Improving value assessment of high-risk, high-reward biotechnology research: the role of 'thick tails'

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This paper presents work toward improving the efficacy of financial models that describe the unique nature of biotechnology firms. We show that using a 'thick tailed' power law distribution to describe the behavior of the value of biotechnology R&D used in a Real Options Pricing model is significantly more accurate than the traditionally used Gaussian approach. A study of 287 North-American biotechnology firms gives insights into common problems faced by investors, managers and other stakeholders when using traditional techniques to calculate the commercial value of R&D. This is important because specific quantitative tools to assess the value of high-risk, high-reward R&D do not currently exist. This often leads to an undervaluation of biotechnology R&D and R&D intensive biotechnology firms. For example, the widely used Net Present Value (NPV) method assumes a fixed risk ignoring management flexibility and the changing environment. However, Real Options Pricing models assume that commercial returns from R&D investments are described by a normal random walk. A normal random walk model eliminates the possibility of drastic changes to the marketplace resulting from the introduction of revolutionary products and/or services. It is possible to better understand and manage biotechnology research projects and portfolios using a model that more accurately considers large non-Gaussian price fluctuations with thick tails, which recognize the unusually large risks and opportunities associated with Biotechnology R&D. Our empirical data show that opportunity overcompensates for the downside risk making biotechnology R&D statistically more valuable than other Gaussian options investments, which may otherwise appear to offer a similar combination of risk and return.

Introduction

Traditional valuation techniques consider R&D expenditures as either an opportunity cost [1,2] or as objects offering economic returns that behave in a Gaussian manner (i.e., have expected returns that do not fluctuate much around their expected values) [1]. Returns are defined as the log-difference between two consecutive stock quotes - in this study, we look at low-frequency daily returns. While this may be the case for many types of investments, some researchers have found it to be incorrect in the case of R&D [1,3]. Specifically, we found that the commercial value extracted from biotechnology R&D behaves in a complex manner largely due to high uncertainties related to project outcomes. This results in commercial products characterized by largely fluctuating returns, which are better represented by an asymmetric power law. In the worst-case scenario, the R&D proves to have no value – that is, the entire initial investment in R&D is lost. However, successful commercialization can, in some cases, greatly outstrip earlier predictions, especially if sudden unexpected benefits are

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identified (e.g., unforeseen additional uses of an active molecule or superior performance than originally anticipated) [3–5]. The financial returns are, therefore, constrained in the negative side to the value of the investment in R&D while unconstrained on the positive side.

This results in an asymmetric 'thick tailed' distribution reflecting the uncertain outcomes of key milestone experiments or regulatory decisions that are characteristic to the commercialization of high-risk, high-reward biotechnology R&D. We found this to be the case for the most research-intensive small cap biotechnology firms studied here. In fact, these firms are in most cases best described by a power law distribution (e.g., a Cauchy distribution) [6,7] as opposed to the traditional Gaussian distribution used by financial analysts. This result has a significant impact in cost of capital models used to value the commercial value of R&D in biotechnology firms. By using a Gaussian-based model to model the future returns from R&D investments, managers will be underestimating risk but also largely underestimating the potential benefits to the firm. This results in an under-valuation of the potential commercial value resulting from R&D activities.

Biotechnology firms are interesting and relatively unique for a number of reasons. Of relevance to this study, biotechnology firms typically perform complex and costly R&D activities relying on the resulting intellectual property to extract rents from those R&D efforts. These R&D activities can go on for a decade before they can be commercialized [8,9]. The long time scale of such efforts makes futures prediction particularly sensitive to the chosen initial conditions and assumptions – especially if the model does not account for the ability of management to make periodic changes to optimize their return during this lengthy R&D phase. Biotechnology firms also have relatively low manufacturing cost combined with a high price to earnings ratio. The uncertainty in the value of biotechnology products largely resides in the uncertainty of outcome of its R&D activities.

The biotechnology industry in general is itself shaped by a highly cyclical pattern of R&D failures and successes and can be characterized by sudden growth followed by steep losses. These large and repeating price correction events are indicative of market expectations coming face to face with the realities of high uncertainty surrounding R&D activities [9]. Better valuation of biotechnology research begins with having a more representative model that captures the uncertain process of value creation through R&D and resulting opportunities created from having the option to favorably react to a changing environment [10,11].

Investing in R&D

R&D Projects are typically valued using some form of Discounted Cash Flow (DCF) technique, which is simply an estimation of the future cash flows resulting from a present day investment in R&D [2]. A survey of the top 28 leading pharmaceutical and biotechnology companies suggests that nearly all these companies apply a discounted cash flow technique to evaluate R&D projects [12].

The cash flows are discounted to their present value using a single fixed discount rate that is meant to capture all the risk details of a particular R&D investment. To do this, an analyst has to accurately estimate the R&D project's success probability and future potential market and distill that information into one rate variable. A high level of risk will reduce the present value of R&D and can lead to either withdrawing a project's funding or choosing to fund the project based on non-quantitative arguments – such as competitive necessity or strategic imperatives. Such a technique does not properly account for the flexibility or opportunity created from the R&D itself over time. R&D projects that typically last several years are also less attractive under DCF analysis because there is no simple way to incorporate and capitalize on new information (e.g., based on project milestones) and because any discount rate will heavily reduce the present day value of these at risk investments [13,14]. In reality, faced with new information, managers can increase the investment in response to success or market demand or cut funding for a project that is not successful. This flexibility has an inherent value that is not captured by the DCF technique.

Calculating the Net Present Value (NPV) of R&D through different project milestones requires an analyst to estimate a different discount rate for each time period – adding complexity to an already sensitive part of the valuation process. For example, it may be worthwhile to undertake R&D with a negative NPV when an early investment results in information on the future market potential of this product. It is specifically because R&D projects operate on a large time scale with high uncertainty that managerial flexibility is valuable.

Real options techniques are a direct extension of financial options and were introduced as a way to account for managerial flexibility and to capitalize on the opportunities that arise from uncertainty as an outcome of R&D and a result of uncertain market demands. The cost to perform research in a biotechnology firm can be thought of as an investment option that is necessary to later commercialize the resulting product [15]. That is, investments in R&D give the performer the option – with no obligation – to commercialize in the future [12,15–17]. These sorts of options can be used to create opportunities that take advantage of economic and/or social benefits resulting from discovery or to minimize competitive and environmental risks that could result from its absence (i.e., a competitive insurance policy). As mentioned above, current capital budgeting techniques such as DCF are inappropriate for assessing these investments because they result in rejecting potentially favorable R&D projects.

Real Options Pricing models allow for the statistical modeling of investments with an uncertain outcome, such as the selection of worthwhile research projects. The dominant two techniques in practice and theory rely on the use of the Black-Scholes equation or the binomial tree in the discrete case (i.e., binomial trees tend toward the Black-Scholes equation in the continuous limit) [18]. These techniques both give the fair price of having the option to purchase a stock at a fixed price at a pre-defined later time (i.e., a European option). Alternatively, they give the fair price of R&D, which gives one the option to introduce a product to market after the successful completion of R&D. While the investment community extensively uses the Black-Scholes equation, analysts and managers of research have for the most part avoided its application [12] despite its potential as a decision support tool in the identification and selection of projects [19]. There have been documented anecdotal cases of option techniques being successfully used in the past by some large biotechnology firms [8] and have also been touted as providing a material improvement in project and asset evaluation in the IT [14], mining [20] and the oil and gas sectors