Firm heterogeneity in biotech: absorptive capacity, strategies, and local-regional connections

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ABSTRACT

This paper focuses on the characteristics of biotech firms with various levels of R&D activity. It does this by exploring the relationship between R&D intensity, alliances and the extent of regionalisation of firms' activities using evidence from a survey of US-based biotechnology firms. We profile two firm prototypes: research oriented firms and product oriented firms, focusing on their characteristics, strategies, and operations. These include activities devoted to exploration and exploitation through alliances with universities (more exploration) and with pharmaceutical companies (exploration and exploitation), and locational needs which facilitate both exploration and exploitation.

Keywords: biotechnology, R&D intensity, alliances, local-regional processes

1. INTRODUCTION

Biotechnology firms are inherently research and development (R&D) intensive (Pisano 2006, Khilji et al. 2006, Gans and Stern 2003). While it is R&D that is critical to the survival and growth of firms, the strategies firms adopt in harnessing that activity for survival and growth, vary considerably. Studies have shown that biotech firms can be creators of knowledge and market driven enterprises (Oliver and Montgomery 2000). Full integration of R&D, pilot manufacturing, large-scale manufacturing, and marketing is rare. Internal variety in strategy and innovative output is matched by variations in need for external input to augment exploration (upstream) and exploitation (downstream) activities. This input often takes the form of alliances with industry and universities, domestic and foreign, designed to acquire, assimilate, transform, and exploit knowledge (Lee 2007, Pisano 2006). The facility to capitalise on external resources depends on firms' levels of absorptive capacity (Cohen and Levinthal 1990, Veuglers 2005, Shefer and Frenkel 2005). A proxy for absorptive capacity is the R&D intensity (Cohen and

Levinthal 1990), that is, internal learning potential or the capacity to absorb external input which complements internal R&D (Bierly and Chakrabarti 1996, Kim and Inkpen 2005, Kodama 1995). However, very little analysis has been undertaken on how firms with varying levels of R&D intensity differ in terms of firm characteristics, alliances, business strategies, and performance and how this translates into the extent to which they draw on regional resources.

The purpose of this paper therefore is to further our understanding of firm-level heterogeneity in the biotech sector using R&D intensity as a proxy for absorptive capacity (Koza and Lewin 1998, Del Canto and Gonzalez 1999, Tsai 2005). Specific objectives are to understand firm-level characteristics (e.g., size, innovation, revenue, internationalization), business strategies, reasons for pursuing alliances with university and industry, and the extent to which firms' needs are met at the regional level. No a priori hypotheses can be suggested based on the literature to characterize similarities and differences in the above constructs (i.e., firm characteristics, strategies and local needs) for firms with varying levels of absorptive capacity. Instead, this paper explores whether firms with higher levels of R&D intensity are focused on exploration. Exploration is loosely defined as being more research orientated than a focus on product development, which may not necessarily be dependent on the stage of the firm but more on functional orientation (i.e., technology platform, drug discovery, diagnostics). For example, some biotech founders are serial entrepreneurs and opt for new start-ups rather than pushing forward with integration.

The rest of the paper is organized into three sections. In the first section we develop the conceptual framework reviewing the literature on absorptive capacity, R&D and alliances in the

sector with industrial partners and with universities. In the second, we present the context, methodology for the study and the empirical analysis, highlighting the complexity of the sector by portraying the different markets of research- and product-oriented firms. Third, in our conclusions, we demonstrate a marked diversity between the two groups, especially in the critical importance of alliances with large firms and universities. The survey shows that regionalization of resource acquisition is generally not as strong as suggested by the literature, except in one respect; the key locational attribute is the availability of skills in the local labour market.

2. RESEARCH CONTEXT

2.1 Absorptive Capacity, Firm Characteristics, and Strategies

Our framework for analysis is based on the concept of 'absorptive capacity'. We begin by explaining the concept's relevance to this study by discussing each of the three elements of the study. These are R&D intensity and variations in innovative outputs; the need for external input and the form, extent, and content of alliances with other firms and with universities; and locational factors, the regionalization of some and not other activities of biotech firms.

2.1.1 *Diversity of R&D Intensity and Innovative Outputs*

The diversity of R&D activity within a sector is a useful way of analysing how firm-level R&D intensity relates to research and translational activities, as well as external inputs. As Roger (2002) points out, there is a distinction between the input of R&D process and outputs such as innovation. The two of course are connected. Lin et al (2006) find that commercialization orientation and R&D intensity complement each other and that a firm's commercialization

orientation can play a more important role than R&D in the process of exploiting the value of technology assets. With respect to the biotech sector, according to Pisano (2006, 119), R&D intensity differs in three respects from other R&D intensive sectors. Firstly, profound and persistent uncertainty rooted in the limited knowledge of human biological systems makes drug R&D a highly risky venture. Second, drug R&D requires interdisciplinary involvement (molecular, cell biology, computational chemistry, genetic engineering and so on, see www.bio.org). Third, much of the knowledge in the diverse disciplines is tacit, which means that harnessing collective learning is particularly difficult.

The absorptive capacity concept is one which also recognizes the cumulative nature of learning, as well as uncertainty and diversity. The concept has been directly applied to study learning and the application of learning in small biotech firms and is implicit in much of the work on alliances in the biotech sector. Gittleman and Kogut (2003), for example, studied the United States biotechnology industry as a community of practice caught between two evolutionary logics by which valuable scientific knowledge and valuable innovations are selected. They analyzed publications and patents of 116 biotechnology firms during the period 1988-1995. Their findings suggest that the role of the small, research-intensive firm is to create a repository of knowledge; to act as an organizational mechanism to combine the capabilities of versatile scientists within and outside the boundaries of the firm; and to manage the selection of scientific ideas to produce valuable technical innovations. Technical innovations require considerable creativity capacity. Traore (2004) in a study of the Canadian biotech sector used the concept of absorptive capacity in understanding the creative capacity of firms. By using the number of products and processes at all stages of development as an indicator of creative capacity, her study results show that

absorptive capacity, relational capital, learning, expansion into international markets, and firm characteristics are all key determinants of creative capacity. This study also emphasized diversity. Not all these factors were found to be equally important at all stages of product development. For example, results show that at the R&D stage, success drivers are firm absorptive capacity and firm characteristics. Issues related to product commercialization, however, had no bearing on creative capacity at that stage. Expansion into international markets and experience in biotechnology are the greatest firm creative capacity assets at the commercialization stage.

