The Journal of Business Inquiry 2018, 18, Issue 2, 82-99
http:www.uvu.edu/woodbury/jbi/volume18
ISSN 2155-4072

Intangibles and the Market Value of Biopharmaceutical Startups

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This paper investigates the relationship between various measures of intangible capital and the market valuation of young biopharmaceutical firms. We employ a non-linear model to measure the impact of R&D, patents, alliances, organizational capital, and mergers on the value of 349 newly-incorporated firms between 1980 and 2006. We find that, with the exception of mergers, our measures of intangible capital have positive and significant effects on market values; the impact of R&D declines as firms mature; and the omission of either alliances or organizational capital leads to a significant overstatement of the influence of R&D.

Keywords: Innovation, R&D, Intangible Assets, Market Valuation, Biopharmaceuticals

JEL Classification: O32, L65, E22, G32

I. Introduction

The valuation of firms in technology-based industries is among the most challenging tasks in finance. Despite considerable research efforts over the last three decades,[1] a substantial unexplained differential remains between book and market values (Amir and Lev, 1996). Various studies point to a failure to account for intangible assets, rather than "mismeasurement of conventional equity or the vicissitudes of the stock market," (Hulten and Hao, 2008, p. 1) as the primary source of this differential. Valuing intangible assets of young technology-based firms, which typically derive the bulk of their value from such assets, is "notoriously difficult" (Guo *et al.*, 2005, p. 3). Prime examples of this, and the focus of our study, are newly-incorporated biopharmaceutical firms, which invest heavily in intangibles[2] and have impressive track records with respect to innovation. We analyze the relationship between R&D-based intangibles and the value of young firms[3] where information asymmetries are particularly acute and financial information is of limited value.[4]

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[1] Numerous studies have explored this relationship. Examples include Griliches (1981), Cockburn and Griliches (1988), Hall (1993), Lev (2001), Chan *et al*. (2001), and Hall *et al*. (2005), among others.

[2] The biopharmaceutical sector is one of the most R&D-intensive in the United States, with companies investing over 12 times the amount of R&D per employee than manufacturing industries overall; see Phrma.org, 2017 State of the Industry (http://phrma.org/industryprofile/).

[3] During the first 12 years after their incorporation.

[4] Although prior studies have investigated the impact of various intangibles on firm value, we consider the impact of several intangibles simultaneously with the goal of parsing out the different effects. Related works include:

We use a market value function based on hedonic Tobin's *Q* equations first introduced by Griliches (1981).[5] This is the standard approach used in the literature to test the influence of various measures of intangible assets on firm performance using stock market data. We expand the standard version of the value function to include additional terms, capturing several intangibles that are unique to the biopharmaceutical industry and for which data are publicly available. In selecting our intangible asset measures, we work under the premise that any outlay intended to increase future rather than current revenues should be considered a capital investment (as in Corrado *et al.*, 2006). Therefore, spending on R&D, new patents, and even improved organizational structures should, in principle, be counted as investment.

A general consensus exists in the literature that R&D conducted by firms is an input in the production process whose output is an intangible asset.[6] R&D is especially critical in the biopharmaceutical industry according to Filson *et al.* (2015). To measure the R&D output, most studies have used the number of patent applications a firm has filed, weighted by the number of citations those patents receive to adjust for their quality, and thus economic value.[7] Patent information has limitations however—it measures knowledge output at the end of the discovery stage and at the beginning of a potential product development. In a great majority of cases, however, patented inventions do not even enter the product development stage, and of those that do, relatively few are developed into final marketable products.[8] For this reason, it is important to test the impact of another measure of R&D success, namely the clinical pipeline[9] that tracks pharmaceutical product development through a number of well-defined stages and which is a

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Trajtenberg (1990), who demonstrates that patents are important for optical scanners; Megna and Mueller (1991), who find that advertising is an important source of intangible capital in the distilled beverage and cosmetic industries; Megna and Klock (1993) and Shane and Klock (1997), who show that R&D expenditures and citation-weighted patent metrics measure intangible capital in the semiconductor industry, respectively; Chan *et al.* (1997) and Filson and Oweis (2010), who show that alliance formation has a positive impact on the value of biotech firms; Klock and Megna (2000), who demonstrate that spectrum license data can be used as a metric of intangible capital of cell phone companies; Rzakhanov (2004), who shows that advertising and clinical trials are important in the biotech industry; Darby *et al.*(2004), who study the value of R&D, citations, and human capital in biotech; Filson (2004), who examines the impacts of advertising and promotional alliances on the value of young e-commerce firms; Gleason and Klock (2006), who show that advertising is also important in the pharmaceutical and chemical industry; Hulten and Hao (2008), who study the impact of organizational development on the market value of a sample of pharmaceutical firms; and Gupta *et al*. (2017), who analyze the relationship between market value and firm investments in customer acquisitions and customer service.

