
Discontinuities and senior management: assessing the role of recognition in pharmaceutical firm response to biotechnology

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Despite an increasing emphasis on the role of senior management cognition in shaping organizational action, there have been few attempts to link top management mental models to strategic choice in the face of discontinuous innovation. This paper uses 23 years of data covering 15 major pharmaceutical firms to explore the degree to which each firm's response to the revolution in biotechnology was shaped by the senior team's recognition of biotechnology's importance. Controlling for a number of important alternative explanations, we show that recognition may be an important predictor of action, suggesting that cognition at the most senior level can play a critical role in shaping established firms' response to discontinuities.

1. Introduction

While there is general agreement that discontinuities create problems for established firms, there is no consensus as to why discontinuities should be so difficult to manage (Cooper and Schendel, 1976; Tushman and Anderson, 1986; Henderson and Clark, 1990; Utterback, 1994; Christensen and Rosenbloom, 1995). Scholars have suggested such culprits as rigidities in organizational capabilities, inability to manage changes in value networks and failures of incentives; but, in general, this body of the literature has not focused attention on management's cognitive processes (those explanations that link management noticing and interpreting the nature of the technological change with translating those perspectives into strategic choice and action). While this stream of work draws on a research tradition that dates back to Cyert and March (1963) and Simon (1947)—a tradition that stresses that organizations are constrained to search only 'locally' for plausible solutions (Nelson and Winter, 1982)—it has only indirectly hinted at the specific role of managerial cognition.

The idea that senior managers play an important role in setting strategy has, of course, a long and distinguished pedigree, dating back (at least!) to Andrews (1971) and Selznick (1957). Tushman and his collaborators, for example have found that those firms that successfully navigate major discontinuities have more variance in team

tenure and background or tend to replace their senior management teams at critical moments, suggesting that senior management teams play an important role in shaping firm response (Virany *et al.*, 1992; Tushman and Rosenkopf, 1996). Similarly, Eisenhardt and Bourgeois (1988) show that management has significant discretion in what they term 'high velocity environments', a conjecture that is certainly consistent with the hypothesis that the ability to reframe mental models may be a critical skill in the face of discontinuity. Yet, cognition itself is not explicitly addressed.

This leaves the intriguing question of whether the mental models of senior management may be at least partially responsible for the difficulties many firms face in responding effectively to discontinuities. In general the nature of a discontinuity—indeed the fact that it is a discontinuity at all—can only be known in retrospect (Anderson and Tushman, 1990). This highlights the uncertainty and complexity facing managers at these times: the specific characteristics of the discontinuity, the dimensions along which it will have impact and the appropriate path of action are very rarely obvious in the moment. For example, Vincenti (1994) showed that retractable landing gear for airplanes was not immediately recognized by many in the industry as a discontinuity and as a potential dominant design relative to the 'pants'-type fixed landing gear. Similarly Rosenbloom and Cusumano's (1987) portrayal of the Betamax–VHS video tape battle made it clear that, while most saw that video tape was important, the real nature of the discontinuity and the specific dimensions of merit were not apparent until later. All of these factors known *ex post* are unknown *ex ante*. Players thus need to make sense (Weick, 1995) of their situation in an era of ferment before they can act, opening the door to the possibility that existing cognitive maps may play a significant role in shaping their responses (Hambrick and Mason, 1984).

Yet, there is significant theory and evidence to suggest that senior management mental models should not matter in this context. At one extreme, economists have argued that established firm 'failure' to invest in new technologies is a rational response to differential incentives for investment (Henderson, 1993; Gans and Stern, 2000). At the other extreme, population ecologists have argued that powerful inertial forces such as the need to maintain legitimacy in the eyes of key stakeholders make significant organizational change extraordinarily hard (Hannan and Freeman, 1989; Barnett and Carroll, 1995). Burgelman's more in-depth case study work has suggested that Intel was able to manage a major discontinuity in its business, despite the fact that senior management failed to recognize a number of major shifts in the firm's environment, because the senior management team did not interfere with autonomous decisions generated at the local level (Burgelman, 1994).¹

Researchers have begun to make the empirical case for the importance and role of management mental models during eras of ferment, showing that cognitive maps change in response to environmental discontinuities (Barr *et al.*, 1992). This has been demonstrated in the case of Polaroid where their apparently paradoxical response to the

¹Although, more recently, Burgelman has suggested that Intel's recent success can be attributed to Andy Grove's superior strategic vision (Burgelman, 2002).

transition from analog to digital imaging technologies—early technical leadership but failure to be competitive in the digital camera market—can be explained by management belief structures that placed primacy on technical excellence and modeled economic success on a razor/razor blade model that was ultimately inappropriate in the digital world (Tripsas and Gavetti, 2000). In another example, the development of cochlear implants, beliefs among scientists about what was technically possible and about which criteria to use in evaluating technologies interacted with the actual technologies themselves in a reciprocal relationship to shape the trajectory of the technology (Garud and Rappa, 1994). Other than these papers, and despite an increasing emphasis on managerial cognition in the research literature (Huff, 1990; Walsh, 1995), there have been limited attempts to link top management mental models to strategic choice and action in the face of dynamic, discontinuous events.

Taken together, this research suggests that in such ‘weak situations’ (Mischel, 1968) where the characteristics are not clear enough to dictate action, the executive’s mental model of the environment, not the ‘objective’ characteristics of the situation, become the basis strategic choice (Finkelstein and Hambrick, 1988). However, it leaves a number of important questions unanswered. First, it is largely case based. While these findings are immensely provocative, they immediately raise the question of whether the effect is observable in larger samples. Second, this research often fails to control effectively for alternative explanations for established firm response (such as capabilities and industry position that would largely discount the separate effect of managerial cognition): given the wide variety of explanations that have been advanced for established firm failure, we believe that this is a critical omission.

In this paper, we focus our analysis on the pharmaceutical industry and its response to biotechnology. The emergence of biotechnology was a critically important scientific, technological and business discontinuity for the pharmaceutical industry (Henderson *et al.*, 1999) and represents an ideal opportunity to explore managerial recognition and response. Biotechnology led a significant number of firms to change their technological identity (Zucker and Darby, 1997), fostered the entry of over 1000 new firms in a 25-year period, and created a wide variety of new products, processes and modes of research and development.

Zucker and Darby’s (1996) analysis of this discontinuity found that those pharmaceutical firms that adopted biotechnology were significantly larger than their competitors. Here we extend their results first by incorporating measures of senior managements’ recognition of the importance of biotechnology in an analysis of the determinants of firms’ response; and second, by including controls for a number of other critical variables that might have shaped incumbent firm action.

We present an analysis of 23 years of data on the response of 15 major US and UK pharmaceutical companies to the biotechnology revolution. In the absence of a precise structural model of the underlying phenomena, we seek simply to show systematic relationships between our key variables once important controls are put in place. The analysis proceeds through an estimation and interpretation of a diffusion equation:

$$Y_{j,t} = (X_{j,t-m} Z_{j,t-m} \epsilon)$$

where $Y_{j,t}$, the dependent variable, is a measure of the extent to which firm j has responded to biotechnology in time t . The key explanatory variable $X_{j,t-n}$ is a measure of the importance that the top management of a particular firm places on biotechnology in a prior year and $Z_{j,t-n}$ is a vector of control variables, also lagged.²

Using a measure of senior management recognition derived from each firm's letter to shareholders and a number of measures of strategic response, including gene sequence patents, all biotechnology patents, biotechnology papers and equity-based alliances, we show that top management recognition of biotechnology is systematically associated with strategic action, even when controlling for firm and year fixed effects, previous activity and a number of important alternative explanations. While our results raise a number of intriguing questions, they are consistent with the belief that senior management's sensemaking—their recognition and interpretation of the environment—may be an additional explanatory factor in understanding firm action and performance in subsequent periods as they navigate technological uncertainty.

The rest of the paper proceeds as follows. We begin Section 2 with a brief review of the advent of biotechnology and of the pharmaceutical industry's response to it, in order to demonstrate that senior managerial recognition of its importance might plausibly have a very significant effect on firm response. In Section 3, we then turn to a discussion of our sample construction, of our measures of senior management recognition and firm response, and of our control variables. Section 4 presents our results and Section 5 concludes.