2.1.2 External Input

Factors interrelated with innovative outputs and absorptive capacity are the scope of alliances. Outside sources of knowledge span the spectrum from informal networks to formal strategic alliances with university and industry (Dickson et al. 1997). This has been termed "alliance capitalism", defined as "the organisation of production and transactions as involving both co-operation and competition between wealth creating agents" (Dunning 1997, 73). In the bio-pharma industry, alliances are often driven by large pharmaceutical companies which are increasingly looking to partner with smaller dedicated biotech firms (DBFs) to improve their R&D performance and their clinical development (Kaitin 2007), while biotech firms are seeking to establish a market presence, access to business resources and risk reduction (Lee 2007).

The need for external input to in-house R&D activity per se was recognized by Cohen and Levinthal (1990). They begin their article with the following argument: "Outside sources of knowledge are often critical to the innovation process, whatever the organizational level at which

the innovating unit is defined." They state that, "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities. We label this capability a firm's absorptive capacity and suggest that it is largely a function of the firm's level of prior related knowledge" (p.128). They cite research which shows that firms that conduct their own R&D are better able to use externally available information, implying that absorptive capacity may be created as a by-product of a firm's R&D involvement.

Lane and Lubatkin (1998) argue that Cohen and Levinthal's definition of the construct suggests that a firm has an equal capacity to learn from all other organizations. They modify the concept at the firm-level as "relative absorptive capacity" to study pharmaceutical-biotechnology R&D alliances. In their version, one firm's ability to learn from another firm is argued to depend on the similarity across firms in terms of (1) knowledge bases, (2) organizational structures and compensation policies, and (3) dominant logics. They found that the similarity of the partners' basic knowledge, lower management formalization, research centralization, compensation practices, and research communities were positively related to inter-organizational learning. Moreover, the structure of alliances (vertical and/or horizontal) also has a greater impact on firm performance than can be explained by absorptive capacity (see also Rothaermel and Deeds 2004). In other words, the relationship between absorptive capacity and alliances is complex contingent upon various factors which are firm-specific as well as specific to firms' environment. Other studies of R&D collaboration in biotech and other high tech sectors have also considered internal R&D capabilities and the relationship with external R&D alliances. Many have found that they are not substitutes but complementary (Arora and Gambardella 1994, Mowery and

Rosenberg 1989, 1996, Pisano 1988, 1990, 1991, Greis et al 1995, Powell et al. 1996). Internal capabilities enable effective screening and evaluation of research done outside, while external partnering provides access to new technologies and minimizes the cost, time, and risk involved in R&D (Van den Bosch et al. 1999). In fact, R&D intensity is a significant predictor of collaborative efforts (Hagedoorn 1995), which reach global scales as well (Liebeskind et al. 1995, Madhok and Osegowitsch 2000, Powell et al. 1996).

Participation in collaborative networks is systemic and changes over time but there is considerable debate over the evolutionary path. Some observers note that as biotech firms grow, both in age and size, they expand their research and financial linkages (Powell et al. 1996, 2002), hence their absorptive capacity changes. Zucker and Darby (1996) on the other hand, suggest an opposite pattern: smaller dedicated biotechnology firms (DBFs) increase alliance formation early in their life cycle when they shift from the exploration stage to commercial exploitation of their innovations, they reduce the number of their alliances eventually to decrease potential risks from collaboration. Firms therefore must strike a balance not only in their exploration versus their exploitation activities, but also in combining in-house research expertise with external R&D alliances to expand their knowledge base.

George et al. (2001) argue that alliances should not be seen as individual events or transactions, but rather their synergistic effects should be recognised as a coherent portfolio. They suggest that portfolio characteristics will be associated with a high technology firm's innovative and financial performance, that they will influence absorptive capacity. Their study tested these propositions using a sample of 2456 alliances formed by 143 biopharmaceutical firms. The results indicated

that alliance portfolio characteristics and absorptive capacity jointly influence performance. This study provides further evidence of the value of Cohen and Levinthal's (1990) "absorptive capacity" argument in helping clarify this search for striking a balance between internal and external activities: according to them a firm is more likely to benefit from collaborative arrangements with external partners when its internal capabilities are sophisticated enough to allow it to absorb new knowledge.

Also recognising temporal aspects of external inputs, Newey and Shulman (2004) extend the concept to systemic absorptive capacity, with an emphasis on how in complex emergent technologies, product-market success depends on efficient linkages between changing lead innovators within the R&D process. This systemic absorptive capacity is the cumulative efficiency in the use of absorptive capacity to link changing lead innovators across successive milestones in R&D product development. Their unit of analysis is a complex high technology product and the system of alliance linkages formed to progress a product through R&D milestones, rather than single firms or single alliances in R&D.

