues of innovative opportunity appear. Thus it is challenging for firms to keep up with emerging innovative frontiers especially in a dynamic technological and scientific field like biotechnology.

This study looks not just at the challenges faced by firms but, conceptually and empirically, points to solutions that may be available. Organizations can choose from a range of mechanisms to acquire and utilize knowledge that can not only affect their innovativeness but also their ability to adjust their technological and innovative trajectories. The study compares the effect of three key collaborative mechanisms related to knowledge acquisition and innovation. I suggest that the collaborations of individual scientists across organizations gives firms a diverse set of knowledge inputs from a range of external sources and this provides early signals about various innovative directions of the field. The knowledge inputs so obtained and incorporated in to research at the individual level are less impacted by the constraining elements of the organization's routines, structure and culture, and can thus help to redirect the mindset of decision making within the firm and reorient the innovative directions of the firms towards emerging innovative areas. The empirical findings support this idea.

I also argue that two other collaborative mechanisms – strategic (technological) alliances and internal collaborations - are products of existing firm, systems, expertise and world view, and serve to harness knowledge that matches, or is close to, existing activities and trajectories. They are, therefore, likely to enhance local search and help harden existing innovation trajectories. In a dynamic environment, as new areas of innovation unfold, firms that employ these mechanisms will tend to find themselves drifting further away from the evolving frontier of innovation in the field. The empirical analysis confirms these expectations as well. Finally, I show that the level of technological specialization of the firm influences the breadth of the search process. Specialized firms are less likely to increase their alignment with the emerging center of innovation. I also find that specialization reinforces the effect that strategic alliances and internal collaborations have on the direction of future innovation.

This study seeks to build upon, and contribute to, the extant literature in strategy and technology in several ways. Previous research has pointed out that external knowledge can be useful for enhancing the level and quality of innovation within firms (Stuart, 2000; George et al. 2002b; Castellacci, 2009). The research focuses not only on testing the impact of external knowledge on the quality and the quantity of innovation (a question that has been well researched) but rather on the influences of this knowledge on the direction of innovation. Further, I move beyond investigating whether external knowledge can be used for exploration by examining the mechanisms (and conditions) that can lead to adjustments in the innovation profile of a firm. Finally, since in fields like biotechnology the locus of innovation of the field changes across time, I examine which firms are likely to be able to alter their innovative trajectories to keep close to the emerging innovative areas in the field.

One of the main contributions of this study is that while acknowledging that various collaborative mechanisms can be similarly useful in determining the extent of knowledge acquisition and application, there are important differences in how they influence the direction of innovation. Strategic alliances and internal research collaborations may enhance innovation and be useful in extending existing innovative abilities, but they tend to do so along existing trajectories. Strategic alliances and internal collaborations are likely to be useful collaborative tools in fairly stable technological and innovative environments where firms can choose and build their abilities along predictable trajectories. External collaborations at the individual level may be particularly useful in dynamic and uncertain environments since they appear to facilitate and enhance the flexibility of firms to innovate in areas of emerging opportunities.

This research builds on other recent papers that emphasize the role of individuals in knowledge transfer and innovation (Song et al. 2003; Zucker et al. 2002; Rothaermel and Hess, 2007). Individuals have been looked upon as useful conduits for knowledge transfer across firms, and the research confirms this perspective. It is interesting to note that one of the core ideas in organizational design is that various intra-organizational tools and levers are used to align the incentives and actions of individual employees towards the main objectives of the organization. Yet I find here that the value of individual collaborations across organizational boundaries emerges in part from the fact that individuals search a diverse knowledge base and incorporate knowledge and insights that may not be fully aligned with the organization's current way of thinking and practices. In doing so, these individual collaborations can help redefine the perspective of the firm, allow the firm to rethink the landscape of innovative possibilities, and move the innovative trajectory in new directions.

An interesting issue is the contrasting effects of the two external modes of collaboration. Strategic alliances are formal mechanisms formed and implemented at multiple levels of the organization. Alliances can, therefore, be viewed essentially as organizational level mechanisms. Individual scientific collaborations, on the other hand, are often informal in nature and formed at the level of the individual scientist. Here I look at the contrasting effects of these mechanisms on innovative direction. The research is in line with several recent theoretical and empirical studies which argue on the importance of a multilevel perspective when analyzing organizations (Reuer and Arino, 2007; Geels, 2004; Brass et al. 2004). I not only show a direct effect of individual actions on organizational outcomes, but also find a strong interaction effect between the individual and organizational level.

