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Financial success in biotechnology: company age versus company science

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Abstract

The purpose of this research effort is to use the tenets of institutional theory to explore the relative stock market success of biotechnology companies. Previous research (Deng, Z., Lev, B., Narin, F., 1999. Science and technology as predictors of stock performance. Financial Analysts Journal 55(3), 20–32.) has highlighted the relationship between the quality of companies' technology, as measured using quantitative patent indicators, and their stock market valuation.

Institutional theory (DiMaggio, P.J., Powell, W.W., 1983. The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. American Sociological Review 48, 147–160.) might suggest that there are many institutional outcomes that are decoupled from the actual activities of the organization. From this view, much of a firm's effort might involve signalling components, including the age of the company and other similar activities.

Our results are that older companies have significantly higher stock market valuations, and that those companies had fewer PhD's as their Chief Executive Officers (CEOs). These findings suggest that the stock market often looks favourably upon older established biotechnology companies that are run by professional managers rather than pioneering scientists.

Keywords: Financial success; Biotechnology; Company science

1. Overview

Although biotechnology in the form of the crossbreeding of animals and the development of hybrid plants has existed for many years, the US biotechnology revolution really began in 1973. In that year, Stanley Cohen of Stanford University and Herbert Boyer of the University of California at San Francisco discovered the basic technique for recombinant DNA, which became the basis for genetic engineering (Cohen et al., 1973). New companies followed quickly with some forming as early as 1975 and 1976 (Zucker and Darby, 1997).

Even with the tremendous growth in US biotech (over 300 publicly traded companies in 2003) and the millions made by investors and scientists, it is still somewhat unclear exactly what biotech's contributions to the worldwide pharmaceutical industry will be. However, according to the Biotechnology Report of Ernst and Young (2003), due in a large part to its robust pipeline of new products, the industry is poised to be profitable for the first time in its 30-year existence. This is one of the main reasons that biotech continues to be an important industry to analyse and examine. However, we also believe that more work needs to be done in the area of corporate financial success beyond the initial public offering (IPO). It is in this area that we hope to make a contribution.

We will employ a methodology that uses a group of science and technology indicators to evaluate the stock market performance of a firm (Thomas and McMillan, 2001). We then rank a group of 35 biotechnology firms based on their Valuation Percentile, i.e. the difference between their technological valuation (theoretical) and their stock market (actual) valuation. Next, using institutional theory as our theoretical foundation, we examine a number of non-scientific firm variables that might explain the differences.

2. A brief review of institutional theory

In general, institutional theorists are more interested in explaining uniformity than diversity (DiMaggio and

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Powell, 1983). Isomorphism, a central construct within institutional theory (Westney, 1993), captures the extent to which organizational designs adopted within organizational fields tend toward increasing homogeneity over time. This emphasis on uniformity leads institutional theorists to focus on the organizational field, or even society at large, as the primary unit of analysis.

Another important aspect of institutional theory focuses on the issue of legitimacy. There are many definitions for legitimacy, but one of the most frequently cited is 'legitimacy is a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions' (Suchman, 1995). Legitimacy is a societal comparison based on socially agreed upon industry characteristics, which determine whether a company is desirable, proper, and appropriate, as a place to work and as a place to invest. It is this legitimacy vis-à-vis investing issue on which we want to focus for the biotechnology industry.

With their genesis in university labs, it is not surprising that many biotechnology firms have had PhD-level scientists as their CEOs and as other senior managers. Many times, of course, these individuals were the founders, such as Swanson and Boyer at Genentech (McMillan, 1999). Yet, it would also not be surprising that the investment community might look askance at exacademics heading up these firms. Though the academics have great expertise at developing new drugs and products, they are perhaps less likely to have had much experience at bringing those products profitably to market, and therefore, the investment community might prefer to see more seasoned managers at the helm of these companies.

Drawing on the above theory, we propose that the following three variables might explain differences in how the investment community views (values) a particular biotechnology firm: the age of the firm, whether the CEO is a PhD or not, and the percentage of the top management team (TMT) that has a PhD.