The concept of system encompasses the close association between the birth and growth of the biotech sector and alliances with universities as well as industry. From its inception, the biotechnology sector has been characterized by scientific discontinuity and radical breakthroughs, with industry observers using adjectives like "competence destroying" (Powell et al. 1996) and "naturally excludable" to depict the sector's innovations (Zucker and Darby 1996, Zucker et al. 1998). For Pisano (2006, 116), the biotech sector "fused the two domains" of science and business as universities have become "active participants in the business of science", and the boundary between a biotech firm and universities is often blurred. This assertion is

supported by Fabrizio's (2004) study of 83 biotech and pharmaceutical companies over time - more in-house basic science research and collaboration with university scientists by a firm are associated with more exploitation of published scientific research and shorter lag times between existing knowledge and new firm inventions exploiting this knowledge.

2.2 Regionalisation of Resource Inputs

Most of the research tracing the industry's evolution in its early days focused on university-industry knowledge spillovers and the crucial informal and formal links with the academic science base (Audretsch and Stephan 1996, 1999, Feldman 2003, Kenney 1986, Prevezer 2001, Prevezer and Toker 1996, and Zucker et al. 1998). Liebeskind et al.'s (1995) case studies of two successful California-based biotechnology firms and their informal linkages with scientists external to the firm show the importance of social networks[1]. These cases also illustrate how informal alliances provide organizational learning flexibility through learning-by-doing, reduced R&D costs and reduced R&D time, as well as the ease of switching sources of learning without incurring additional negotiation costs. In their study, the importance of informal links is analyzed using a count of collaborative publications and patents of scientist-employees of biotechnology firms. The authors note significant contributions by scientists from institutions outside California, as well as outside the United States. They conclude that the presence of long-distance relationships reduces the strength of the argument that biotechnology collaborations are regionally or even locally embedded, which in their opinion diminishes the role of geography in

[1]Based on Liebeskind et al. (1995, pp. 6-7), a social network is defined as a collectivity of individuals among whom exchanges take place that are supported only by shared norms of trustworthy behavior (reciprocity, respect for intellectual property rights, honesty in research). Unlike hierarchies, but like markets, social networks involve exchanges between legally distinct entities. Unlike markets, but like hierarchies (governance of exchange within a firm), social networks support exchange without using competitive pricing or legal contracting. Shared norms of exchange in trust-based relationships ensure a fair outcome.

explaining the formation of alliances in the biotechnology industry.

This view is at odds with work by Cooke (2002, 2004, 2005) who examined firm clusters in proximity to knowledge sources in science-based clusters. In the case of biotechnology, universities are key magnets. Likewise Autant-Bernard et al. (2006) in examining the determinants of the creation of biotech firms found that high levels of scientific activity within a region is necessary to sustain a continuous flow of new business creation. The likelihood of firm creation depends on scientific and technological organizational factors such as cooperation between academic and private organizations. Thus, the absorptive capacity of individual firms is also related to the regional as well as the national and international availability of knowledge. This is because regional and local tacit knowledge as well as the availability of information elsewhere is potentially a key factor in whether firms can "recognize the value of new, external information, assimilate it, and apply it to commercial ends." Moreover, location is one of three signaling mechanisms which can overcome information asymmetries, as well as aid the evaluation of a potential alliance partner's resource-base and product commercialization capacity (Coombs and Deeds 2000 in Lee 2007).

In sum, the concept of absorptive capacity and its development encompasses a number of elements which will be used next to examine the results of the study. These are that R&D intensity is a proxy for a firm's capacity to absorb, assimilate and use knowledge and is an indicator of whether firms are exploration or exploitation orientated. It has been applied to analysis of firm-level activities, as well as systems of informal and formal alliances. Finally, the concept allows an understanding of the extent to which linkages are affected by factors at local

compared to national and international geographical scales.

3. METHODOLOGY AND RESULTS

3.1 Methodology

The methodology adopted here draws on studies which have analysed product development as the key component in the competitive strategies in the biotech sector. In summarizing a roundtable discussion of pharmaceutical industry leaders, Kaitin (2007) argues that to maintain a 5-8 percent growth goal, companies are required to develop and introduce between two to nine new products a year; in the last five years, the top ten pharmaceutical firms have typically brought about 0.6 new drug products to market annually. Consequently, firms that outsource non-core strengths are the most likely to survive and grow (Kaitin 2007). Further indicating the interconnection of firms within the industry, Kaitin's report for the Tufts Center for the Study of Drug Development indicates that product-oriented firms will increasingly rely on research-oriented ones to improve their product development capabilities (see also Pisano 2006).

The analysis presented here is based on a survey of US biotech firms in 2004-2005. Two lists were consulted for the survey: firms with primary focus on human health and those with primary focus on agricultural and other types of biotechnology. The ratio of human health firms to other is slightly over 3:1. Some firms are inherently heterogenous—for example, diagnostics and therapeutics are often combined, and agricultural biotechnology firms often focus on environmental biotechnology. The data sources for the lists were the North American Biotechnology Directory supplemented with lists available from the Biotechnology Industry Organization and BioSpace. The names of agricultural biotechnology and other firms were

compiled from the Information Systems for Biotechnology (ISB), the Biotechnology Industry Organization, and BioSpace. The total number in the list was about 1300 firms. A sample of approximately 500 firms received the survey in 2003-2004; 362 were randomly picked from the health group and 151 were randomly selected from the non-human health category. A total of 142 responses were obtained: 94 health and 48 non-human health biotechnology firms. The survey process included three mailings, numerous phone calls, faxes, and e-mail reminders. The geographic distribution of the respondents match the regional pattern of U.S. biotechnology firms—the top 3 states are California, Massachussetts, and North Carolina (close to one-third of the total sample of 142 respondents). The two broad groups are combined to understand the overall characteristics of firms in this sector; such aggregation has been used by the pioneering studies on the U.S. biotechnology industry (Prevezer 2001).