[5] Other examples of this approach can be found in: Cockburn and Griliches (1988), Megna and Klock (1993), Klock *et al.* (1996), Shane and Klock (1997), Klock and Megna (2000), Hall *et al*. (2000), and Hall *et al.* (2005).

[6] Numerous studies have shown that R&D expenditures have a large impact on the market value of firms (Hall *et al*., 2005 and others).

[7] The large-scale use of patent data in economic research goes back to Scherer (1965), Schmookler (1966), and Griliches (1984). Prior literature shows that quality-adjusted patents do seem to add information above and beyond that obtained from R&D input measures (see Trajtenberg, 1990; and Hall *et al*., 2000 and 2005).

[8] An average of four years from beginning discovery research to beginning human clinical trials involving thousands of rejected compounds, and an average of eight years from beginning human clinical trials to introducing a new approved drug with an approximately one-in-five chance of success (Filson *et al*., 2015).

[9] In order for a company to market a product, it has to be approved by the Federal Drug Administration (FDA). The process involves different phases: The first one is the Pre-Clinical studies. Then, it files an Investigational New Drug Application with the FDA (IND). If approved, then it goes to clinical trials. There are three clinical trials: Phase I, Phase II, and Phase III. If a drug passes all of the three clinical trials, then a firm files a New Drug Application (NDA). If the application is approved by the Board of Review, then it can commercialize the drug.

strong indicator of a firm's future cash flows[10] (see Sharma and Lacey, 2004; McNamara and Baden-Fuller, 2007).

Given the significance of R&D expenditures in the biopharmaceutical industry, an important question concerns the relationship between a firm's age and the value of its R&D investment. In the fast-changing technology-based industries, the fit between a firm's innovative infrastructure and the current technological environment is critical to the success of the firm. In principle, the impact of age on R&D quality can be either positive or negative. Older firms have more experience and might benefit from economies of scale and/or scope, for example. At the same time, the more mature firms may suffer from overinvestment[11] and also from having more entrenched R&D programs, both of which increase the likelihood that their innovative output becomes mismatched with current market demands. In the latter case, age, experience, and accumulated competencies can be a burden for firms as they try to adapt to, or develop, new technologies (Henderson and Clark, 1990; Henderson, 1993). Furthermore, in recent decades there has been a tight link between scientific discovery and new products—new firms have often been spinouts from universities formed by star scientists to exploit the latest scientific discoveries. This has tended to provide an edge for young/small firms.[12]

Despite large investments in R&D, numerous observers have pointed to dwindling prospects for new drug discoveries and a wave of pending patent expirations as a major concern for the biopharmaceutical industry. This has forced firms to supplement their internal R&D with external sources of innovation, such as strategic technology alliances, and to gain R&D synergies through acquisitions (see Higgins and Rodriguez, 2006; Danzon *et al.*, 2007; Grabowski and Kyle, 2008). Both alliances and acquisitions enable companies to quickly access technological assets (Lerner *et al.*, 2003), to expand their knowledge base, and to exploit their existing technological edge (Hagedoorn and Duysters, 2002). Unlike acquisitions, however, in an industry where projects are particularly uncertain, risky, long, and expensive, alliances provide flexibility and are relatively cheap to set up (Filson and Morales, 2006). Firms can experiment by creating alliances with different partners and disband them quickly if warranted by changes in the market conditions. If a firm instead chooses the acquisition route, then it "is able to grow quickly, but it shrinks with great difficulty as resources come under managerial control" (Chan *et al.*, 1997, p. 203). A misevaluation of the target firm by an acquirer can therefore be very costly for the firm. Given the importance of alliances and M&As in the biopharmaceutical industry, we test for their respective impacts on market value.[13]

Our final intangible metric tracks investments in organizational capital. Similar to R&D and other intangibles, spending on a new management system, employee training, marketing and/or sales teams seeks to improve the financial performance of a firm and should therefore be

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[10] Besides increasing the likelihood of increased future sales, successful clinical trials also create positive externalities that are valuable to the firm. The firm's experience with product development, and its familiarization with a myriad of regulations that govern it, can create positive spillovers to the development of other products and further future sales. These spillovers increase the firm's capabilities in product development which at the same time raises the likelihood of profiting from more products in the market (Danzon *et al*., 2005).

[11] This according to the life-cycle hypothesis (see Grabowski and Mueller, 1975).

[12] Darby *et al.* (1999) analyze the role of star scientists on the market value of biotechnology firms.