3. Initial data collection and methodology

The first purpose of this paper is to describe a method through which indicators of technology quality and commitment to R&D can be related to a group of biotechnology companies' stock market performance. This is an extension of a technique we introduced in a previous work (Thomas and McMillan, 2001). There are two initial stages in this method. In the first stage, we develop a market-to-book valuation of companies based on the quality of their technology and their commitment to R&D. This is achieved using a set of quantitative patent and R&D indicators, including patent impact, links to science, innovation speed and R&D intensity. These indicators are described in detail in Section 4. This research builds on previous work by Deng et al. (1999), which used only two patent indicators (patent impact and links to science) and did not produce market-to-book valuations for individual companies.

In the second stage, we compare these technology-based market-to-book valuations with companies' actual market-to-book valuations. This two-stage process facilitates identification of companies that are under and over valued in the stock market.

3.1. Developing company valuations based on the quality of patent portfolios

The first stage in our analysis was to develop a valuation of companies based on the quality of their patent portfolios. Patent quality was measured using a number of *patent citation* indicators. A typical US patent cites about eight earlier US patents, one or two foreign patents, and one or two non-patent references, of which the majority are science references (citations to scientific papers, meetings, etc.). The underlying assumption in patent citation analysis is that a patent which is highly cited, i.e. is referred to by many subsequently issued patents, is likely to contain technological advances of particular importance. For example, Albert et al. (1991), in cooperation with Eastman Kodak Laboratories, reported that patents ranked highly by Kodak's staff were more frequently cited than patents of lower rank. The patent citation indicators used in this analysis were as follows.

Current impact index (CII). The CII shows the impact of a company's patents on the latest technological developments. It is a measure of how often the previous 5 years of a company's patents are cited by patents issued in most recent year, relative to all US patents. A CII of 1.0 shows that the last 5 years of a company's patents are cited as often as expected, compared to all US patents. A CII of 1.1 indicates 10% more citations per patent than expected, and so forth. Note that CII is a synchronous indicator, and moves with the current year, looking back 5 years. As a result, when a company's patents from recent years start to drop in impact, this is picked up quickly as a decline in the current year's CII.

Science linkage (SL). Science Linkage is a measure of the extent to which a company's technology builds upon cutting-edge scientific research. It is calculated based on the average number of references on a company's patents to scientific papers, as distinct from references to previous patents. Companies whose patents cite a large number of scientific papers are assumed to be working closely with the latest scientific developments.

Technology cycle time (TCT). In general, companies that are innovating rapidly tend to be more successful in product development than companies relying on older technologies. This leads to another citation indicator, the Technology Cycle Time (TCT). TCT is a measure of the median age of the US patents cited on the front page of a company's patents. A tendency to cite older patents is an indication that a company utilizes older technology. The average TCT is as short as 3 or 4 years in rapidly evolving industries, such as electronics, and as long as 15 years in industries that change more slowly, such as shipbuilding.

Using multiple regressions, these patent indicators, along with companies' R&D Intensity (R&D expenditure/sales) were mapped against actual valuations of companies on the stock market. The purpose of this analysis was to find the combination of patent indicators that is related most closely to companies' actual market valuations. The company valuation measure used was actual market-to-book (MTB). This measures the relationship between the stock market value of a company, and the value of the assets it has on its balance sheet. A high MTB shows a company that the market feels has value over and above the assets revealed on its balance sheet. This value may emerge in part from the quality of a company's technology, which is not explicitly shown on its balance sheet.

Eight separate regression analyses were carried out, for the end of each year between 1990 and 1997. Hence eight regression equations were produced, each with companies' Actual MTB as the dependent variable, and their patent and R&D indicators as independent variables.

The coefficients associated with the independent variables changed each year. However, a relatively high degree of consistency was discovered in five of the coefficients—normalized CII, normalized SL, non-normalized SL, normalized TCT, and R&D intensity (normalized refers to indicators that have been normalized by industry.) A new set of eight regression equations were therefore generated, using only the five relatively stable indicators as independent variables. The coefficients associated with these variables in the new equations are shown in Table 1.