2. Biotechnology as a major discontinuity

Biotechnology provides a rich and complex context in which to explore these issues, since the emergence of biotechnology was not a single, well-understood event but

²Notice that our approach differs significantly from much of the existing work in managerial cognition. Researchers in managerial cognition typically study a small number of firms: single or paired studies are the most common, e.g. Huff and Schwenk's (1990) case studies of Chrysler and an oil company, or Barr *et al.*'s (1992) examination of two railroad companies over a long period of environmental change. Those that use a cross-sectional design—e.g. Thomas *et al.*'s (1993) path analyses on 156 hospitals or Porac *et al.*'s (1995) evaluation of the Scottish knitwear industry—generally focus on relatively stable settings where it is difficult to examine issues of strategic change or at a minimum have not examined a changing environment over time. Up until recently, only a few 'small n ' studies have examined the link between top management perceptions of the environment and performance (e.g. Bourgeois, 1985). Some current studies are moving to capture larger samples of firms and make a statistical connection between cognition and firm performance, taking into account the degree of market change. Sutcliffe and Weber (2000) examine the link between the accuracy of management's perception of the stability of the market and firm performance across 86 firms in multiple industries with various degrees of instability. Houghton *et al.* (2000) examine 63 hospitals and suggest that top management team absorptive capacity is directly connected with superior capacity utilization in a period of market upheaval.

rather a complex mix of scientific, technical and business model changes that unfolded over several distinct phases (Murray and Kaplan, 2001). In this section, we briefly review the critical events and trends in its history to show that, *ex ante*, the nature and implications of biotechnology were not immediately obvious, and that it is thus plausible that senior managerial interpretations of the phenomenon had a significant effect on the ways in which each firm responded to it.

Publication in 1953 of the structure of DNA by Watson and Crick ushered in a period of rapid scientific change. Although it was greeted with considerable fanfare in the scientific community, the commercial implications of the discovery were not immediately evident. It was only in the 1960s that scientists began to speculate on the widespread potential of molecular biology to shape agriculture, healthcare and the wider industrial sector. The structure of DNA provided the foundations for a new scientific agenda in molecular biology but the discovery that ultimately led to commercial applications came in 1973 when Stanley Cohen and Herbert Boyer established a series of 'cut and paste' techniques for DNA fragments (cloning genetically engineered molecules in foreign cells) (Cohen *et al.*, 1973). In hindsight, this breakthrough, which was followed closely by the first generation of monoclonal antibodies in 1975 (Kohler and Milstein, 1975), is now widely viewed as the punctuation or discontinuity that created the potential for the biotechnology industry. At the time, the fact that this *was* a discontinuity was apparent only to a few in industry and academia, and even for them there was very little clarity about how the technology might ultimately evolve.

By any measure the pharmaceutical industry was well established by the 1970s. Large scale R&D was a substantial barrier to entry, while high profits were supported by the long-term protection of patents and by substantial investments in regulatory, sales, marketing and expertise. However, despite the productivity of the post-war period, pharmaceutical firms entered the 1970s increasingly concerned with their ability to maintain innovative output and its associated profitability (Comanor, 1986).

Biotechnology was not immediately regarded as a potential solution to this problem. There was widespread fear that it would lead to the development of bacteria containing cancer-causing genes that might spread to the human population. There was also concern that discoveries in biotechnology might not be readily appropriable (it was not clear if patents in this area would be either possible or enforceable). Eli Lilly was early to embrace biotechnology—in part because there was a possibility that the first breakthroughs would be in artificial insulin, a product that would immediately threaten the Lilly franchise in insulin products—but its competitors, by and large, held back and focused their energy instead on the adoption of the techniques of 'rational' or 'science-driven' drug discovery (Henderson *et al.*, 1999).³

³The techniques of 'rational' drug discovery are not identical to those of biotechnology. 'Biotechnology', broadly defined, draws on knowledge of genetics and of the structures of very large molecules, typically proteins, and their therapeutic benefits. 'Rational drug discovery' draws on knowledge of the mechanisms by which small molecules—conventional drugs—affect the body. The two are now closely

Entrepreneurs and venture capitalists were less cautious. Genentech was founded in 1976, and a number of other biotech startups followed. By 1980, many of the initial concerns had been alleviated: resolution of *Diamond v. Chakrabarty* by the US Supreme Court gave inventors the right to patent living organisms; the Asilomar conference in 1975 had established ethical guidelines for biotech research; and the Genentech initial public offering (IPO) in 1980 (the first IPO of a biotech startup) proved that the market valued these technologies.

At this point, some of the large pharmaceutical companies jumped more actively into the biotech fray: Eli Lilly had licensed the worldwide rights to recombinant human insulin from Genentech and in 1985 acquired Hybritech for \$375 m; Schering-Plough acquired DNAX Research Institute in 1982 for \$30 m; and Bristol-Myers acquired Genetic Systems for \$294 m. By 1986, there were seven biotechnology-derived products on the market, including human insulin and human growth hormone. Among them were the first recombinant vaccine (developed by Merck) and the first drug based on monoclonal antibodies (for graft rejection). Scientific publications and patents in the biotechnology field, relatively rare in the early 1980s, took off and were appearing at a rate of more than 4000 patents and 9300 publications per year in the overall industry by 1986.

By the late 1980s, the technologies and products of biotechnology were well established among biotechnology companies and a small number of the pharmaceutical firms, but there was considerable debate about whether biotechnology was best thought of as a source of specific protein products ('large molecule' drugs) or as a research tool (for 'small molecule' drugs). By 1990, fourteen new biotechnology products had been released (counted by NCE, or new chemical entity, rather than therapeutic indication) to treat diseases ranging from hemophilia to leukemia to cystic fibrosis; but in a parallel effort, several new biotechnology firms, including Vertex in Cambridge, MA, were founded not to produce proteins but to produce small-molecule 'traditional' drugs. In contrast to the older biotechnology firms, Vertex and other firms like it aimed to use the tools of biotechnology together with computer-based rational drug design to dramatically improve the conventional drug discovery process. The advent of gene and antisense therapy and the initiation of the Human Genome Project, which was started in 1990, further complicated the picture.

This complex and turbulent environment bears many of the marks of an 'era of ferment'—a period of technological evolution in which alternative product and market concepts battle with each other and in which there is enormous uncertainty about how the technology can be best exploited. Most importantly, for the purposes of our study, the established pharmaceutical companies reacted in a very wide variety of ways to the new technology. As demonstrated in Figure 1, some—particularly Merck and Lilly—moved quite aggressively to embrace the new technology, although the two firms used it

interlinked, but throughout the 1970s, 1980s and early 1990s they represented very different approaches to drug discovery.

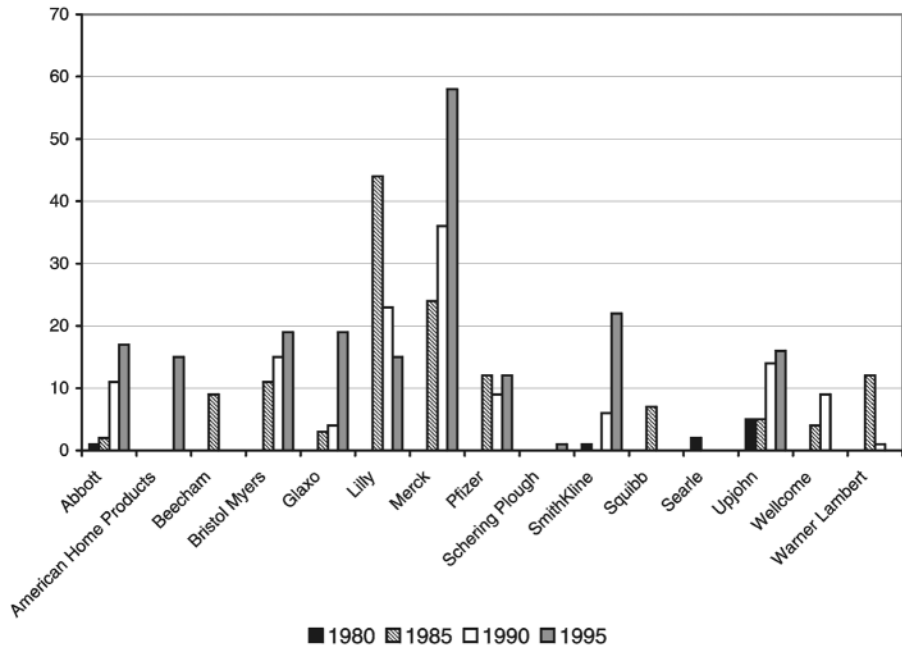


Figure 1 Number of biotechnology patents for 1980, 1985, 1990, 1995.

in quite different ways. Others were much more reluctant to invest in biotechnology, moving more hesitatingly to explore its possibilities.