[13] Several papers have looked at post-merger firm performance including Filson *et al.* (2015) find that post-merger R&D intensity varies across a sample of pharmaceutical firms; Danzon *et al.* (2007) show that merging firms experience a slower growth and lower operating profits. In an authoritative study, Chan *et al*. (1997) conclude that firms that enter into an alliance improve their operating performance (in the five-year period surrounding the event), and that technical alliances trigger a stronger, positive response from equity investors.

considered an investment.[14] We use firms' selling, general, and administrative (SG&A) expenses as a proxy for their investment in organizational capital.[15] According to Hulten and Hao (2008), "at least a fraction of such expenditures should be treated as capital for accounting purposes" (p. 13). The difficulty in measuring this variable has led economists to typically account for it by using fixed effects. However, the more recent literature (including Corrado *et al.*, 2006; Hulten and Hao, 2008; Peters and Taylor, 2017) provides guidance on the measurement issues.

Our main findings indicate that a host of intangible assets—R&D, the patent portfolio, technology alliances, and organizational capital—have a positive and significant influence on the market value of young biopharmaceutical firms. R&D investments display diminishing returns: as firms age, they get less bang for their R&D buck. We find that the M&A activity mostly has an insignificant influence on the market value of the acquirers' shares. Lastly, our results show that the omission of either technology alliances or organizational capital leads to a substantial overstatement of the importance of R&D. These findings demonstrate the merit of investigating this topic at a granular level—the results otherwise may be seriously misleading due to omitted variables.

The rest of the paper is organized as follows: Section II presents the econometric specification; in Section III we construct the different measures of intangible capital and describe the data sources; Section IV discusses the results of the model; finally, Section V summarizes the main conclusions.

II. Methodology and Estimation

In the market value model, the firm is treated as a set of tangible and intangible assets where the marginal shadow value of its assets is measured by the hedonic price of the firm. The value function is:

$$V_{it} = q_{it} f(X_{i1t}, X_{i2t}, X_{i3t}, \ldots X_{int}), \quad (1)$$

where V_{it} represents the value of firm *i* at time *t*. X_{i1t}, X_{i2t}, and X_{int} denote the various tangible and intangible assets of firm *i* at time *t*. q_{it} is the current market value coefficient of the firm:

$$q_{it} = exp(b_i + c_t + u_{it}), \quad (2)$$

where b_i is the firm-specific effect, c_t is the time effect, and u_{it} is an individual disturbance term. To estimate the econometric model, we assume that the firm's assets are additively separable (as in Hall, 1990):

$$V_{it} = q_{it} [A_{it} + (\beta) K_{it}]^{\sigma}, \quad (3)$$

[14] Brynjolfsson *et al.* (2002) and Brynjolfsson and Hitt (2005) illustrate the case of corporations' investments in information technology during the 1990s, which were intended to increase the effectiveness of their management. Bloom and Van Reenen (2007) provide evidence that these investments increased the value of a company. Black and Lynch (2005) report similar results for investments in worker training.

[15] Lev and Radhakrishnan (2005) argue that the SG&A expense includes most of the expenditures that generate organization capital.

where A_{it} represents tangible assets of the firm, β is the relative shadow price of intangible assets, and K_{it} is a measure of intangible assets. After assuming constant returns to scale ($\sigma = 1$), and dividing by A_{it}, we have:

$$\frac{V_{it}}{A_{it}} = q_{it}\left[1 + \beta\left(\frac{K_{it}}{A_{it}}\right)\right]. \qquad (4)$$

Lastly, defining Tobin's Q as $Q_{it} = V_{it}/A_{it}$ and taking logs, we get:

$$\log Q_{it} = \log\frac{V_{it}}{A_{it}} = b_i + c_t + u_{it} + \log\left[1 + \beta\left(\frac{K_{it}}{A_{it}}\right)\right]. \qquad (5)$$

Hall *et al.* (2005) explain that theory is not clear about: (i) the way intangibles (K_{it}) should be specified, and (ii) the effects of intangibles on market value. The process of value creation in the biopharmaceutical industry is complex as it depends on intangibles that allow a firm to signal success, to appropriate its returns, and to enable them to carry out a successful innovation process. We assume that the innovation process occurs when firms combine their tangible assets with multiple knowledge assets. Each intangible influences market value differently, however. R&D expenses, for instance, have an effect on value by signaling commitment to the core activities of biopharmaceutical firms. Patent portfolio size and quality, on the other hand, influence the performance of a firm's shares by providing information to investors on the status of knowledge production and the synergies and economies of scale created by that knowledge. The number of drug candidates going through clinical trials indicates a firm's success in moving from discovery to development and closer to a possible product. Alliances and M&As have an effect on value by signaling that a firm is enhancing or expanding its technological capabilities and exploiting possible synergies through external technology. And lastly, a firm's investments in the development of its management systems and its employees will likely lead to a better-run, and thus more valuable, organization. We assume the investors take into account these pieces of information as they assign a value to a firm. With this in mind, we estimate the following equation using a non-linear least squares model:

$$\log Q_{it} = b_i + c_t + \log\Big(1 + \alpha_1\frac{R\&D_{it}}{A_{it}} + \alpha_2\frac{PAT_{it}}{R\&D_{it-1}} + \alpha_3\frac{CITES_{it}}{PAT_{it}} + \alpha_4\frac{ORG.CAP_{it}.}{A_{it}} + \alpha_5\frac{CLIN.TRIAL_{it}}{R\&D_{it}} + \alpha_6\frac{ALLIANCES_{it}}{A_{it}} + \alpha_7\frac{M\&A_{it}}{A_{it}}\Big) + u_{it}. \qquad (6)$$