The survey included questions on firm-level characteristics, business strategies, patenting, product development and alliances. R&D intensity (R&D intensity is defined as the percentage of revenue expended on R&D), a firm-level characteristic and a proxy for absorptive capacity, is used to classify firms in two groups using the mean value (40 percent) as the point of differentiation: low R&D intensive firms and high R&D intensive firms as indictors as differences in absorptive capacity. Similarities and differences between the two R&D groups are examined. To do this, characteristics used to compare and contrast the two categories to explain diversity within this sector are: size measures, knowledge/innovative output, revenue sources, the association between innovation and revenue, strategies with regards to exploration and exploitation, reasons for alliances with universities (more exploration) and pharma (exploration and exploitation), and location needs facilitating exploration and exploitation.

3.2 Results

The analysis below focuses on firm characteristics and alliance as well as location strategies to highlight firm-level heterogeneity in the biotech sector based on differential absorptive capacities. R&D intensity is used as a proxy for absorptive capacity. Firms are grouped into two categories using the average value for R&D intensity for the sample. The discussion of the characteristics of the two groups of firms is further sub-divided into two sections below: (i) market segment and size distribution, and (ii) R&D, innovation, and performance

3.2.1 *Market Segments and Size Distribution*

Table 1 shows that firms with low R&D intensity are quite diverse in terms of market segmentation but firms with high R&D intensity are heavily concentrated in the therapeutic sector. The distribution of firms in the sample across the employment categories[2] is not very different for the two groups of biotech firms. However, the revenue distribution shows a larger percentage of high R&D intensity firms (henceforth referred to as high R&D and low R&D firms) in the micro category (firms with revenue less than $10 million) - almost three quarters of all firms with high R&D intensity are micro compared to only about half the firms with low R&D intensity.[3] In sum, the high R&D firms are smaller in terms of revenue and more focused on therapeutics (e.g., drug discovery, exploration of new frontiers) while the low R&D firms are slightly larger with relatively more diverse markets. The values on the share of internal R&D are comparable for two groups showing similar needs for external input although the average level of R&D intensity for low R&D firms is 13.7 percent versus 81.6 percent for the high R&D firms. This suggests that differences in absorptive capacity translate into sub-sectoral, financial

[2]Five categories of employment: <=10, 11-50, 51-100, 101-500, >500; firms with less than 500 employment are defined as small and medium-sized enterprises (SMEs)
[3]Further discussion of revenue is presented below in the section on strategy.

and developmental characteristics rather than the level of need for external input.

3.2.2 *R&D, Innovation, and Performance*

The mean number of patents is slightly higher for high R&D firms but the mean number of new products is higher for low R&D firms (Table 2). The two groups are highly comparable in the numbers of products going through stage three clinical trials but the low R&D firms are ahead of the high R&D firms in their share of products in the regulatory process. Product orientation is further confirmed for the low R&D firms with the figure for the average value of revenue (79%) from product sales. The high R&D firms generate only 46 percent of their revenue from product sales on average. The high R&D group is also heavily dependent on funds from contracts and collaborations for their revenue generation. Both groups serve export markets but the export intensity is slightly higher for the low R&D firms as compared to the high R&D firms. Approximately, 78 percent of the low R&D firms reported owning their own manufacturing facility compared to about half of the high R&D firms. Both contract out production work. Both groups have foreign subsidiaries--more low R&D firms have subsidiaries compared to high R&D firms.

Both groups are highly innovative given the industrial sector within which they have to compete. The high R&D firms are investing a larger share of their revenue in R&D,[4] but are not necessarily pure research boutiques with 100 percent of their revenue invested in R&D functions. As noted in Table 2, the number of firms with no products in clinical trials and regulatory process is comparable between the two groups. The diverse market orientation of the

[4]Any comparison of dollar values is not possible; disclosure/proprietary issues prevented firms from giving out R&D dollar figures

low R&D group has allowed the firms to exploit their innovation and hence the average percentage of revenue generated from product sales is much higher for this group. Both recognize the importance of production in-house and external contracts. The international orientation shows the ability of biotech innovators to exploit their discoveries in the worldwide market by becoming "born globals." In the above section, differences in absorptive capacity seem to reflect divergent product orientation, with one group (low R&D intensity) showing the existence of developed markets (based on the nature of their functions rather than age or stage of firm development) mainly in the diagnostic sector.

Table 3 shows the association of R&D intensity with innovative output categories and revenue sources. The chi-square values for patents, products in clinical trials and regulatory processes reconfirm that the two groups are very similar when we consider exploratory activities (e.g., patent and product development). The rest of the chi-square values reconfirm the difference between the two groups. For example, low R&D firms are more or less evenly distributed between the two product categories (0-1 or more than one product). However, three-fourth of the high R&D firms is in the 0-1 product category. The pattern is very similar for the revenue grouping, that is, an even split between micro (less than 10 million) and other firms for the low R&D firms category but 71 percent of low R&D firms belong to the micro category.

The association between the two groups of firms and revenue sources highlight the following differences: (i) over three-quarters of low R&D firms derive above average revenue from product sales compared to about one-third of the high R&D firms (chi-square 13.03 p=.000), (ii) only 15 percent of low R&D firms get above average revenue from contracts but 69 percent of

high R&D firms receive above average revenue from contractual agreements (chi-square 25.4 p=.000), (iii) only 17 percent of low R&D firms receive above average revenue from royalty/licensing but the distribution of firms across the licensing categories is almost an even split for the high R&D firms (chi-square 10.54 p=.001), and (iv) while 40 percent of low R&D firms have high levels of export intensity, only 22 percent of the high R&D group show high levels of export intensity (chi-square 3.5 p=.06). A large share of low R&D firms has higher than average share of revenue from product sales and exports while more high R&D firms have higher than average revenue from contracts and licensing activities. High R&D firms are either providing service through contracts or undertaking co-R&D, co-product development/production or co-marketing. High R&D firms are also suppliers of knowledge to other biotech firms and a variety of other industrial sectors and as a result, they rely on licensing as a major source of revenue.