The period thus provides a particularly intriguing opportunity to explore the role of senior management cognition in shaping established firm response. The established pharmaceutical firms differed significantly from each other. They have different histories, different technological capabilities and different market positions. Some of them were much larger and in much better financial shape than their rivals. Was it these differences that shaped the rate at which they responded to biotechnology, or can one separately identify a role for managerial cognition? This is the research question to which we now turn.

3. Sample and variable construction

Recall that we hope to estimate a reduced form diffusion equation:

$$Y_{j,t} = (X_{j,t-m} Z_{j,t-m} \epsilon)$$

where $Y_{j,t}$ is a measure of the extent to which firm j has responded to biotechnology in time t ; the primary explanatory variable, $X_{j,t-m}$ is a measure of senior management cognitive recognition of biotechnology, and $Z_{j,t-m}$ is a vector of control variables.

Table 1 List of pharmaceutical firms covered in the analysis

Firm	Years in data set
Abbott Laboratories	1973–1998
American Home Products	1973–1998
Beecham	1973–1988
Bristol-Myers (Squibb)	1973–1998
Glaxo (Wellcome)	1973–1998
Eli Lilly	1973–1998
Merck	1973–1998
Pfizer	1973–1998
Schering-Plough	1973–1998
Searle	1973–1984
SmithKline (Beecham)	1973–1998
Squibb	1973–1988
Upjohn (Pharmacia and Upjohn)	1973–1998
Warner Lambert	1973–1998
Wellcome	1973–1994

3.1 Sample construction

Our sample includes comprehensive data about the 15 largest US and UK pharmaceutical firms for the period 1973–1998, where size was defined by pharmaceutical sales in 1973.⁴ The 15 companies are listed in Table 1. This sample neglects some important continental European and Japanese pharmaceutical companies (such as Hoffmann La Roche). Unfortunately since the construction of our measure of ‘recognition’ relies on textual analysis of company annual reports, our only feasible approach was to restrict

⁴We chose the 15 largest firms on the basis of data contained in James’s 1977 study (James, 1977), eliminating any company in which pharmaceutical sales were less than one-third of total sales since we believed the dynamics of the senior management discussion to be significantly different from more ‘pure play’ firms. Of the original 33 research-oriented ethical pharmaceutical companies with pharmaceutical sales over \$200 m in 1973, 10 were eliminated because their pharmaceutical sales were less than one-third of total sales (including such companies as Johnson & Johnson, Bayer and Ciba-Geigy). We then eliminated eight firms (Hoffmann La Roche, Sandoz, Takeda, Boehringer Ingelheim, Roussel-Uclaf, Schering AG, Shionogi and Tanabe) because annual reports could not be obtained in English for the entire period 1973–1998. We had considered the option of translating these earlier reports but felt that it would be inappropriate for the following reasons: (i) many of the earlier annual reports in the native languages of the home countries of these pharmaceutical firms did not conform to the US and UK formats and therefore often did not include a ‘letter to shareholders’ or equivalent; and (ii) even in the cases where a letter to shareholders or its equivalent was present, we were concerned that the vagaries of translation would not give us reliable results since the analysis is based on counts of particular words. For these reasons, we did not consider it appropriate or feasible to include this more comprehensive list of firms.

the sample to those firms who published their annual reports in English over the entire time period. We focused on the largest firms as being most likely to be subject to ‘incumbent firm failure’ and on the period 1973–1998 since 1973 is the year in which Cohen and Boyer published the key findings that are widely regarded as triggering the beginning of the biotechnology industry.

Note that this sample mutates over time. Where there are 15 companies in the sample in 1973, by 1998 there are only 11. Three of the companies were purchased by other companies in the sample: Beecham by SmithKline in 1989, Squibb by Bristol-Meyers in 1989, and Wellcome by Glaxo in 1995. Searle exited our sample in 1985 when it was purchased by Monsanto. Our results may thus suffer from some sample selection bias, since ‘failing’ firms (perhaps those who do not respond to biotechnology) exit the sample (though, as we will note later, this does not seem to affect our results).

3.2 *The dependent variable: measures of strategic response*

There are a wide variety of plausible ways in which to measure the degree to which incumbent pharmaceutical firms took action in response to biotechnology. In the ideal case, one would measure direct investment in biotechnology research, but, unfortunately, detailed investment data of this type is extraordinarily difficult to obtain in any kind of systematic way. One might imagine that counts of biotech drug projects or drugs launched would be the most direct measure of biotech strategic action (indeed, in a separate analysis, we found a general relationship between senior management recognition and the number of biotechnology drugs introduced by the 15 firms). However, using drug counts introduces a number of problems. Most importantly, they only cover large-molecule drugs which only represent a small portion of total activity in biotechnology as many firms used biotech techniques in improving search for small-molecule drugs.⁵ In the absence of these more direct measures, we use four proxies: gene sequence patents, biotechnology patents in general, biotechnology publications and biotechnology equity alliances.

Patents are a well-established measure of innovative output among pharmaceutical firms—patent protection is a critical source of economic rents in this industry—and are thus widely used to measure research productivity and capability building (Henderson *et al.*, 1999; Sorensen and Stuart, 2000). Moreover Henderson and Cockburn (1994) showed that in some circumstances patents are a reasonable measure of investment in research.

We first use a simple count of gene sequence patents assigned to any one of the 15

⁵There were also practical constraints on using drug counts, primarily due to the long time lags from investment to launch which would make the determination of association between recognition and response quite difficult. Also, since there were only 35 drugs launched by all of the 15 companies over the entire period we studied, drug counts would likely be a particularly noisy measure of strategic action. If instead, we chose to use biotech drug projects (rather than launches), we are hampered again by the focus on large molecule drugs only and the lack of data (from the key source, PharmaProjects) going back to the beginning part of our sample period.

companies in the sample, a measure also used by Zucker and Darby (1996) in assessing pharmaceutical firm transformation of technical identity in the face of the biotechnology revolution. While they used data from GenBank, our source for genetic sequence patents is Derwent Inc.'s *GENESEQ* database. These data are only available from 1980, so we use a shorter panel to test the association of recognition with this measure of strategic action.

Because gene sequence patents are an extremely narrow measure of firm activity in biotechnology, we also use a count of *all* biotechnology-related patents. We include any biotechnology patent covering genetic engineering and fermentation, biochemical engineering, sensors and analysis, biotechnology-based pharmaceuticals, cell cultures, biocatalysis and downstream processing. All patents for a firm and for any majority-owned subsidiaries are included (e.g. we include any patents filed by Immunex during 1994–1998, the period in which they were majority owned by American Home Products). Our source for patent data is Derwent Inc.'s *World Patent Index* (for 1973–1981) and *Biotechnology Abstracts* (for 1982–1998) databases.⁶

Our third measure is a count of biotechnology-oriented scientific publications. Publication counts are an important indicator of the thrust of research activity. Pharmaceutical companies tend to publish at rates equivalent to research institutes and universities, and publication counts have been previously construed as representing the level of investment in basic science (Gambardella, 1995). Publication rates are a particularly critical measure of firm response since turn-around time in the relevant scientific fields is so short: articles can typically be written and published in few months. This is likely to make publication rates a particularly useful early measure of firm response. It also alleviates the concern that both senior management recognition and any firm response are being driven by unobserved investment in a prior period.

We included the same technical categories of publications as for patents. Our sources for scientific publications are Derwent Inc.'s *Biotechnology Abstracts* database (for 1982–1998) and ISI's *Science Citation Index* (for 1976–1981). Because data on publications before 1976 is not available, we imputed values for publications 1973–1975; however, since publication activity in biotechnology for the 15 firms studied was quite low in the late 1970s, the activity in the 1973–1975 period was essentially zero. In addition, because ISI data for publications for Schering-Plough were not available, we imputed publication levels for 1973–1981. Since Schering-Plough had a particularly low publication rate throughout the entire time period of the study, we believe this procedure should not create any significant bias in the results. The results are robust to their omission.

As a fourth measure of biotechnology-related strategic action, we count the number of biotechnology equity deals between our pharmaceutical companies and bio-

⁶For the period 1973–1981 there is no database that specifies whether a patent should be considered biotechnology or not. Therefore, the 1973–1981 patents for the firms in the dataset were hand coded to make a determination of whether they met the criteria for inclusion in the biotechnology patent set, using the same criteria as the *Biotechnology Abstracts*.