In Equation (6), $R\&D_{it}/A_{it}$, $ALLIANCES_{it}/A_{it}$, and $M\&A_{it}/A_{it}$ represent measures of knowledge and network stocks, namely stocks of R&D, technology alliances, and M&As, weighted by assets. $PAT_{it}/R\&D_{it-1}$ and $CLIN.TRIAL_{it}/R\&D_{it}$ are stocks of patents and drug candidates in clinical trials weighted by the $R\&D$ stock.[16] $CITES_{it}/PAT_{it}$ is a measure of patent portfolio quality. Finally, $ORG.CAP_{it}/A_{it}$ represents our measure of a firm's investment in organizational capital.

[16] To construct the patent yield, we divide the patent stock by the first lag of R&D stock because most of the effect of R&D on patenting occurs in the first year (see Hall *et al.*, 1986).

III. Data and Measures

Our sample consists of all firms incorporated between 1980 and 2006 whose primary 4-digit Standard Industrial Code (SIC) involves the biopharmaceutical industry (SIC 2834 and 2836). The sample of firms and the financial statement data for the first 12 years after their initial public offering (IPO) is collected from Compustat. The first available fiscal year in Compustat is assumed to be the year of the IPO. We collect information on patents, including application year, and year of citations, from the 2006 edition of the National Bureau of Economic Research (NBER) database described by Hall *et al.* (2001)[17] and the United States Patent and Trademark Office (USPTO). Alliance and clinical trials data are obtained by searching the Thomson Reuters Recap IQ Deal Builder and Development Optimizer databases, which track biopharma deals and drug development progress, respectively.

To ensure that we are focusing on the right firms, we further refine the sample by keeping only those firms that S&P's Global Industry Classification Standard (GICS) places in the Pharmaceuticals & Biotechnology & Life Sciences industry. Because of our interest in the value of clinical trials, we drop firms whose business description mentions animal health. Our next refinement drops those firms that have no Thomson Reuters Recap IQ Deal Builder record. To keep our focus in small firms, we drop the firms whose annual revenue exceeds $100 million in the first three years after incorporation. Lastly, we drop those observations where R&D or employee information is missing. The final sample is an unbalanced panel of 349 firms. Basic statistics for the main variables used in the study are reported in Table 1.

Our dependent variable is the Tobin's Q ratio, which is defined as the ratio of the market value of a firm's financial claims to the replacement cost of its assets. To construct the Q ratio, we follow Erickson and Whited (2006) and calculate the market value of the firm as the sum of total assets and market value of equity[18] minus the sum of the book value of equity and deferred taxes, all adjusted for inflation.[19] We use the book value of total assets as a proxy for the replacement cost of assets.[20] The average Q in our sample is 6.04, indicating a more significant presence of intangibles in this industry compared to the overall economy (Hall *et al.*, 2001 estimate the economy-wide Q to be 2).[21]

We use the R&D expenditure history of each firm to compute its stock of R&D. The R&D stock is constructed using the perpetual inventory method described by Hall (1990). We assume a depreciation rate (d) of 15 percent and a growth rate (g) of 8 percent.[22] Our initial value for R&D stock was calculated, using the first available (post-1979) R&D observation, as $R\&D\ stock_0 = R\&D_0/(d+g)$. The average value of R&D intensity (*R&D stock/Assets*) is 2.55, which is substantially higher than 0.35 calculated for a cross-industry sample by Hall *et al.* (2005). This illustrates just how significant R&D expenditures are for the firms in our sample.

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[17] The database contains information for more than 3 million patents granted from 1976 to 2006; this dictated the choice of our sample period.
[18] The data for the market value of equity was obtained from Compustat. Firm's market value of equity is calculated as the price multiplied by the number of shares outstanding at the end of the fiscal year.
[19] We adjust all the variables measured in dollars for inflation using the 2015 Consumer Price Index.
[20] Alternative measures are not materially different. Chung and Pruitt (1994) show that the book value of assets has a 98 percent correlation with alternative measures that have been proposed.
[21] Gleason and Klock (2006) report an average value for Q ratio of 3.6 for the chemicals industry, while Klock and Megna (2000) note that the average Q for the wireless communications industry is 10.8.
[22] Hall (1990, p. 39) shows that the exact choice of depreciation rate does not significantly change the production function estimates. Our choice of 15 percent is common in the literature.