This table reveals that, in most cases, there were positive values for normalized CII and non-normalized SL and R&D, and negative coefficients for TCT and normalized SL. However, the TCT coefficient was less stable than the others. The average R^2 value of the regression models across the period 1990–1997 was 0.08. F statistics revealed that five out of the eight models were significant at the 1% level, and a further two models were significant at the 5% level. Although the R^2 value is relatively low, suggesting that the relationship is somewhat noisy, it is similar to the R^2's between earnings and Actual MTB reported by Lev and Sougiannis (1996).

Table 1
Regression coefficients 1990–1997

Year	Constant	CII (normalized)	SL	SL (normalized)	TCT (normalized)	R&D intensity
1990	0.27	0.37	0.33	−0.11	−0.01	0.17
1991	0.44	0.34	0.17	0.01	−0.01	0.09
1992	0.64	0.35	0.22	−0.07	0.03	−0.01
1993	0.51	0.27	0.07	−0.06	0.02	0.11
1994	0.66	0.25	0.04	−0.08	−0.01	0.10
1995	0.77	0.25	0.09	−0.06	−0.01	0.25
1996	0.26	0.52	0.03	−0.14	−0.16	0.05
1997	0.45	0.66	0.23	−0.15	−0.20	0.09

Due to the consistency in the coefficients four of the variables (i.e. excluding normalized TCT) it was possible to combine them to produce a single regression equation that related patent indicators to Actual MTB valuations for the period 1990–1997. The initial coefficients for this equation were the means of the coefficients from the eight models. Sensitivity analysis was then carried out on the equation, with each of the coefficients being changed up to 10% in each direction to establish whether alternative equations would produce MTB values that correlated more closely with Actual MTB values. Small changes were made in the coefficients as a result of this analysis.

The final equation produces a technological MTB valuation for each company based solely upon the quality of its patent portfolio. This valuation is defined as the Tech MTB. The formula used for the Tech MTB in this paper is:

$$\text{Tech MTB} = \exp(0.4 + 0.4 \times \text{CIInormed} + 0.15 \times \text{SL} + 0.011 \times \text{R\&D} - 0.09 \times \text{SLnormed})$$

Entering the patent and R&D indicators for a given company into this equation provides a technology-based valuation of that company. It should be noted that the number of patents is not included in the calculation of Tech MTB scores. The size of a company's patent estate was found to be unrelated to its MTB valuation. It is not the *number* of patents that is important, but the *quality* of these patents. Hence, there is no inherent bias in the model towards large companies with extensive patent portfolios.

4. Relating Tech MTB and Actual MTB values

Given that the Tech MTB valuations have their foundation in mapping patent indicators onto Actual MTB valuations, it might be expected that these two valuations of companies would be similar. However, multiple regression fits a single model to all cases, so that each case has a residual term associated with it. Based upon this residual, it is possible to define whether the company, based upon its technology, is overvalued (Actual MTB > Tech MTB) or undervalued (Tech MTB > Actual MTB).

Particular interest is paid to those companies with the largest relative residuals. These are the most undervalued and overvalued companies in the sample. To identify these companies, all companies in the sample were placed into percentiles according to their Tech MTB, with 100 assigned to the company with the highest Tech MTB, and one to the company with the lowest Tech MTB. Companies were then placed into percentiles according to their Actual MTB, with 100 representing the highest Actual MTB[2].

For each company, the Actual MTB Percentile was subtracted from the Tech MTB Percentile. Companies were then placed into percentiles on the basis of the resultant differential, to produce the Valuation Percentile of each company. The highest Valuation Percentile (100) was assigned to the companies with the largest positive differential. The Tech MTB Percentile of these companies exceeded their Actual MTB Percentile by the largest amount. These companies were therefore the most undervalued in the sample. The lowest Valuation Percentile (1) was assigned to the most overvalued companies in the sample, whose Actual MTB Percentile exceeded their Tech MTB Percentile by the largest amount.