Table 2 Descriptive statistics for alternative measures of strategic actions

(a) Summary statistics					
	<i>n</i>	Mean	SD		
Weighted biotech words	307	0.04	0.08		
Gene sequence patents	247	5.85	16.21		
Biotech patents	307	9.18	17.47		
Publications	307	9.00	11.16		
Equity deals	307	0.54	1.07		
(b) Correlation coefficients					
	Weighted biotech words	Gene sequence patents	Biotech patents	Biotech publications	Equity deals
Weighted biotech words	1.00				
Gene sequence patents	0.12	1.00			
Biotech patents	0.15*	0.81*	1.00		
Biotech publications	0.17*	0.13*	0.54*	1.00	
Equity deals	0.21*	0.31*	0.31*	0.12*	1.00

*Significant to the 0.05 level.

technology startups. This is a less typically used but equally interesting measure of strategic action in that alliances are usually reviewed on a case-by-case basis directly by the top management team. Alliance data are drawn from a database maintained by Recombinant Capital (ReCap), Windhover's *Pharmaceutical Strategic Alliances* (Vols I–X), and an additional search of related industry literature.⁷

Table 2 provides summary statistics and correlation coefficients for these four measures of strategic action (as well as the measure of recognition which we discuss below). Table 3 gives their values over time. Patents and publications have their first major growth period in the early 1980s, while alliances only pick up at the end of the decade. All activity seems to lull in the early 1990s; and while patenting and alliances pick up again later, scientific publications continue their decline. In addition, the coefficient of variation generally gets smaller over time, indicating that there has been some type of convergence in the industry. In our analysis, we therefore include year fixed effects rather than a time variable because while the changes in the dependent and independent variables are generally increasing over time, this is not smooth on a year-by-year basis.

⁷We experimented with a measure of deals defined as *any* deal done between a pharmaceutical firm and a new biotechnology firm, including licensing, R&D, production and distribution deals. The results were unchanged, and we report the measure described above because we believe that the underlying data on which it is based are significantly more reliable than the alternative measure.

Table 3 Means and coefficients of variation over time for alternative measures of strategic action

	Gene sequences		Patents		Publications		Equity deals	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1976	–	–	0.07	3.87	0.27	3.00	0.00	0.00
1977	–	–	0.00	0.00	0.60	0.23	0.00	0.00
1978	–	–	0.07	3.87	0.67	1.85	0.00	0.00
1979	–	–	0.07	3.87	1.20	2.09	0.00	0.00
1980	0.20	3.85	0.60	2.25	1.07	2.05	0.00	0.00
1981	1.27	3.46	0.67	1.67	1.20	1.61	0.07	3.87
1982	0.13	3.87	4.60	1.11	6.20	1.12	0.20	2.80
1983	0.13	3.87	6.33	1.41	8.00	0.99	0.00	0.00
1984	0.33	1.85	6.53	1.13	8.80	0.96	0.07	3.87
1985	1.07	1.39	9.79	1.20	12.50	0.89	0.29	1.64
1986	0.86	1.28	7.43	1.20	11.14	1.02	0.21	2.70
1987	1.64	1.25	9.00	1.19	13.07	0.98	0.07	3.74
1988	1.71	1.15	7.50	1.07	11.86	0.89	0.50	1.52
1989	2.42	1.29	11.83	1.04	15.50	0.87	0.42	2.16
1990	2.58	1.17	10.92	0.94	16.42	0.81	0.67	1.61
1991	5.17	0.77	13.83	0.95	17.50	0.84	0.75	1.52
1992	7.08	0.94	15.50	1.37	15.67	1.00	1.67	1.31
1993	6.50	0.93	13.25	1.36	13.00	1.01	1.08	1.07
1994	10.00	1.21	13.83	0.82	15.58	1.03	1.42	0.70
1995	12.64	0.79	18.45	0.78	17.18	0.90	1.82	0.91
1996	14.09	0.77	20.45	0.68	11.82	0.75	1.73	0.58
1997	20.91	1.35	23.82	1.25	12.27	0.50	1.91	0.95
1998	37.36	1.53	38.55	1.54	7.73	0.76	1.18	0.99

3.3 Measures of recognition

Our major empirical challenge was to construct reasonable quantitative measures of top management mental models that can be entered into regression models. To date, this has been accomplished primarily using demographic measures as proxies (Virany and Tushman, 1986; Norburn and Birley, 1988; Ancona and Nadler, 1989; Wiersema and Bantel, 1992), though in a recent cross-sectional analysis, survey data of management impressions of industry change were used (Houghton *et al.*, 2000).

Here we use normalized word counts derived from the letters to shareholders from the annual reports of each of sample company as our primary measure of recognition.⁸

⁸This thematic rather than relational approach to textual analysis may be an older technique that has fallen out of favor with the advent of semantic and more recently network analyses, however, given the need to generate quantitative measures over a large number of texts, the thematic approach seems the simplest and most appropriate (Roberts, 1997)

We define biotechnology words as the set of commonly used expressions that are synonymous with or a subset of biotechnology.⁹ In our sample, the total number of biotechnology-associated words in any year ranges from 0 to 13 with an average of a little over one per year. The raw count is normalized by the number of paragraphs in the letter to shareholders to allow comparison across years and across companies. The normalization is important since the number of paragraphs in the letters to shareholders varies from 4 to 87 with an average of 26.¹⁰

The strength of this measure is its objectivity and replicability. Annual reports in general, and the letters to shareholders in particular, have been used in a number of studies of managerial cognition and offer a number of advantages.¹¹ Because they are documents produced *ex ante*, their use avoids the problem of retrospective bias, and they are directly comparable across firms and over time. Other potential sources such as press releases or speeches, in contrast, are not consistently available across the sample, and internal sources such as minutes from board meetings are extremely difficult to obtain.

Moreover substantial qualitative evidence suggests that the letter to shareholders is written or closely reviewed by the chairman and/or CEO, and that it is distributed to the executive team for comments and revisions. In addition, for fiduciary reasons, it is unlikely that a company would suppress discussions of important issues in the letter to shareholders, even if these did not reflect entirely favorably on the company (Freeman, 1998). Fiol's (1995) study of the forest products industry comparing internal (strategic planning documents) and external (annual reports) viewpoints showed that while judgments about the specific nature of an issue (threat or opportunity) were not significantly related in the two kinds of documents, the basic thematic emphases (in this case, regarding control) were the same. We believe that letters to shareholders can therefore be reasonably taken as top management's beliefs about what is important for the company's performance and future prospects, and have been used as such in other recent work on the pharmaceutical industry (Osborne *et al.*, 2001).

The major drawback of the use of word counts as a measure of senior management's

⁹We used the following words and their variants in our counts: biotech/biotechnology, cloning, gene, genetic, genetic engineering, genomics, growth factor, molecular biology, monoclonal antibody, nucleotide, protein, recombinant DNA (or rDNA). These were generated through a preliminary review of all of the letters to shareholders as well as selected business periodicals for the entire time period.

¹⁰In our analyses, we examine both 'stock' (accumulated number of mentions in the letter to shareholders discounted by 20%) and 'flow' (mentions in a particular year) measures of recognition. Our results are robust to the use of either measure. We also used both one- and three-year time lags. The results are robust to the use of the three-year lag (though only marginally significant), but selected tests beyond the three-year time period produced noisy results.

¹¹Examples include analysis of the affect of cognitive maps and mapping on the performance and survival of two railroads using 25 years of annual reports (Barr *et al.*, 1992), 'revealed causal maps' in the television manufacturing industry from annual reports and the leading industry magazine (Narayanan, 1990), and an explanation of the different responses to the Japanese auto invasion by US car manufacturers using annual reports (Freeman, 1998)

cognitive response is that while it is likely to measure the *strategic importance* of the issue in the eyes of senior management, it does not speak to the *interpretation* that senior management is using. It is conceivable, for example, that the CEO could devote a lot of time to the discussion of biotechnology in the context of explaining why he/she believes that it is not central to the future of the firm. However, we believe that in this case, having read all of the letters to shareholders, the measure of biotechnology words does reflect a positive strategic interpretation—it seems clear to us that senior management only discuss biotechnology in the annual report when it is viewed as central to the firm's future strategic success. While in further work we hope to develop more nuanced measures of senior management cognitive maps—perhaps through a program of qualitative interviews—we view the analysis presented here as a first step towards exploring the degree to which senior management awareness of the new technology is associated with each firm's response.