Table 1: Summary Statistics for U.S.-Based Biopharmaceutical Firms Incorporated Between 1980-2006

	N	Mean	Std. Dev.	Min.	Max.
Market Value ($mil.)	2,182	446.66	1,125	0.05	17,352
Book Value of Assets ($mil.)	2,182	136.00	305.39	0.11	4,696
Tobin's *Q* Ratio	2,182	6.04	9.96	0.21	218.25
R&D Stock ($mil.)	2,182	117.83	149.78	0.20	1,675
Patent Stock	2,182	15.29	32.94	0	511.16
Citation Stock	2,182	117.10	155.42	0	1,138
Organizational Capital Stock ($mil.)	2,182	11.83	31.42	0	489.05
Technology Alliances Stock	2,182	6.18	7.16	0	52.32
Mergers Stock	2,182	0.39	0.94	0	13.50
Clinical Trials Stock	483	7.78	7.69	0	47.77
R&D Stock/Assets	2,182	2.55	5.10	0.01	62.20
Patents/R&D Stock	2,182	0.22	0.50	0	9.26
Citations/Patents	2,182	13.18	22.23	0	275.96
Organizational Capital/Assets	2,182	0.40	2.22	0	46.98
Technology Alliances/Assets	2,182	0.22	0.94	0	24.50
M&A/Assets	2,182	0.04	0.87	0	33.28
Clinical Trials/ R&D Stock	483	0.06	0.06	0	0.33

Notes: Calculations for all variables, except clinical trials, are based on 349 public biopharmaceutical firms in the sample. The numbers reported for clinical trials are derived using observations from 64 firms. The dollar amounts are in 2015 dollars.

By matching the NBER patent data to the firm-level Compustat data, we construct patent and citations stock values using the same perpetual inventory method with the same depreciation and growth rates used to obtain the R&D stock. If any two firms in the sample merged during the target period, we combine the information under the surviving firm's name.

Patent citations suffer from several potential sources of bias, the most obvious of which is truncation. The number of citations for any patent is truncated in time because only citations received until the end of the dataset are observed. This concern is more pronounced for more recent patents which may be too new to be cited at all. To minimize this truncation problem, we have collected additional data from the USPTO and updated the NBER dataset to include all citations received through 2016.[23] Given that our sample period ends in 2006, we have at least ten years' worth of citation information for each patent in our sample. The ten-year citation profile is reasonable considering that most of the citation activity in biopharmaceuticals occurs between the fourth and the eighth year of the patient's life (Hall *et al.*, 2005). Nonetheless, we use the estimated parameters for the pharmaceutical industry from Hall *et al.* (2007) to further correct the observed citation rates. Table A1 in the Appendix reports these parameters. Once we correct the truncation

[23] Previous methods to solve truncation problems related to patent citations are found in Hall *et al*. (2001) and Hall *et al*. (2005).

problem, we follow the same method used to construct the R&D and patent stock values to construct the citation series.

The firms in our sample are involved in diverse alliances; however, in this study we focus only on technology alliances as those are the most significant alliances for the innovation process (see Chan *et al.,* 1997). To construct the stock of alliances we count the number of alliances that a firm entered into in a given year and used the perpetual inventory method as before. We use the same method to construct the M&A stock. Thomson Reuters Recap IQ Deal Builder treats M&A activity as one type of alliance. Table A2 in the Appendix reports the number of new alliances, M&As, patent applications, and new firms incorporated in each year during our sample period.

For the clinical trials data, unfortunately, the Thomson Reuters Recap IQ Development Optimizer database provides data for only a small subsample of firms (64 firms). We collect information on the number of Phase I, Phase II, Phase III and Phase IV interventional studies per year for each of the firms in this subsample. We count the total number of clinical trials initiated in a given year and construct the clinical trial stock by applying the same method as with the other intangible stocks.

Lastly, following Hulten and Hao (2008), we construct a measure for the organizational capital stock by applying the perpetual inventory method to a fraction (30 percent) of past SG&A expenses.[24] Although it is not clear what the appropriate depreciation rates are for this intangible asset, for the sake of consistency and for ease of comparison with the other measures, we use a depreciation rate of 15 percent.

Our control variables include a firm's number of employees, its age, a dummy for patenting firms, and year dummies. Because many young biopharmaceutical firms have no revenues to report and because their assets are usually intangible, the best measure of firm size in this industry is headcount (Powell *et al.*, 1996). We define a firm's age as the year of the observation minus the year of the IPO plus one. An interaction variable between R&D intensity and age is also constructed to measure the impact of R&D intensity on the firm value over time.

IV. Results

Table 2 reports the results from the estimation of various specifications of the market value equation, with year dummies, number of employees, firm age, and a dummy for patenting firms used as controls. Column 1 displays the baseline estimates for R&D intensity, patent yield, citation intensity, and R&D over time, Column 2 incorporates the intangible measures that we construct (organizational capital, technological alliances, and M&As), Column 3 investigates the impact of intangibles on the very young firms (in the first six years after their IPO), and lastly, Column 4 reports the results of the model when we control for firm-specific fixed effects.