4.5 Specific Limitations

While I have used different models and approaches to ensure the robustness of the results, some limitations remain. First this study is focused on a single industry, which raises questions about the generalizability of the results. The biotechnology industry is special in its reliance upon basic scientific research and its unique product development and approval process. Second, patent and article based measures are limited in the extent to which they can capture firm innovation and collaboration behavior. They may under-represent the individual collaborative activity of companies, since they only measure the collaborations that lead to publications. Nevertheless they provide one of the best measures currently available to empirical research and I have applied them and interpreted them with the necessary care and rigor.

5 CONCLUSION

Though prior research has show, that collaborative mechanism and individual actors matter in the innovation process of firms only very limited research crossed both affects and examined the effect of individual level collaboration on firm level innovation. This dissertation tried to shield light on this issue by examine two fundamental questions: *(1) Do individual-level collaborations positively affect firm-level innovation?* and *(2) Do individual collaborations across firms facilitate firms innovatingat the frontier of emerging?*

To answer the first question I used primarily organizational learning literature. I build on the work Cockburn and Henderson (1998), Rothermel and Hess (2007) and Zucker et al. (2007), who highlight the importance of individual activities in the innovation process, but have not been focusing on individual collaboration specifically and thus did not isolate the effect of individual collaboration from other innovation mechanism. Additionally, previous studies did not investigate moderating factors. The results of this part of the dissertation shows that even after controlling for factors that have been suggested to impact the innovative output of a firm, (quality of a firm's star and non-star scientists, individual-level scientific ability, strategic alliances, and R&D investment) the extent to which a firm's scientists collaborate on scientific articles positively influences the firm's innovative performance. Therefore, this dissertation isolates and highlights the role of individual collaborative activity in enhancing a firm-level innovation. Additionally, this effect is moderated by regional knowledge strength.

However, contrary to the hypotheses, the results do not reveal an interaction between the individual and organizational collaboration mechanism.

The second question focused more on the quality of the innovation resulting from individual level collaborations. It is more related to evolutionary economics and the concepts of path dependency and local search. Prior research in this tradition has shown the firms search for knowledge locally i.e. in the neighborhood of their past practice and their current capabilities and expertise and its very difficult to change their technological trajectories (Nelson and Winter, 1982; Stuart and Podolny, 1996; Rosenkopf and Almeida, 2003; Benner and Tushman, 2003). However, in science and technology driven industries innovation is continuous, sometimes radical, and often rapid (Archibugi and Bizzarri, 2004) and, keeping close to the cutting edge of science and technology is difficult. The challenge for firms is not just to innovate but, when necessary, building innovative capabilities and expertise in new areas in order to keep close to the emerging frontier of innovation in the field. I proposed that individual level collaboration of scientist might provide a tool to help firms to overcome this challenge. Because they can reach across organizational boundaries to collaborate with others on research activities and this can provide the organization with useful additional inputs for innovation. Additionally, these collaborations do not just lead to an increase in knowledge, but importantly facilitate insights and access to the knowledge from a wider spectrum than otherwise not available to the firm.

The results support this arguments, firms with a greater number individual collaborations are more likely to move closer to the frontiers of innovation in biotechnology, while firms with greater number of strategic alliances and internal individual collaborations are likely to move further away. I also find that technological specialization negatively affects the match with the future innovation frontiers and it reinforces the effect of strategic alliances and internal collaborations on future innovation.

Besides the specific contributions discussed in the previous parts, I would like to highlight two overall contributions of this dissertation. Firstly, individual collaborations have a positive influence and innovation performance and enable firms to innovate in ways otherwise difficult to achieve. This suggests that individual collaboration provide an additional tool for managers at the individual-level, which helps in increase innovation performance. Thereby, it can not be assumed that individual collaboration are completely endogenous of the overall firm strategy, however, managers can intentionally integrate them in the strategy process. It might be difficult to organize and foresee individual collaboration top down, but top management can create structures and incentives to foster their creation.

Secondly, the results build on a well established stream of research that examines the effect of collaboration at the organizational level. However, the dissertation moves beyond the emphasis of firm level collaborative mechanisms and highlights the importance of individual collaborations. Thus it shows the role of the underlying sociology of individuals in influencing observable organizational outcomes. In this way, it adds to the growing body of research that focuses on the implications of individual level phenomena such as mobility of engineers or hiring of star scientists in explaining organizational level outcomes. The research makes also the point that it can be fruitful to investigate the interdependencies between both levels.

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