3.4 Controls for alternative explanations

Firm and year dummies. We include firm fixed effects in most of the regressions to control for the fact that firms may have heterogeneous competencies that shape their response to biotechnology. Year dummies are included to control for the fact that the cost of responding to biotechnology almost certainly fell dramatically over the time covered by our data, and for the fact that simple institutional isomorphism might have led some firms to invest in biotechnology as the period progressed.

Economies of scale. Zucker and Darby (1996, 1997) found evidence for the hypothesis that the adoption of biotechnology was largely driven by economies of scope and scale, and Cockburn *et al.* (2000) note that, in strategic theories of the firm, scale is important in that it provides the resources to adopt new approaches that drive performance. We thus include total firm sales and total R&D spending to control for potential economies of scale in the adoption of biotechnology.¹² While ideally one would measure scale as a function of *pharmaceutical* sales and R&D, these data are typically not reported for the entire period (for sales) or at all (for R&D). However, since we selected only firms with a high percentage of sales in pharmaceuticals, we believe that this introduces only minimal error into our analysis.

Financial performance. We include firm operating income as a percentage of sales to measure the extent of financial well-being. The literature provides ambiguous predictions as to the effect of this variable. On the one hand, higher returns could represent the availability of firm-wide resources for investment in a new technological field; on the other hand, it could be that firms with higher returns might be more complacent (or

¹²An additional explanation could be that economies of scope in R&D across multiple different life sciences areas could condition decisions to adopt biotech (as an example, some firms such as Aventis, Novartis and Monsanto actively positioned themselves as life sciences firms in the late 1990s). We do not include this control variable in the analysis because it appeared to be less critical over the time period we examine and for the firms in our sample.

perhaps that firms with lower returns would be more risk seeking) with regard to the adoption of new techniques (Bowman, 1982; Kahneman *et al.*, 1994). Again, as with firm sales, this variable is measured with error since it includes all firm profits and sales and not just those associated with the pharmaceutical business.

Competitive actions. Both economic and institutional arguments would suggest that strategic response might be driven by some form of isomorphism in which firms respond to the actions of the other members of their competitive set (DiMaggio and Powell, 1983). To control for this possibility, we include competitive actions measured as the sum of patents, publications or deals for all the other firms in the sample in the previous year.

Prior related competence. Several studies of incumbent firm response to technological discontinuities have focused on the degree to which the discontinuity is competence enhancing or competence destroying (Tushman *et al.*, 1986; Henderson and Clark, 1990). We attempt to measure the degree to which biotechnology is complementary to the existing skills of a pharmaceutical firm using two measures.

First, we attempt to measure the *scientific orientation* of the firm. Cockburn *et al.* (2000) found that the rate at which large pharmaceutical firms adopted the techniques of science-driven drug discovery was largely determined by the degree to which they were active participants in the community of public science in the late 1970s and early 1980s, as measured by PUBFRAC, the fraction of researchers whose names appear on a patent who also appear as an author on papers published within two years of the patent application. Since active participation in biotechnology is also widely believed to be dependent on close connection to public science, we included this measure in our analysis as a measure of the firm's innovative competence. (For more detail on the construction of this variable, see Cockburn *et al.*, 2000).

As another measure of each firm's innovative competence, we also included the share of firm patents devoted to therapeutic areas that were most closely associated with science-driven drug discovery (cardiology and oncology) to assess the scientific understanding accumulated in the firm. We hypothesized that firms that have a higher proportion of their research output in fields that require higher degrees of science might be more receptive to biotechnology (an 'absorptive capacity' argument: Cohen and Levinthal, 1990).

Market position. Classical strategy theory is premised on the idea that a firm's position in the market will affect its strategic choices. While the economic literature provides mixed findings in this area, Cockburn *et al.* (2000) present some evidence consistent with the hypothesis that firms with a high market share (and thus some sort of monopoly power) should be more likely to adopt new techniques because they will have the most to gain. Here, we use the firm's market share in cardiology and oncology to control for this hypothesis.

Table 4 Descriptive statistics for controls and alternative explanations

	<i>n</i>	Mean	SD
Sales (\$ bn)	307	4.78	4.08
Operating income as a percent of sales	307	0.23	0.08
R&D (\$ bn)	307	0.47	0.48
Average competitor patents	307	8.76	8.44
Average competitor publications	307	8.89	6.00
Average competitor deals	307	1.65	2.17
Pubfrac	178	0.58	0.14
Share of cardiology patents	178	13.26	10.24
Share of oncology patents	178	1.77	2.80
Cardiology sales as a percentage of firm sales	178	8.63	8.95
Oncology sales as a percent of firm sales	178	1.52	3.28
Cardiology market share	178	3.64	5.73
Oncology market share	178	9.01	18.06

Balance of power within the firm. It may also be the case that the balance of power within a firm may affect the adoption of new techniques. If sales come mainly from science-oriented fields, for example, decision-making may naturally favor new techniques that also have a substantial scientific component. To attempt to control for this effect, we include total share of firm sales represented by drugs in cardiology and oncology in the analysis.

The data for prior related competence, market position and balance of power are measured in 1981 and entered as initial conditions in a restricted dataset of only 12 of the 15 firms for which this data is available. Table 4 summarizes the mean and standard deviation for each of our control variables. Notice that we do not include any measure that might allow us to control for Christensen and Bower's hypothesis: that the rate at which a firm adopts a new technology is a function of the degree to which it offers margins comparable to the existing business (Christensen and Bower, 1996). We think that there was very little reason to believe that investments in biotechnology would yield lower margins than investments in more conventional drug discovery techniques—indeed rather the reverse—so that in this case the hypothesis is unlikely to be relevant.

4. Results

4.1 Qualitative evidence and descriptive statistics

There is very substantial variation across firms in both the degree to which senior management recognized the advent of biotechnology and in the timing and extent of

subsequent action. Companies such as Bristol-Myers (later Bristol-Myers Squibb) or Eli Lilly exemplify the most typical pattern: these firms began talking seriously about biotechnology in the late 1970s or early 1980s, then dramatically increased their patenting and publication activity in the later 1980s and began making alliances in the early to mid-1990s. Bristol-Myers (Figure 2) historically focused on oncology, and saw potential in biotechnology to aid its efforts in finding treatments for cancer. Acquisitions of Oncogen and Genetic Systems in the mid-1980s, the letter to shareholders claimed, 'provide the company with an excellent capability in the emerging science of biotechnology and its application for therapeutic purposes . . .' (Bristol-Myers, letter to stockholders, 1985). By 1986, the Bristol-Myers top team indicated that biotechnology and genetic engineering specifically were the 'the biomedical advances that are expected to dominate drug discover and therapy by the early part of the century' (Bristol-Myers, letter to stockholders, 1986). This emphasis by top management on the importance of biotechnology was followed by a period of rapid growth in patenting and publications. Their commitment grew steadily through the 1990s, manifesting itself in intensified investment in biotechnology, in particular in searching for technologies on the outside:

Our new department of External Science and Technology will focus on future alliances and early-stage science (in biotechnology). We added to our facilities in Syracuse to begin to make these biotechnology products. . . . And we dedicated a new Center for the Study of Genetics and Cellular and Molecular Biology in Strasbourg, France. The center is part of the company's ongoing commitment to fund long-term research in molecular genetics. . . . (Bristol-Myers Squibb, letter to stockholders, 1994)

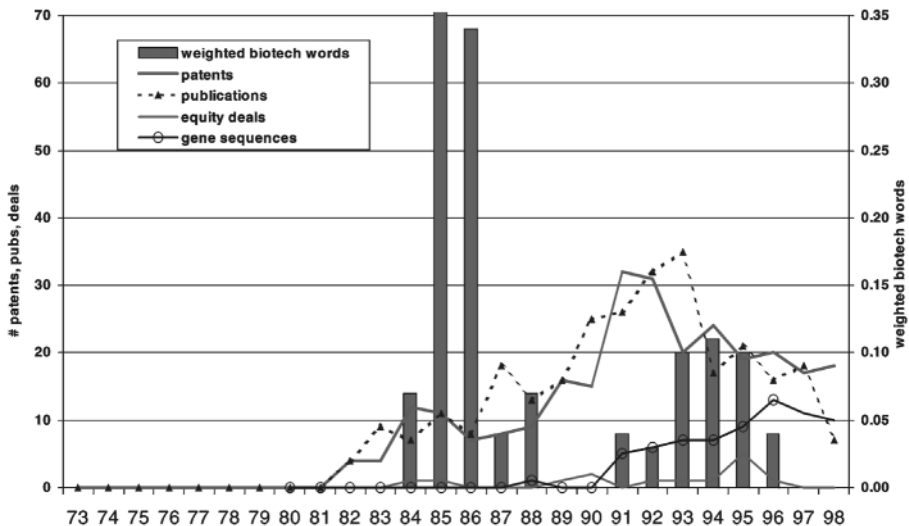


Figure 2 Bristol-Myers (later Bristol-Myers Squibb) recognition and response—a typical pattern.