The results presented in the first column confirm the importance of R&D, patents, and citations in explaining some of the variation in Tobin's Q. The reported coefficients for these three intangibles are statistically significant at the 1 percent, 10 percent, and 5 percent level, respectively. The regression results in Column 1 also indicate that R&D intensity displays diminishing returns: as firms get older, they gain less value from their R&D investments. The interaction term (R&D intensity * firm age) is negative and significant at the 5 percent level.[25] The regressors of this model explain 24.1 percent of the variation in the Q ratio, which is in line with that of many studies

[24] Hulten and Hao (2008) provide the calculations that justify the 30 percent fraction. Eisfeldt and Papanikolaou (2013 and 2014) and Peters and Taylor (2017) use a similar approach to estimate the stock of organizational capital.
[25] This result is consistent with the findings of Gleason and Klock (2006).

on this topic (for example, the r-squared ranges between 0.222 and 0.260 for different specifications of the same model in Hall *et al.*, 2005).[26]

Table 2: Market Value as a Function of R&D, Patents, Citations, Stocks, Alliances, Organizational Capital, and M&As, 1980-2006. Non-linear Model with Dependent Variable: log Tobin's *Q*

	(1)	(2)	(3)	(4)
R&D / Assets	0.264^{***}	0.155^{***}	0.190^{***}	0.136^{***}
	(0.064)	(0.052)	(0.071)	(0.052)
Patents / R&D	0.301^{*}	0.250^{*}	0.304^{**}	0.353
	(0.155)	(0.142)	(0.148)	(0.248)
Citations / Patents	0.005^{**}	0.004^{**}	0.004^{*}	0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Org. capital / Assets		1.079^{***}	1.494^{***}	0.586^{**}
		(0.249)	(0.343)	(0.274)
Tech. alliances / Assets				
		0.714^{**}	0.557^{*}	1.156^{**}
		(0.302)	(0.296)	(0.463)
M&A / Assets		-0.274	-0.164	-1.242^{***}
		(0.754)	(1.083)	(0.382)
(R&D / Assets) * Age	-0.002^{**}	-0.002^{**}	-0.005^{***}	-0.001
	(0.001)	(0.001)	(0.002)	(0.001)
Employees	-0.150^{*}	-0.131^{*}	-0.502^{***}	0.354^{***}
	(0.079)	(0.077)	(0.176)	(0.137)
Firm age	-0.012	-0.007	-0.013	-0.036^{***}
	(0.011)	(0.011)	(0.019)	(0.012)
D (Patents=0)	-0.138	0.012	-0.043	-0.950^{***}
	(0.086)	(0.084)	(0.093)	(0.246)
N	2,182	2,182	1,220	2,182
R^2	0.241	0.300	0.375	0.638

Note: The estimated coefficients on the fixed and time effects are not reported, but are jointly statistically significant at the 0.01 level. Robust standard errors clustered by firm are shown in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

In the second variant of our model, we add the additional intangible measures that we constructed. The results indicate that in addition to R&D, patents, and citations, both alliance stock and organizational capital stock (relative to assets) have positive and highly significant impacts on the values of sample firms' *Q*. The coefficient for the M&A stock relative to assets, however, is statistically insignificant at conventional levels.[27] The additional regressors improve the

[26] Other studies report comparable values for r-squared. Examples include: Baum and Thies (1999) report r-squared ranges between 0.125 and 0.225; the r-squared in Gleason and Klock (2006) ranges between 0.117 and 0.281.

[27] This result is in line with much empirical research on mergers, which finds that gains from mergers accrue entirely to target firm shareholders. For the acquiring-firm shareholders, the gains are either negative or not significantly different from zero. For a summary of empirical evidence see Jensen and Ruback (1983), Jarrell *et al.* (1988), and Andrade *et al*. (2001).

performance of the model substantially (explaining 30 percent of the variation in Tobin's *Q*) and indicate potential misspecification in the first variant of the model. This conclusion is supported by the fact that the coefficient for R&D intensity drops significantly (from 0.264 to 0.155) when we move from the simpler specification to the complete model (Column 2). The coefficient for R&D intensity remains fairly stable across the various samples and model specifications for which results are presented in columns 2 through 4.

Given the acute information asymmetries that are naturally present for *very young* firms, we investigate whether the relationship between Tobin's *Q* and our various intangibles holds for firms in the first six years after incorporation.[28] The results of this specification (reported in Column 3 of Table 2) reveal that these intangibles explain even more of the variation in Tobin's *Q* (r-squared = 0.375). This indicates that the market value of firms early in their life is more reliant on changes in these intangible assets as compared to later, in their more mature, years.