The Valuation Percentile of a company is a guide to how its valuation in the stock market compares to a valuation of it based solely upon its technology. A company with a Valuation Percentile of 100 has strong technology that is not recognized by the stock market. Meanwhile, a company with a Valuation Percentile of 1 has a valuation in the market that cannot be justified on the basis of its technology (although there may be other factors that explain its high valuation). A company with a Valuation Percentile of 50 is regarded as fairly valued, based upon the quality of its technology.

5. Biotechnology company data collection

Using the previous methodology, we examined a total of 35 US biotechnology companies, and compared their 2003 Tech MTB percentiles with their Actual MTB percentiles, which thus provided a ranking of their respective Valuation Percentiles. The results are provided in Table 2.

Additional data were then collected on the age (variable AGE) of the firms (2003 minus year of incorporation), whether the CEO had a PhD or not (CEOPHD), the percentage of the top management team with a PhD (PERTMT), and finally the control variable of R&D expenditures. R&D in this context is regarded as a control reflecting the varying sizes of the companies in the sample. All data were collected from MergentOnline for 2002 except the R&D data, which was gathered from company SEC filings.

[2] We used percentiles to rank companies because some companies have extremely high MTB or Tech MTB valuations. The former may be caused by the method used to calculate company book values. The latter may result from unusual patent referencing practices, such as companies citing large numbers of their previous patents. As a result of these cases, the distribution of both MTB and Tech MTB are highly skewed, and using percentiles rather than raw values reduces the impact of these outliers.

Table 2
Technology and stock market valuations of biotechnology companies

Company	TECHPERC	MTB PERC	VAL-PERC
Emisphere Technologies, Inc.	97.68	4.64	99.53
Nanogen, Inc.	96.98	3.94	99.30
Caliper Technologies Corp.	98.84	7.66	98.84
Guilford Pharmaceuticals, Inc.	96.75	11.37	97.67
Maxygen, Inc.	99.77	23.90	96.28
Cell Pathways, Inc.	75.87	18.79	91.40
Diversa Corp	100.00	47.56	89.30
Ribozyme Pharmaceuticals, Inc.	45.48	0.50	84.88
3-Dimensional Pharmaceuticals	79.35	35.96	83.72
Curis, Inc.	38.98	1.16	80.93
Corvas International, Inc.	42.00	9.51	78.60
Incyte Genomics, Inc.	30.16	4.87	72.33
Human Genome Sciences, Inc.	37.82	17.40	68.84
Symyx Technologies, Inc.	97.91	78.19	68.60
Myriad Genetics, Inc.	58.24	41.07	66.74
Tularik, Inc.	43.16	28.54	65.58
Pharmacopeia, Inc.	37.59	29.70	61.63
Millennium Pharmaceuticals	37.35	33.18	59.77
Invitrogen Corp.	4.87	25.29	51.86
Geron Corp	77.26	58.00	48.84
Lynx Therapeutics	73.78	63.57	46.99
Regeneron Pharmaceuticals	61.72	62.88	41.90
Affymetrix, Inc.	95.59	97.68	40.97
Enzon, Inc.	71.46	77.26	40.05
Genzyme Corp.	68.21	76.33	37.73
Celgene Corp.	69.61	89.56	31.02
Cell Therapeutics	29.00	50.35	30.79
Heska Corp	17.63	43.62	27.78
Immunomedics, Inc.	39.91	70.07	25.69
ICOS Corp	50.81	83.99	24.31
Genelabs Technologies, Inc.	34.57	78.65	14.35
Cephalon, Inc.	53.13	97.91	13.66
Chiron Corp	34.11	79.12	13.19
Biogen, Inc.	31.55	77.49	12.27
Genentech, Inc.	25.99	72.62	11.81

6. Results

We examined the relationship between the three company characteristics (age of company, percent of top management with a PhD or MD, and whether the CEO has a PhD or MD), and the technology and stock market valuations of companies. Due to the small number of companies in the sample, we were restricted in terms of the statistical tests we could use. Due to the small sample, care must also be taken in analysing the results.