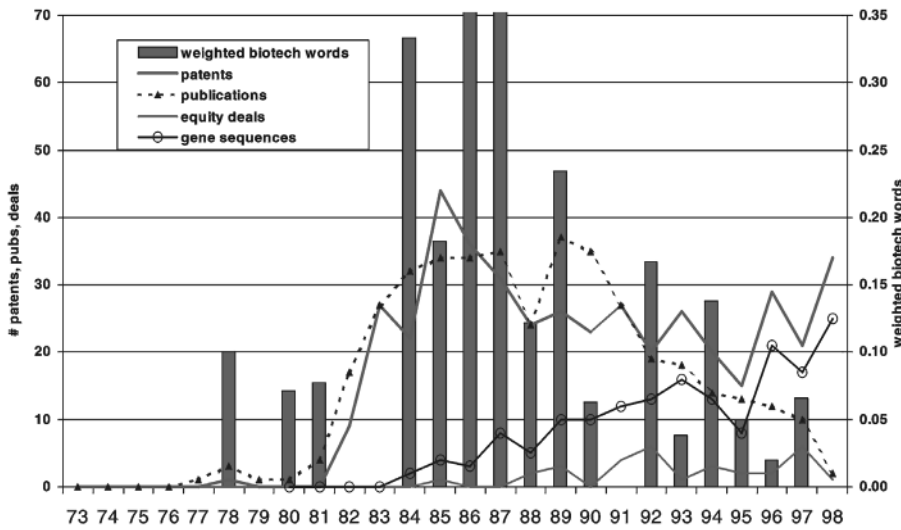


Figure 3 Eli Lilly recognition and response—an early responder.

This was followed by an upturn in their alliance activity in the late 1990s.

Eli Lilly was quicker to jump on the biotechnology opportunity (Figure 3). As early as 1977, it devoted a whole section of the annual report to biotechnology, saying ‘Nothing, perhaps, symbolizes the life science revolution more dramatically than research with recombinant DNA . . .’ (Eli Lilly, annual report, 1977). In 1978, the CEO indicated that ‘significant attention is being given to newer research programs in the immunological mechanism of the body, recombinant DNA, how plants convert sunlight to chemical energy, and many other fundamental studies’ (Eli Lilly, letter to shareholders, 1978). The first thrust was biosynthetic human insulin, pursued aggressively to protect Lilly’s diabetes franchise, but this quickly grew to a broad focus on biomedical research. This early emphasis by top management was followed by rapid growth in patenting and publications in biotechnology. By the mid-1980s, Lilly was focused as much on improving research approaches for traditional small molecules as on synthesizing large molecules such as insulin.

Lilly is applying recombinant DNA technology to many areas of research. Molecular biologists are using this scientific tool to study genes, receptors, and enzymes. Their discoveries may speed up efforts to develop new chemical agents in several therapeutic categories. In addition, company scientists are using this biotechnology to develop natural proteins, such as activated protein C, and to modify natural proteins, such as tissue plasminogen activator. (Eli Lilly, letter to shareholders, 1987)

By the mid-1990s, Lilly had fully integrated biotechnology into its pharmaceutical effort:

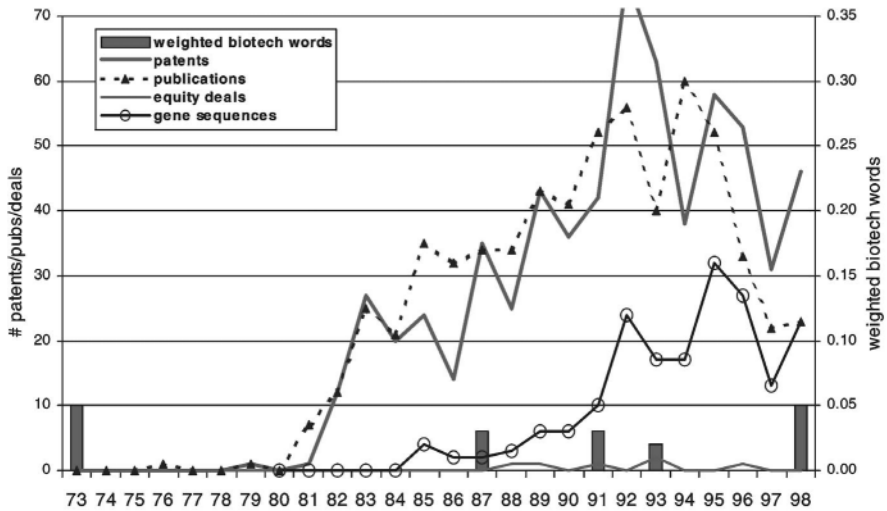


Figure 4 Merck recognition and response—an exception.

A . . . critical capability is biotechnology, a distinct Lilly strength. We are among the world's largest and most experienced biotech companies—with proven abilities to discover, develop, and manufacture both small organic molecules and large natural molecules.

(Eli Lilly, letter to shareholders, 1994)

Not all of the companies in the sample followed this pattern. These outliers demonstrate the heterogeneity of firm recognition and response and highlight the difficulties inherent in obtaining appropriate measures of both concepts. For example, as shown in Figure 4, Merck referred very little to biotechnology in its annual reports (though focused heavily on broader scientific issues) but published and patented in the area quite aggressively. Merck's letters to stockholders contain many references to its 'remarkably strong research organization' (1976), 'the important contributions our research makes to science and health' (1979), and its 'superior technological innovation in biology, chemistry, and engineering' (1985). Its strategy was to utilize 'high technology in every aspect of research—from biotechnology and basic research, to increasing speed in clinical development, gaining faster regulatory approvals, and demonstrating health outcomes' (1991). Because Merck was (and is) a highly science-oriented firm, it appears to have interpreted biotechnology not as a major discontinuity but rather as the emergence of a new technique for improving the search process for small molecules. This demonstrates that our measure of recognition, which focuses on use of biotechnology-specific words, only captures the extent to which a firm saw biotechnology as a separate technology, distinct from its regular activities.

4.2 Quantitative results

Despite this heterogeneity across our sample and the potential flaws in our measures, we find systematic patterns of association between recognition and response to biotechnology in more quantitative analyses. In this section, we discuss the results from several sets of regressions. Tables 5–8 examine the effect of top management recognition of biotechnology on each of our measures of strategic action in turn.¹³ Table 9 explores the degree to which senior management recognition is a distinct construct by determining whether it is predicted by strategic action.

In Tables 5–8, we present our core results: strategic actions (defined as the number of biotech patents, gene sequences, publications or equity deals) as a function of the stock of weighted biotechnology-related words.

In each table, models 1–3 make use of our full sample of 15 firms, while models 4 and 5 include a richer set of controls but use only the 12 firms and the 18 years for which we are able to construct these additional variables. Year effects are included in every model, and firm effects are included in models (1–4). Model (5), which includes the richer set of controls, omits firm effects since we measure the value of our control variables only once—in 1981—and they are thus collinear with firm fixed effects.¹⁴ Due to the overdispersed nature of the dependent variable count data, we use a negative binomial regression model. Overall, the results are very robust when strategic action is defined in terms of patents and gene sequences, marginal when defined in terms of publications and not there at all in the case of equity deals.

In Tables 5 and 6, we show the results for gene sequences and biotech patents. An increase in the normalized number of mentions of biotechnology in the letters to shareholders is positively and significantly associated with either type of patenting in subsequent years, even when controlling firm and year fixed effects (models 5–1 and 6–1) and for previous patenting (models 5–2 and 6–2). Introducing controls for firm size, financial well-being and competitive activity do not change the main direction of the effects (models 5–3 and 6–3), although both scale and competitive activity do have a statistically significant effect on the rate of biotechnology-related activity

The inclusion of the richer set of controls in model (5–5) and (6–5) does not change the core result. Intriguingly, the degree to which a firm is ‘pro-publication’ does not seem to affect the degree to which it invests in biotechnology—a counterintuitive result given the very strong results of Cockburn *et al.* (2000) and one that gives increased credibility to our finding that senior management recognition plays a very important role in shaping a firm’s actions.