Although Column 4 in Table 2 reports the estimates obtained from the model that includes firm-specific fixed effects, as Hall *et al*. (2005) argue, employing fixed firm effects in this context is problematic.[29] The primary concern comes from the fact that a firm's various intangible measures will be highly correlated with its individual effect since intangible stocks are part of a firm's long-term strategy and, as such, they change very slowly over time. Additionally, in an industry where strategic competition between firms is the norm, "the assumption that differences across them are 'fixed' or permanent is not a particularly good one." (Hall *et al*., 2005, p. 26). Thus, it should be noted that the results in Column 4 are not very reliable.

Comparing the estimated coefficients reported in columns 2 and 4 of Table 2, we observe that patent-related intangibles and our interaction variable (R&D intensity * firm age) are no longer statistically significant. Although not reported here, the same outcome is obtained when fixed effects are employed in the baseline model (Column 1). The stocks of R&D, organizational capital, and technology alliances capital (relative to assets) are all positive and statistically significant at the 5 percent level (R&D is significant at the 1 percent level). The coefficient for M&A/Assets is negative and significant at the 1 percent level. It is worth noting that the magnitude of the coefficient for organizational capital in Column 4 deviates substantially from the estimates reported in columns 2 and 3. This is likely a result of the overcorrection we introduce by using fixed firm effects.

Considering the importance of clinical trials in the biopharmaceutical industry, we also estimate the model for a subsample of 64 biotechnology firms for which we were able to find clinical trials data in the Thomson Reuters Recap IQ Development Optimizer database. Although we do not report the results of the regression for this subsample (483 observations), all the estimated coefficients have the expected sign but they are statistically insignificant at conventional levels.[30] This is likely due to the small size and the potential selection bias in the sample.[31] The fact that this subsample is comprised of only "leading" biotech firms makes comparisons with the other sample specifications invalid.

The coefficients for the different control variables have the expected signs. For example, in the first three specifications of the model, the size of the firm (measured through the number of

[28] The choice of six years is somewhat arbitrary (half of the 12 years); however, the results are very similar to choosing other thresholds (four, five, or seven years).
[29] In fact, controlling for unobserved firm-specific fixed effects is very uncommon in this strand of literature. Blundell *et al*. (1999), Bloom and Van Reenen (2002) are prominent exceptions.
[30] The positive influence of clinical trials on the market value is also reported by Rzakhanov (2004).
[31] The Thomson Reuters Recap IQ Development Optimizer offers clinical trial data on "leading biotech companies" according to Recap IQ Factsheet (http://recap.com/sites/rc/files/pdf/recap-iq-factsheet.pdf).

employees) has a negative influence on its *Q* value, indicating that, on average, smaller firms have a higher *Q*. This result is statistically significant in all variants of the model and the sign of its coefficient in columns 1 to 3 is consistent with the findings of Gleason and Klock (2006) who note that firm "size is likely to be inversely related to expected growth opportunities" (p. 308). When controlling for fixed firm effects, the coefficient for firm size becomes positive (and significant at the 1 percent level), implying that within any given firm an increase in firm size is associated with a higher *Q*, on average. The coefficient on firm age is negative but only statistically significant (at the 1 percent level) in the last variation of the model (Column 4). This negative relationship is likely due to organizational rigidities and rent-seeking according to Loderer and Waelchli (2010).[32] Lastly, the coefficient on the binary variable that identifies patenting firms is not statistically significant in models 1 through 3.

To get an indication of the economic magnitude of the estimated effects, we use the coefficients of models 1 and 2 in Table 2 to calculate the quantitative impact of each of the main variables on market value. The average values of semi-elasticities and robust standard errors clustered by firm are reported in Table 3.

Table 3: Computing the Impact of Knowledge Stocks on Market Value

	(1)	**(2)**
Ratios		
R&D / Assets	2.549	2.549
Patents / R&D	0.216	0.216
Citations / Patents	13.18	13.18
Organizational Capital / Assets		0.398
Technology Alliances / Assets		0.217
M&A / Assets		0.041
Marginal Effects (Semi-Elasticities)		
$\frac{\partial \log Q}{\partial (R\&D\ /\ Assets)}$	0.105^{***}	0.050^{***}
	(0.014)	(0.013)
$\frac{\partial \log Q}{\partial (Patents\ /\ R\&D)}$	0.120^{**}	0.081^{*}
	0.056	(0.042)
$\frac{\partial \log Q}{\partial (Citations\ /\ Patents)}$	0.002^{**}	0.0012^{**}
	(0.001)	(0.0005)
$\frac{\partial \log Q}{\partial (Org.Cap.\ /\ Assets)}$		0.348^{***}
		(0.056)
$\frac{\partial \log Q}{\partial (Alliances\ /\ Assets)}$		0.231^{**}
		(0.091)
$\frac{\partial \log Q}{\partial (M\&A\ /\ Assets)}$		-0.089
		(0.244)

Note: Computed using the estimated coefficients in columns 1 and 2 of Table 2 evaluated at the mean. Robust standard errors clustered by firm are shown in the parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

[32] Loderer and Waelchli (2010) report a highly significant (and robust) negative relationship between firm age and profitability for a large sample of cross-industry firms.