The first question we addressed was whether any of the company characteristics outlined earlier is correlated with either the technology valuation of companies, or their actual stock market valuations. The correlation matrix in Table 3 shows the results of this analysis.

The first column of this matrix shows the correlation of the companies' ages with their various characteristics. As can be seen, company age was significantly correlated with variables CEOPHD, TECHPERC, MTBPERC, VALPERC, and RD. This suggests older companies are led by non-PhD-holding executives, produce weaker technology, have

Table 3
Correlation matrix ($N=35$)

	Age	PERTMT	CEOPHD	TECH PERC	MTB PERC	VAL PERC
PERTMT	−0.27 (0.12)					
CEOPHD	−0.36 (0.03)	0.86 (0.00)				
TECHPERC	−0.36 (0.04)	−0.08 (0.64)	−0.07 (0.68)			
MTBPERC	0.56 (0.00)	−0.23 (0.18)	−0.45 (0.01)	−0.04 (0.81)		
VALPERC	−0.72 (0.00)	0.14 (0.43)	0.32 (0.06)	0.56 (0.00)	−0.83 (0.00)	
RD	0.51 (0.00)	−0.04 (0.82)	−0.21 (0.22)	−0.33 (0.05)	0.27 (0.12)	−0.41 (0.01)

PERTMT, percentage of top management team with a PhD; CEOPHD, binary variable showing whether CEO of company has a PhD or MD; TECHPERC, Technology MTB percentile; MTBPERC, Actual MTB percentile; VALPERC, measure of the extent to which company is under or over valued; RD, company R&D expenditures in millions; AGE, 2003 minus the year of incorporation.

higher market valuations, are less attractive investment opportunities, and are generally bigger.

Second, there is a significant negative relationship between companies' actual market valuation and the possession of a PhD by their CEO. This suggests that the stock market does not necessarily have a positive view of companies that are led by prominent scientists. Instead, companies run by non-scientists may gain greater favour in the stock market.

Finally, we do not find a significant relationship between the percentage of the TMT that has a PhD and any variable. This seems to suggest that PhD's on the top management team have much less of an impact than that of the CEO with a PhD.

7. Conclusions and discussion

In a previous paper (Thomas and McMillan, 2001), we introduced a technique for valuing companies based on the quality of their patented technology. These valuations were compared with companies' actual stock market valuations to establish whether they are under or over valued. In this paper, we seek to examine the question of why some companies' stock market valuations should differ from the value of their technology, particularly in apparently technology-driven industries such as biotechnology.

We examined three variables that may explain some of the frequent disparity between companies' actual and technology-based valuations. These variables were chosen based on the tenets of institutional theory. We found that there was a significant positive relationship between the age of companies and their market valuation, and a significant negative relationship between companies' market valuations and the possession of a PhD by its CEO. Taken together, these findings suggest that the stock market often looks favourably upon older established biotechnology companies that are run by professional managers rather than pioneering scientists.

The high valuations of these older biotechnology companies are not necessarily based on the quality of their patented technology. We found that newer companies led by CEO's holding a PhD tended to produce higher impact patents than older companies led by non-PhD's.

This study may thus provide a first indication that the stock market does not value biotechnology companies solely on the basis of their technological qualities. Rather, there is evidence to suggest that familiarity with established companies, and confidence in the ability of professional managers, may lead investors to favour companies with these characteristics.

The results of this study are based on a small sample of biotechnology companies, which affects the significance of our statistical findings. However, the results from this small sample are promising, and suggest that more extensive research in this area may be worthwhile. In particular, adding more companies to the sample is necessary to determine whether the results of this study can be generalised. It may also be useful to examine the relationships discussed here over time. This may show the stock market's reaction to events such as the appointment of professional management teams by biotechnology companies.

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