Taken together, these results are quite striking: even when controlling for a panoply of alternative hypotheses, our admittedly rather distant measure of managerial recognition retains its separate effect on strategic action.

¹³Where we can, we use the time period 1976–1998 to test our findings in order to accommodate tests of both one- and three-year lags of the independent variables.

¹⁴Cockburn *et al.* (2000) show that these measures vary hardly at all over time, and are best thought of as a fuller measure of the firm fixed effect.

Table 5 Recognition as a determinant of response: weighted biotech words as a predictor of *gene sequence patents*, controlling for firm and year fixed effects and selected alternative explanations (conditional fixed effects negative binomial regression)

Dependent var: gene seq	15 firms, 1981–1998			12 firms, 1981–1998	
	(5–1)	(5–2)	(5–3)	(5–4)	(5–5)
<i>n</i> =	247	247	247	178	178
Log of stock of weighted biotech words (<i>t</i> – 1)	0.44**** (0.09)	0.45**** (0.09)	0.31*** (0.09)	0.34*** (0.10)	0.54**** (0.09)
Log of stock of previous gen seq (<i>t</i> – 1)		0.07 (0.12)	–0.14 (0.13)	–0.12 (0.14)	0.09 (0.14)
Log of sales (<i>t</i> – 1)			–0.70* (0.31)	–0.39† (0.33)	0.11 (0.34)
Log of R&D (<i>t</i> – 1)			0.92*** (0.28)	0.68* (0.33)	–0.51 (0.44)
Operating income percent (<i>t</i> – 1)			–0.89 (1.38)	–0.83 (1.47)	0.73 (1.58)
Competitor gen seq (<i>t</i> – 1)			–0.14**** (0.03)	–0.16**** (0.04)	–0.13* (0.06)
Pubfrac					–1.50 (1.20)
Share of cardiology patents					0.01 (0.01)
Share of oncology patents					–0.26*** (0.08)
Cardiology sales as % of firm sales					–0.04** (0.02)
Oncology sales as a percentage of firm sales					–0.83** (0.29)
Cardiology market share					0.09 (0.14)
Oncology market share					0.16** (0.06)
Constant					–1.21
Pseudo <i>r</i> ²					0.30
Log likelihood	–375.45	–370.48	–352.26	–282.38	–329.03
χ^2 /Wald χ	393.10	395.65	497.85	376.66	282.55
<i>P</i> of χ	0.00	0.00	0.00	0.00	0.00

Note: to save space, coefficients for year effects not reported in this table.

†*P* ≤ 0.10; **P* ≤ 0.05; ***P* ≤ 0.01; ****P* ≤ 0.001; *****P* < 0.0001.

Table 7 shows the same five models using scientific publications as the measure of strategic action. Publication behavior is highly serially correlated (firms are much more likely to publish if they published the year before) and larger firms are much more likely to publish in biotechnology, consistent with Zucker and Darby's earlier (1997) finding. Senior management recognition, as measured by word count in the annual report, is

Table 6 Recognition as a determinant of response: weighted biotech words as a predictor of *biotech patents*, controlling for firm and year fixed effects and selected alternative explanations (conditional fixed effects negative binomial regression)

Dependent var: patents	15 firms, 1976–1998			12 firms, 1981–1998	
	(6–1)	(6–2)	(6–3)	(6–4)	(6–5)
<i>n</i> =	307	307	307	178	178
Log of stock of weighted biotech words (<i>t</i> – 1)	0.33**** (0.07)	0.15** (0.06)	0.16** (0.06)	0.13* (0.06)	0.25**** (0.06)
Log of stock of previous patents		0.81**** (0.08)	0.77**** (0.08)	0.80**** (0.08)	0.55**** (0.07)
Log of sales (<i>t</i> – 1)			–0.26 (0.21)	–0.01 (0.20)	0.47* (0.23)
Log of R&D (<i>t</i> – 1)			0.84**** (0.20)	0.22 (0.17)	0.33 (0.27)
Operating income percent (<i>t</i> – 1)			–1.51 (1.03)	–1.09 (1.05)	–2.62* (1.20)
Competitor patents (<i>t</i> – 1)			–0.05 (0.05)	–0.01 (0.14)	–0.01**** (0.16)
Pubfrac					0.74 (0.83)
Share of cardiology patents					–0.01 (0.01)
Share of oncology patents					–0.05 (0.05)
Cardiology sales as percentage of firm sales					0.01 (0.01)
Oncology sales as a percentage of firm sales					–0.23 (0.15)
Cardiology market share					0.02 (0.02)
Oncology market share					0.03 (0.03)
Constant					0.15
Pseudo <i>r</i> ²					0.20
Log likelihood	–670.14	–605.10	–587.86	–466.35	–523.78
χ^2 /Wald χ	238.81	439.48	413.19	297.53	266.62
<i>P</i> of χ	0.00	0.00	0.00	0.00	0.00

Note: To save space, coefficients for year effects not reported in this table.

† $P \leq 0.10$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; **** $P < 0.0001$.

significantly correlated with publication in the larger sample, and is positively signed but not significant in the smaller.¹⁵

¹⁵As a limited test of the potential for selection bias related to the mergers and acquisitions (M&A) activity among the companies in our sample, we reran all of the analyses using only the companies in the database that were not involved in M&A. This leaves us with seven companies (Abbott, AHP, Lilly, Merck, Pfizer, Schering Plough and Warner Lambert) totaling 161 observations. For models 1–3, the

Table 7 Recognition as a determinant of response: weighted biotech words as a predictor of *biotech publications*, controlling for firm and year fixed effects and selected alternative explanations (conditional fixed effects negative binomial regression)

Dependent var: publications	15 firms, 1976–1998			12 firms, 1981–1998	
	(7–1)	(7–2)	(7–3)	(7–4)	(7–5)
<i>n</i> =	307	307	307	178	178
Log of stock of weighted biotech words (<i>t</i> – 1)	0.20**** (0.05)	0.12* (0.05)	0.10* (0.05)	0.07 (0.06)	0.07 (0.04)
Log of stock of previous publications		0.62*** (0.09)	0.40**** (0.09)	0.37*** (0.11)	0.45**** (0.08)
Log of sales (<i>t</i> – 1)			0.30 (0.20)	0.42* (0.21)	0.01 (0.18)
Log of R&D (<i>t</i> – 1)			0.73**** (0.17)	0.64**** (0.17)	0.80**** (0.19)
Operating income percent (<i>t</i> – 1)			–1.02 (0.93)	–0.89 (0.99)	–0.88 (0.87)
Competitor publications (<i>t</i> – 1)			–0.09† (0.05)	–0.09 (0.06)	–0.12† (0.06)
Pubfrac					1.04† (0.57)
Share of cardiology patents					–0.01* (0.01)
Share of oncology patents					–0.08* (0.03)
Cardiology sales as percentage of firm sales					0.01 (0.01)
Oncology sales as a percentage of firm sales					–0.16 (0.11)
Cardiology market share					–0.01 (0.01)
Oncology market share					0.03 (0.02)
Constant					0.40
Pseudo <i>r</i> ²					0.22
Log likelihood	–688.18	–651.22	–628.38	–449.29	–509.45
χ^2 /Wald χ	341.96	456.88	418.80	323.88	284.69
<i>P</i> of χ	0.00	0.00	0.00	0.00	0.00

Note: To save space, coefficients for year effects not reported in this table.

† $P \leq 0.10$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; **** $P < 0.0001$.

results were nearly identical: the signs for the effect of the stock of weighted words were all the same (positive), though the significance was attenuated for models 2 and 3. Models 4 and 5 operate on a smaller dataset due to lack of detailed data for some of the firms. By eliminating firms with M&A activity, this dataset is reduced to four firms and only 72 observations. The results of the analysis are, not surprisingly, quite noisy, and we do not find support in this very limited sample of our findings for models 4 and 5. While the sample limited to companies without significant M&A activity has its own potential for selection bias, we believe this test, at least for models 1–3 where we have an adequate number of data points, signals that the bias in the overall sample of 15 may not be significant.