Considering that the average R&D intensity value is 2.55 with a standard deviation of 5.1, using Model 2 estimates, we can state that firms that are one standard deviation above the mean have a market value that is almost 26 percent higher than the average firm. The average semi-elasticity for the patents yield is even more economically significant: one additional patent per million dollars of R&D increases market value by approximately 8 percent. Citations per patent, on the other hand, have a much smaller impact on the market value of the firms in our sample (semi-elasticity = 0.0012). Indicating just how important investing in organizational capital is for the young biopharmaceutical firms, an increase of 10 percentage points in the organizational capital stock to assets ratio is associated with an almost 3.5 percent increase in market value. One extra technology alliance per ten million dollars of assets increases market value by approximately 2.3 percent. Lastly, the marginal effect of additional M&As is not significant at the conventional levels of significance.

Several observations are notable from the results in Table 3. First, the quantitative impact of R&D in Model 2 is half as big as in Model 1, indicating the lesser importance of R&D when other variables are added. Second, the quantitative impact of patent yield is stronger than the impact of R&D on Tobin's *Q*. The semi-elasticity for the patent yield is also significantly higher than the ones reported by Hall *et al.* (2005 and 2007). This could be because our sample is comprised of only young firms, which are likely to have an unproven record of valuable R&D output; therefore, early success of R&D for these firms is of utmost importance. Third, the largest impacts on Tobin's *Q* come from a firm's investments in organizational capital and the number of technology alliances they create.

V. Conclusion

This paper adds to the literature on market valuation of intangibles by analyzing how the innovation process is transformed into value. We report new estimates of the economic value of several intangibles, tested jointly, in a sample of young biopharmaceutical firms. Our results suggest that in addition to R&D and patents, financial markets recognize the importance of alliances and organizational capital. We also provide some evidence on the established result that firms typically overpay for acquisitions, which naturally reduces their market value. The inclusion of the additional intangibles greatly improves the explanatory power of the model, and changes the magnitude of the R&D coefficient, lowering it drastically. Our results also indicate that the highest R&D investment returns accrue to firms in their early years, declining as they get older. The multiple specifications of the functional form of the valuation equation we consider demonstrate the robustness of these results.

We know high-technology firms generally have poor access to capital since a large fraction of their investment is intangible, which serves little or no collateral value (Berger and Udell, 1998). The situation is even worse for young firms, which rely more heavily on external funding and seldom have any revenue. The estimates reported here serve as quantitative indicators of success for these firms, which is key to securing financing. Firms can also use our findings to decide where to commit their limited resources, which is an important task in highly competitive environments. Estimates of the value of intangibles may also affect competition dynamics at the industry level and potentially lead to reshuffling in the form of M&As. Finally, these estimates may serve as a guide to policymakers in their assessments of future policy changes as they relate to intangibles.

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Appendix A

Table A1: Weights Implied by Estimated Cumulative Lag Distribution for U.S. Patents

Patent Application Year	Lag Year	Citation Factor
2006	10	2.587
2005	11	2.35
2004	12	2.155
2003	13	1.991
2002	14	1.852
2001	15	1.732
2000	16	1.627
1999	17	1.535
1998	18	1.454
1997	19	1.382
1996	20	1.317
1995	21	1.258
1994	22	1.205
1993	23	1.157
1992	24	1.112
1991	25	1.072
1990	26	1.035
≤ 1989	≥ 27	1

Table A2: Firm Activity by Year

Fiscal Year	Number of IPOs	Number of New Patent Applications	Number of New Alliances	Number of Mergers Announced
1980	3	7	12	0
1981	2	18	21	0
1982	5	45	23	0
1983	7	64	32	0
1984	9	112	28	0
1985	14	101	35	0
1986	9	141	43	0
1987	9	174	53	0
1988	16	184	72	0
1989	11	226	88	2
1990	27	281	140	4
1991	22	286	159	7
1992	22	354	208	9
1993	15	468	208	8
1994	16	636	237	15
1995	34	1,328	225	19
1996	10	765	292	12
1997	8	1030	271	23
1998	38	1,047	270	25
1999	16	1,129	293	39
2000	13	1,168	317	40
2001	15	979	352	27
2002	11	558	261	24
2003	12	270	180	29
2004	3	117	208	21
2005	2	24	167	29
2006	0	2	183	21

Note: These figures are based on a sample of 349 firms used for the estimation of the effects of various intangible assets on the value of Tobin's Q, in the first 12 years after incorporation.