3.2.3 *External Input*

Here, we first examine the general corporate strategy of the biotech firms with regard to finding external inputs for R&D, production and marketing operation, and second, specific strategies for pursuing university- and industry-based alliances. Strategic considerations are evaluated by the biotech firms on a five point Likert scale[5] -- these considerations cover a wide range of external inputs to their operations such as alliances, acquisition of other biotech firms, licensing activities, investors, internationalization, and user feedback (Table 4). These have been identified in a number of academic and commercial studies such as Accenture (2004). In the current study, low R&D firms are almost evenly split in considering the importance (H=highly critical and L=not as

[5] Five point Likert scale: 1=not important, 2=somewhat important, 3=important, 4=very important and 5=critically important

critical) of alliance strategies (universities, large companies, and other biotechs) to their operation. On the contrary, a much higher percentage of high R&D firms consider alliance strategies with universities, large companies (chi-square 19.74, p=.000), and other biotech firms (chi-square 8.43, p=.004) as critical to their operations. This finding shows that high R&D intensity is associated with the intent to collaborate or absorb external input.

Both groups have more or less equal share of firms that consider licensing-in technologies and acquisition of other biotechs as critical. Licensing is extremely common in bio-pharma. Examples of mergers and acquisition are also commonplace in this sector as well. For example, the US vaccines firm Chiron acquired the UK Oxford University spin-off company PowderJet in order to obtain its vaccines business which it had acquired through the purchase of Evans Vaccines. Subsequently Chiron was acquired by Novartis (Lawton Smith et al. 2007) (see also Cooke 2004 for examples of acquisitions in the biotech sector).

Internationalization is essential to this sector as well, but the pattern of strategic criticality for establishing a laboratory in a foreign country to enhance R&D is similar for both groups of firms—a small number from both categories regard this function as critical toward sustaining and advancing innovation based commercialization. However, a larger number of low R&D firms compared to high R&D firms view the establishment of production facilities in foreign location as critical (chi-square 4.35, p=.03). A much larger share of firms from both groups consider alliance with foreign firms as critical for penetrating their markets, consistent with Dunning's (1997) discussion of "alliance capitalism" as both groups have exporters and own subsidiaries in foreign locations (Table 1).

More high R&D firms rate the critical importance of domestic (chi-square 10.5, p=.001) as well as foreign investors (chi-square 11.66, p=.000). The survey found that about three-fourths of high R&D firms compared with about one-half of low R&D firms rate "seeking domestic investors" as critical while two-thirds of high R&D firms compared to one-third of low R&D firms consider "seeking foreign investors" as absolutely critical toward sustaining innovations.

Two additional strategies are critical—licensing-out technologies and the incorporation of user feedback to improve R&D, product development and production. A larger share of high R&D firms consider licensing out as critical (chi-square 18.4, p=.000)–these firms do not generate a large portion of their revenue from product sales as shown in Table 1. For both categories, close relationship with users ensures proper feedback, repeat business, and word-of-mouth advertisement of their products—a slightly larger share of low R&D firms rate user feedback as highly critical (chi-square 2.6, p=.10). For example, in agri-biotech, a sector which is highly product oriented, companies strive to keep close contact with farmers who are the primary users of genetically modified seeds. The farmers not only provide information about the performance of different types of seeds but can also provide information on public opinion about genetically modified crops (Bagchi-Sen and Scully 2007). These examples provide further examples of how the concept of absorptive capacity is translated into practice.

3.2.4 *Reasons for Seeking External Input*

From Table 5, strategic consideration with regard to large company alliances can be gleaned. The two groups of firms differ in their evaluation of the reasons for forging alliances with large

companies. Seven reasons are considered. The need of high R&D firms to forge alliances with industrial partners is reconfirmed. Earlier (Table 4) it was noted that over 80% of high R&D firms wanted to collaborate with large firms and other biotechs. In this analysis, accessing R&D funds, risk reduction in R&D, credibility in R&D, attracting third party investors, and accessing research and market information are rated as highly critical by more than 50 percent of the high R&D firms. The two groups are more or less similar in their assessment of the criticality of the following two factors: quality control in R&D and product development as well as scaling up manufacturing.

3.2.5 *Proximity to External Input*

Table 6 shows the importance of physical proximity to local availability of collaborators, scientists, services and government assistance. A larger percentage of high R&D firms compared to low R&D firms rate proximity to universities (already discussed earlier) and other biotech firms as highly critical (chi-square 5.80 p=.01) while a larger percentage of low R&D firms (33%) compared to high R&D firms (15%) rates the availability of local contract manufacturing as highly critical to their operations. Other biotech firms may or may not serve as collaborators but a cluster of firms ensures a rich labor market for scientist. Table 6 shows that over 50% of both groups of firms consider proximity to a scientific labor market as highly critical to the business of biotech. The presence of other biotech firms is also correlated with the presence of related services (e.g., legal), venture capital and government assistance—firms from both groups consider proximity to these three functions as highly critical.

3.2.6 *Regional Needs*

The close association between universities and the biotech sector and its evolution is reviewed in Table 7, which further analyses biotech firms' evaluation of alliance strategies with universities. Very similar shares of both groups of firms rate the following reasons for university-based alliances as critical: credibility, funding, access to technologies (both early and breakthrough. In terms of ranking, "credibility" seems to be the most important strategic consideration for pursuing alliances with universities. In the analysis of biotech founders and scientific advisory boards, Audretsch and Stephan (2000) have shown how star scientists signal the potential of a company to investors. The importance of universities as sources of knowledge, scientific labour, and other forms of alliance capital (e.g., incubators) are well-known for the biotech sector. A key question is the importance of proximity to universities--the role of Stanford, MIT, Johns Hopkins, University of Wisconsin-Madison and others in the creation on biotech agglomerations/clusters is well accepted but limited data are available to predict that all research one universities in the United States will have similar experience with translational research.