Table 8 Recognition as a determinant of response: weighted biotech words as a predictor of *equity deals*, controlling for firm and year fixed effects and selected alternative explanations (conditional fixed effects negative binomial regression)

Dependent var: deals	15 firms, 1976–1998			12 firms, 1981–1998	
	(8–1)	(8–2)	(8–3)	(8–4)	(8–5)
<i>n</i> =	307	307	307	178	178
Log of stock of weighted biotech words (<i>t</i> – 1)	–0.08 (0.12)	–0.10 (0.12)	–0.04 (0.13)	0.12 (0.15)	0.12 (0.15)
Log of stock of previous deals (<i>t</i> – 1)		–0.37 (0.16)	–0.51** (0.19)	–0.50* (0.23)	–0.43* (0.21)
Log of sales (<i>t</i> – 1)			1.46 (0.86)	0.53 (0.97)	0.78 (0.76)
Log of R&D (<i>t</i> – 1)			–0.73 (0.71)	–0.23 (0.83)	0.05 (0.84)
Operating income percent (<i>t</i> – 1)			10.90*** (3.15)	9.75** (3.24)	11.22*** (3.24)
Competitor deals (<i>t</i> – 1)			–0.23 (0.82)	–0.19 (0.95)	–0.10 (0.94)
Pubfrac					–5.15 (4.12)
Share of cardiology patents					0.02 (0.03)
Share of oncology patents					–0.15 (0.10)
Cardiology sales as percentage of firm sales					–0.12** (0.04)
Oncology sales as a percentage of firm sales					–0.44 (0.39)
Cardiology market share					–0.02 (0.07)
Oncology market share					0.09 (0.08)
Constant					–2.10
Pseudo <i>r</i> ²					0.34
Log likelihood	–170.11	–167.66	–160.53	–111.97	–133.15
χ^2 /Wald χ	299.46	70.14	259.92	53.69	138.87
<i>P</i> of χ	0.00	0.00	0.00	0.00	0.00

Note: To save space, coefficients for year effects not reported in this table.

†*P* ≤ 0.10; **P* ≤ 0.05; ***P* ≤ 0.01; ****P* ≤ 0.001; *****P* < 0.0001.

For equity-based deals (Table 8), there is no significant association between measures of recognition and action. This suggests three possibilities. (i) Our current measure of deals is not as well defined or as comprehensive as that for patents and publications. (ii) There is some other mechanism that connects recognition to response in the form

of deals. (iii) Deals are a completely separate process¹⁶ from the sensemaking top management does about the firm and its environment and that the letters to shareholders reflect the issues that are important to the leadership with regard to internal efforts only (e.g. patenting and publication activities by the R&D group).

One objection to these results showing a positive association between management recognition and subsequent action (for three of the four outcome measures) would be that they simply indicate some kind of management coherence. One might imagine, for example, that middle management instigates research projects that, if successful, lead to patents and publications and simultaneously bubble up to the visibility of senior executives who highlight them in the annual report. Ideally, we would like to present some detailed qualitative evidence demonstrating the directionality of the association. In its absence, we tested our key variables ‘in reverse’ by regressing our measure of ‘recognition’ against each of our major measures of ‘action’ with firm and year fixed effects. We found no significant association between the stock of gene sequences, patenting, publications or deals and subsequent mentions of biotechnology in the letter to shareholders, which is at the very least consistent with the hypothesis that management recognition is not simply a product of the firm’s prior experience (see Table 9).

Taking the results of our main regressions that cognition precedes action together with evidence that previous actions are not associated with cognition, we provide substantiation that management recognition is a separate construct from previous organizational activities and an indicator of future strategic action.

5. Conclusion and directions for further research

The central goal of this paper was to explore the relationship between managerial recognition and strategic response in the case of significant discontinuity. Our findings are consistent with the hypothesis that managerial sensemaking (recognition and interpretation) of the environment may be an additional explanatory factor in understanding firm actions during periods of technological discontinuity. We find strong qualitative, descriptive evidence for a relationship between managerial recognition of biotechnology and strategic action of publishing and patenting by some firms and some suggestive support from the regressions. A count of biotechnology related words in the annual letter to shareholders is significantly correlated with next year’s gene sequence and biotechnology patents, and, in the larger sample, with biotechnology publications.

While it is always possible that these results reflect the presence of some omitted, unobserved variable that has driven both outcomes—it might be the case, for example, that successful research in biotechnology drives both managerial recognition and patenting and publication behavior—a number of factors lead us to believe that these

¹⁶Evidence, for example, that profits have an entirely different effect on the rate of patents and publications (negative) and on alliances (positive and significant) is but one indicator that this is an entirely separate process driven by different dynamics.

Table 9 ‘Testing in reverse’—response as a predictor of recognition: stock of biotechnology patents, publications and deals as predictors of mentions of biotechnology in letters to shareholders controlling for firm and year fixed effects and previous words (conditional fixed effects negative binomial regression)

Dependent var: weighted biotech words	Predictor = gene seq (9–1)	Predictor = patents (9–2)	Predictor = publications (9–3)	Predictor = equity deals (9–4)
<i>n</i> =	247	307	307	307
Log of stock of gen seq patents (lagged 1 year)	0.02 (0.61)			
Log of stock of patents (lagged 1 year)		0.29 (0.48)		
Log of stock of publications (lagged 1 year)			0.43 (0.63)	
Log of stock of deals (lagged 1 year)				0.10 (0.63)
Log of previous weighted words	0.13 (0.46)	0.12 (0.45)	0.09 (0.45)	0.18 (0.43)
Log likelihood	–28.27	–29.80	–29.64	–30.00
χ^2 /Wald χ	5.06	4.98	5.23	4.75
<i>P</i> of χ	1.00	1.00	1.00	1.00

Note: To save space, coefficients for year effects not reported in this table. Effects are not significant for any year in any model. Model 9–1 for 1980–1998. Models 9–2, 9–3, 9–4 for 1976–1998.

† $P \leq 0.10$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$; **** $P < 0.0001$.

results are at the very least consistent with the hypothesis that senior management sensemaking plays an important role in shaping a firm’s response to biotechnology.¹⁷

First, as we showed in Table 9, it does not appear to be the case that successful research—at least as measured by patents and publications—drives managerial recognition. Second, given the tight turn-around schedules characteristic of the field, we believe that biotechnology publication rates are a very good indicator of biotechnology investment, and biotechnology publications appear to be at least partially driven by senior management recognition. Third, the nature of the letters themselves suggest to us that they represent a commitment to a future course of action rather than a reflection on what the firm happens to have blundered into.

The relationship between equity alliances and managerial recognition of biotechnology is more complex. Our results suggest that for strategic actions involving deals, the relationship between recognition and response is more nuanced than in the case of

¹⁷We also tested three-year lags, with the idea that lead time between recognition and response might be longer. Our results are consistent with those for one-year lags. The positive signs are largely the same, though due to the noise introduced by the longer time frame, the results are only marginally significant.

patents and publications. This may be because deals represent only one of a number of different ways in which the biotechnology knowledge capital of a firm can be developed.

Our results could clearly be extended in a number of directions. One obvious alternative explanation of our results is that we have misunderstood the structure of causality. It might be the case, for example, that individual scientists or middle managers make the decision to invest in biotechnology, and that if these investments prove to be successful they lead both to patents and publications and to senior management mention of biotechnology in the annual report. We do not believe this to be the case since we find that publications, in particular, are better thought of as indicators of investments in biotechnology than as signals of successful output, but further work could clearly usefully explore this issue at a more micro level.

More fundamentally, while using word counts from letters to shareholders to measure recognition does offer some important advantages, they are not an ideal measure of the mental framing or cognitive maps of senior managers, and we would like to explore alternative, possibly qualitative, measures. It might also be extremely interesting to examine the link between senior management perceptions of discontinuities and the demographics of senior management teams (an extension of work on in this area by Virany *et al.*, 1992; Tushman *et al.*, 1996).

Nevertheless our results are consistent with the hypothesis that the recognition of key environmental uncertainties at the most senior level shapes certain types of enduring strategic action. This research thus highlights the role of managerial cognition lending weight to the concept that top management plays a crucial role in both interpreting the external environment and shaping the internal response to this environment, and reinforcing some of the qualitative studies making this link (e.g. Garud and Rappa, 1994; Tripsas and Gavetti, 2000)

This work also makes a contribution to the management of technology literature by highlighting the importance of incorporating managerial recognition of discontinuities into our explanations of how established firms respond to these periods of intense change and uncertainty. These explanations have traditionally been missing. Yet, if we take managerial cognition as an explanatory factor seriously, it suggests an interesting midpoint between the inertial arguments of the population ecologists and the incentives arguments of the economists in which inertia may be affected by the degree to which management frames change and incentives are acted on based on how they are perceived. Our empirical evidence provides at least some preliminary indication that this may be the case, and that a gradual evolution in managerial understanding of the nature of discontinuities may play an important role in shaping their own company's actions and ultimately industry evolution.

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