The current analysis shows the importance of needs being met at the regional/local level (see Table 7). It is striking that both groups of firms rate proximity to universities as critical. However, a tabulation of the location of university partners for these two groups of firms shows that about half of low R&D firms and about two-thirds of high R&D firms note as having their main university partner in the local area thus proving that practice is often different from intent/strategy. A large number of firms, especially low R&D firms, collaborate with universities which are elsewhere in the United States.

3.2.7 *The Geography of Absorptive Capacity*

The location of inputs to biotech innovation and commercialization is highlighted by this study. It shows that localization of inputs varies by types of firms. The pattern of the extent of localization needs differs sharply between the two groups and in linkages with universities compared to those with other firms. Results on the location of industrial partners show that for both groups, many have industrial partners which are located out of state (table not shown). Only 28.6 percent of low R&D firms and 19 percent of high R&D firms note having local industrial partners--this matches the trend noted earlier on the criticality of the availability of local contract manufacturers by a slightly larger share of low R&D firms. It should be noted that only 27 out of 43 low R&D firms noted having contract manufacturing of which majority (17) were located out of state; 18 out of 31 high R&D firms noted having contract manufacturing of which majority (14) were out of state. To complicate matter further, not all firms have locally owned manufacturing facilities: about one-fifth of low R&D firms and one-third high R&D firms have out-of-state location of their own manufacturing facilities. These data show that external location of subsidiaries and/or externalization of biomanufacturing is quite common in this sector. The reasons can be speculated upon as the lack of expertise in the local area, the lack of appropriate land (e.g., availability, price) to build facilities, and stringent regulations (e.g., Cambridge, Massachusetts). For example, certain states, such as North Carolina, are developing competitive advantage in biomanufacturing based on their previous experience in related industrial activities.

4. CONCLUSIONS

This paper set out to explore the heterogeneity within biotech firms using evidence from a survey

of US-based biotech firms. Similarities and differences in firm characteristics, alliance strategies, and locational needs are examined using absorptive capacity as the concept to represent heterogeneity. R&D intensity is used as a proxy for absorptive capacity and the biotech firms are divided into two categories which can be distinguished based on their characteristics and strategies to be more research-oriented firms focused on exploration (high R&D intensity) and more product oriented firms (low R&D intensity) focused on commercial exploitation of their innovation. Both groups have similar needs to absorb external input but they differ in their strategies and needs based on their functional, product, and market orientations. In other words, R&D intensity as a proxy for absorptive capacity is useful to conceptualize heterogeneity in biotech firms but broad generalizations for high tech firms can be limited without a closer look at size, innovative output, and performance. Some similarities and differences are highlighted below along with implications for the geography of science-based sector and its potential for local development.

The study identified a number of striking differences between the two groups of firms, and also some similarities. The main differences in the characteristics of firms are that the low R&D firms are in diverse market segments while high R&D firms are mostly in the therapeutics sector. High R&D firms are much smaller both in employment and revenue and the low R&D firms have a far greater number of products and their revenue is twice as likely to come from product sales. Again by definition the high R&D firms are more R&D intensive with the high R&D firms being more than three times as R&D intensive than the low R&D firms, showing distinct intra-sectoral differences (Khilji et al. 2007). Where they are similar is that both kinds of firms supplement their R&D from external sources (e.g., licensing-in technologies, alliances, and acquisition of

other biotechs), have similar numbers of products going through stage three of clinical trials, both exploit their innovations through licensing-out, and pursue internationalization through alliances with foreign firms for marketing purposes; more high R&D firms show interest in internationalization through attracting foreign direct investment to their US facilities (Pisano 1991, 2006, Powell et al 2006). For both groups, close relationships with users (e.g., pharma) is important for technical feedback, repeat business and so on but more high R&D firms rate alliances with larger companies as being critical thus further highlighting diversity within the biotech sector, as earlier suggested by the concept of relative absorptive capacity (Lane and Lubtakin 1998). These firms are focused on research and are keen to commercialize their innovations.

Motivations for alliances with universities are similar for both groups--credibility, funding and access to technologies are cited as critical. Both groups gave equal emphasis on the extent to which they forge links with local universities--around half of the firms rate physical proximity as being of critical importance. However, the high R&D firms are much more likely to have their main university partner in the local region and the low R&D firms are more likely to collaborate with universities elsewhere in the United States. This pattern is not matched by linkages with industrial firms. Just over a quarter of low R&D firms and less than a fifth of high R&D firms have local industrial partners, and many firms did not have their own bio-manufacturing facilities in their home state. Moreover, a larger percentage of high R&D firms rate industrial alliance as critical--this is indicative of their resource limitations but the presence of absorptive capacity given the commitment to R&D. These firms seek assistance with R&D access, risk reduction, and credibility to attract third party investors.

Our results contribute to our understanding of the absorptive capacity as it relates to diverse characteristics and needs of firms that belong to the biotechnology sector. Firms vary by R&D intensity, size, market segments and many other factors. In this paper two groups of firms are compared: one with relatively more research (exploration) orientation than product (exploitation) orientation and the other with relatively more product orientation than research orientation. The paper confirms that research oriented firms' strategies (intent) and practice show the need to augment R&D through external inputs such as alliances.. They do have some marketable products but revenue is mostly generated through licensing-out technologies and contracts as well as collaborations. They seek collaboration with university and industry partners.

The evidence on the importance of the region as a source of external input is counter-intuitive. Although firms emphasize the importance of physical proximity to collaborators (e.g., universities), in reality, a large percentage of their collaborators are not located in the same state. Accordingly, these firms are also internationally oriented to seek investments, collaborations, and markets. They are "born globals" like most biotechs with innovative products.

The low R&D or product oriented firms have some similar characteristics with the high R&D group such as they do have a large number of firms with 0-1 product and firms with products going through third stage clinical trials. Compared with the high R&D intensive group, these firms are more exploration oriented and serve a more diverse set of markets – therapeutics, diagnostics, vaccines etc. These firms are more similar to typical small and medium enterprises in other high technology sectors – they generate most of their revenue from product markets,

they have their own manufacturing but do externalize some bio-manufacturing activities, and they do augment their internal operations through alliances but they do not rate industrial alliances to be as critical as the high R&D firms. They are also much more likely to have local needs. They seek local presence of partners especially contract manufacturers. At the same time, they are more interested than high R&D firms in establishing manufacturing facilities abroad.

This paper shows that the relationship among the following variables differs across firm types thus proving the existence of significant heterogeneity within the biotech sector: R&D intensity, innovation or exploratory activities, product development, exploitation of products, patterns of alliances or existing collaborative practices, and strategic intent in terms of collaboration and proximity to collaborators. The diversity presented here shows that one group of firms is very much similar to small manufacturing firms in general while another group (research-oriented) is focused on outputs that are knowledge-intensive (e.g., patents, technologies) and require various types of resources to be able to successfully exploit their innovative outputs. These knowledge suppliers are critical in the biotechnology value chain and local policymakers need to recognize that these firms need facilitation through local resource provisions (e.g., wetlabs) as well as help in seeking external collaborators (e.g., biomanufacturers) and investors (e.g., foreign companies).

Thus, this paper has shown how different manifestations of the quality of absorptive capacity in the form of diversity of R&D activity in the biotech sector translates into firm characteristics in the form of the nature and scope of in-house research and production activities and external inputs. It presents evidence on differing systemic features within the sub-sectors of biotech, in the scope of innovative inputs and outputs and their location, and especially shows that the

importance of local links with universities should not be overestimated. Thus for biotech firms, absorptive capacity includes the ability to overcome the friction of distance in setting up collaborations to create trans-territorial knowledge and production networks but at the same time appreciating the role of the region as the source of scientific talent and other human capital. The region also provides exposure of the firm to the outer world of collaborators, markets, and financiers. Whether firms with similar scientific achievements located in different parts of the United States will have similar opportunity to capitalize on their scientific breakthrough is still a topic of interest given the current policy agenda on fostering innovation-led economic development.

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Table 1: Firm Characteristics

Characteristics	**R&D Intensity**	
	Low	**High**
Market Segment		
Diagnostic	12.2%	0.0%
Therapeutic	26.8	67.3
Other (e.g., agri, vet, environment)	61	32.7
Year Established (median value)	1983	1992
Employment		
Less than 10	16.3	16.3
11-50	35.0	40.8
51-100	8.7	6.2
101-500	23.8	28.5
>500	16.2	8.2
Revenue Groups		
Less than US $1million	25.5	32.7
US$ 1-10 million	27.5	38.8
US$ 11-25 million	12.5	16.3
US$ 26-50 million	12.5	6.1
More than $50 million	22.5	6.1

Table 2: Patterns in Product Development and Production

Product Development	**Low R&D Intensity**	**High R&D Intensity**
R&D Intensity (percent revenue spent on R&D - mean value)	13.7%	81.6%
% of Internal R&D (mean value)	73.4	68.0
Patents (mean value)	12.0	21.3
Total new products in past 5 years (mean value)	15.6	3.3
Total new processes in past five years (mean value)	2.1	1.3
Products in phase 3 clinical trial[1]		
0	45.0%	50%
1	22.5	28.9
>1	32.5	21.0
Products in the regulatory process		
0	47.7%	66.7%
1	29.5	27.8
>1	22.7	5.6
% Revenue from Product Sales (mean value)	79.4	46.5
% Revenue from Royalty (mean value)	5.9	15.4
% Revenue from Contract/Collaboration (mean value)	15.0	60.6
% Revenue from Exports (mean export intensity)	19.8%	11.2%
Mfg Facility(own)	78%	48%
Mfg (contract)	34%	40%
One or more Foreign Subsidiary	37.8%	17.3%

[1]Percentages are based on 40 firms (40 out of 82 answered this question) for the product oriented group and 38 firms (38 out of 52 answered this question) for the research oriented group

Table 3. Innovative Output and Revenue Sources

Innovation and Revenue	**Categories**	**Product-oriented**	**Research-oriented**	**Chi-square (prob.)**
Patents (mean 16.22)	<=mean	44 (78.6%)	28 (63.6%)	
	>mean	12 (21.4%)	16 (36.4%)	2.73 (.099)
Products in Clinical Trials	<=mean	27 (67.5%)	30 (78.9%)	
	>mean	13 (32.5%)	8 (21.1%)	Ns
Products in Regulatory Process	<=mean	34 (77.3%)	34 (94.4%)	
	>mean	10 (22.7%)	2 (5.6%)	Ns
Products on Market	0-1	35 (42.7%)	38 (73.1%)	
	>1	47 (57.3%)	14 (26.9%)	11.85 (.001)
Revenue Groups	<=10 million	42 (52.5%)	35 (71.4%)	
	>10 million	38 (47.5%)	14 (28.6%)	4.52 (.03)
Revenue from Product sales	<=mean	18 (23.1%)	15 (62.5%)	
	>mean	60 (76.9%)	9 (37.5%)	13.03 (.000)
Revenue from Collaboration/contracts	<=mean	50 (84.7%)	9 (31%)	
	>mean	9 (15.3%)	20 (69%)	25.4 (.000)
Revenue from Royalty/Licensing	<=mean	48 (82.8%)	12 (48%)	
	>mean	10 (17.2%)	13 (52%)	10.54 (.001)
Export Intensity	<=mean	43 (59.7%)	28 (77.8%)	
	>mean	29 (40.3%)	8 (22.2%)	3.5 (.06)

Table 4. Corporate Strategy

Strategy	**Criticality**[1]	**Low R&D Intensity**	**High R&D Intensity**	**Chi-square (prob.)**
Alliance with universities	L	32 (40.5%)	13 (28.3%)	
	H	47 (59.5%)	33 (71.7%)	ns
Alliance with Pharma companies	L	39 (51.3%)	5 (11.1%)	
	H	37 (48.7%)	40 (88.9%)	19.74 (.000)
Alliance with other biotech companies	L	30 (41.1%)	7 (15.6%)	
	H	43 (58.9%)	38 (84.4%)	8.43 (.004)
Acquire other biotech firms	L	51 (65.4%)	29 (63%)	
	H	27 (34.6%)	17 (37%)	ns
License-in technology	L	25 (32.1%)	13 (28.3%)	
	H	53 (67.9%)	33 (71.7%)	ns
Establish R&D labs in foreign countries	L	61 (79.2%)	38 (84.8%)	
	H	16 (20.8%)	7 (15.2%)	ns
Establish manufacturing facility in foreign countries	L	45 (59.2%)	35 (77.8%)	
	H	31 (40.8%)	10 (22.2%)	4.35 (.03)
Establish alliances with foreign firms for distribution in their markets	L	27 (35.5%)	22 (47.8%)	
	H	49 (64.5%)	24 (52.2%)	ns
Aggressively seek domestic investors	L	40 (51.3%)	10 (21.7%)	
	H	38 (48.7%)	36 (78.3%)	10.5 (.001)
Aggressively seek foreign investors	L	49 (64.5%)	15 (32.6%)	
	H	27 (35.5%)	31 (67.4%)	11.66 (.001)
License-out Technology	L	38 (48.1%)	5 (10.6%)	
	H	41 (51.9%)	42 (89.4%)	18.4 (.000)
Learn from Users	L	17 (21.5%)	15 (34.9%)	
	H	62 (78.5%)	28 (65.1%)	2.6 (.10)

[1]Firms are divided into two groups: Low (L) and High (H). The low category ranked the reasons for collaboration as either 1, 2 or 3 on a 5 point Likert scale where 1=not important, 2=somewhat important and 3=important. The high category ranked the reasons as either 4 (very important) or 5 (critically important).

Table 5. Reasons for Collaborating with Large Companies

Collaborate with Large companies to	**Criticality[1]**	**Low R&D Intensity**	**High R&D Intensity**	**Chi-square (prob.)**
Access R&D funds	L	37 (50%)	9 (20%)	10.62 (.001)
	H	37 (50%)	36 (80%)	
Improve quality control in R&D	L	44 (60.3%)	23 (51.1%)	ns
	H	29 (39.7%)	22 (48.9%)	
Reduce risk in R&D	L	37 (50%)	13 (28.9%)	5.11 (.02)
	H	37 (50%)	32 (71.1%)	
Improve credibility in R&D	L	36 (48%)	11 (24.4%)	6.55 (.01)
	H	39 (52%)	34 (75.6%)	
Attract third party investor	L	43 (58.1%)	12 (26.7%)	11.12 (.001)
	H	31 (48.9%)	33 (73.3%)	
Develop products and scale-up manufacturing	L	21 (28%)	11 (24.4%)	ns
	H	54 (72%)	34 (75.6%)	
Access research and market information	L	40 (53.3%)	15 (33.3%)	4.53 (.03)
	H	35 (46.7%)	30 (66.7%)	

[1]Firms are divided into two groups: Low (L) and High (H). The low category ranked the reasons for collaboration as either 1, 2 or 3 on a 5 point Likert scale where 1=not important, 2=somewhat important and 3=important. The high category ranked the reasons as either 4 (very important) or 5 (critically important).

Table 6. Location Needs

Location Conditions	**Criticality[1]**	**Product-oriented**	**Research-oriented**	**Chi-square (prob.)**
Proximity to universities	L	33 (41.8%)	15 (31.9%)	ns
	H	46 (58.2%)	32 (68.1%)	
Proximity to other biotechs	L	51 (64.6%)	20 (42.6%)	5.80 (.01)
	H	28 (35.4%)	27 (57.4%)	
Labor markets – scientists	L	15 (19%)	5 (10.6%)	ns
	H	64 (81%)	42 (89.4%)	
Local venture capital	L	50 (66.3%)	26 (55.3%)	ns
	H	29 (36.7%)	21 (44.7%)	
Local contract manufacturing	L	53 (67.1%)	40 (85.1%)	4.94 (.02)
	H	26 (32.9%)	7 (14.9%)	
Local services (e.g., legal)	L	45 (57%)	23 (48.9%)	ns
	H	34 (43%)	24 (51.1%)	
Local government assistance	L	49 (63.6%)	30 (63.8%)	ns
	H	28 (36.4%)	17 (36.2%)	

[1]Firms are divided into two groups: Low (L) and High (H). The low category ranked the reasons for collaboration as either 1, 2 or 3 on a 5 point Likert scale where 1=not important, 2=somewhat important and 3=important. The high category ranked the reasons as either 4 (very important) or 5 (critically important).

Table 7. Reasons for Collaborating with Universities

Collaborate with domestic universities to	**Product-oriented**	**Research-oriented**
Improve credibility	43.8%	46.7%
Obtain federal funding	27.6	23.9
Obtain early technologies	31.6	27.7
Obtain breakthrough technologies	30.0	26.0