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F. Peter Boer

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Preface

Millions of spectators thrill to sports featuring extreme risk. But few understand that the continuous innovation on which our economy is built also depends on managing extreme risk. Competition is fierce, failure is rife, and the value created for the winners (and often the spectators) can be glorious. Relatively few people have played in this arena, and few of those have analyzed their experience in depth.[1] This is stuff worthy of more attention.

The purpose of this book is to share concepts, case histories, and software that I have developed in more than 30 years of direct experience in managing technology and technology-based businesses, as a director of seven firms, and as a consultant and an educator. Most of my students, both in business school and in industrial short courses, have found the combination of a financial perspective, sensible management methods, and real-world experience in technology management to be valuable, if not unique. This book unifies these themes, and shows the way toward practical, value-based research and development (R&D) management.

WHY IS TECHNOLOGY VALUATION IMPORTANT?

No economic phenomenon is more important to the modern world than the creation of wealth through technological innovation. About a half-trillion dollars are spent on R&D globally to ensure this phenomenon continues. The majority of it occurs in private-sector companies, large and small. In their laboratories, scientists and engineers are tasked to invent, improve, develop, and commercialize new or improved products and processes. Over half of the world's economic growth is produced through this mechanism.[2] But technological innovation is a notoriously risky and competitive business. The value of an idea is diminished not only by the risk of technical or commercial failure, but also by the time value of money and the costs of the R&D effort itself. These three dark factors cannot be ignored. Only a small minority of proposed innovations overcome the obstacles and achieve commercial success.[3] It is the flow of these technological gems that propels the world's economy.

Fortunately, there is a real possibility that an innovation will prove far more valuable than its creators dared imagine—a result that has occurred time and time again. The steam engine was first conceived for the limited objective of pumping water from mines; the options it created for innovation in transportation and manufacturing had yet to be envisioned. The applications of the transistor and the laser, major innovations of our own time, were likewise barely imagined by their discoverers.

Balancing the upsides against the downsides in an uncertain world is complex and nonobvious. There is a school of thought that proclaims the effort is not even worth attempting on a quantitative basis; that fundamental technical competence, attention to the right situational factors (attributes), and good judgment will win through. Indeed a leading book on the link between R&D and corporate strategy argues that "the rigor implied by NPV [net present value] or DCF [discounted cash flow] considerations becomes not only meaningless but potentially harmful."[4] That potential for harm must be acknowledged. Its source is found in low-quality, or very narrow, assumptions that make their way into spreadsheet analysis. However, I do not share this view, and believe that powerful modern planning tools such as cash flow analysis, the electronic spreadsheet, decision analysis, and real options can illuminate the issues in ways that no scoring system based on attributes can. If you have a cannon, shoot it! And be aware that some of your competitors are arming themselves with similar weapons to hone their own battle plans.

AIM OF THIS BOOK

My specific aim is to present a method by which those charged with planning innovation can easily and rapidly calculate the value of a project or project proposal, and a method that takes full account of its risks. I call this financial model *risk-adjusted valuation*. Understanding the method will be fostered by working through detailed examples, each based on a real-world business scenario.

It is a practical imperative that such a calculation be based on a limited set of input parameters, and that these parameters be readily available to the practitioners. The world changes rapidly and abounds with uncertainty, so in this sphere ease of use often outweighs accuracy. My experience is that in a real company any methods that require detailed consultation and verification with a host of internal experts will die of their own weight. By contrast, analyses that are based on numbers from budgets, five-year forecasts, and historical financial ratios, all readily available business documents, will win through.

It is vital that the software be simple and transparent, even though some of the algorithms themselves, such as the Black-Scholes formula, the Markowitz portfolio optimization algorithm, and the growth-in-perpetuity equation, may be mathematically challenging. A "black box" approach will not earn trust. A practical test that these conditions are met is that the software produces the obvious answer for simple cases. Complexity can then be added as desired, while confidence is maintained. For example, I have shown that the Black-Scholes options value converges exactly to a simple decision tree (as it should) when the volatility parameter is set to zero, and the growth-in-perpetuity formula gives a result that is invariant to the choice of horizon year.

Once these technical issues are mastered, the rewards come quickly. The immediate benefit is the ability to see the value of a project at each of its stages (outputs) on the same screen as perhaps two dozen input parameters. A host of what-if questions can be answered in a few keystrokes.

Most research managers will immediately understand the usefulness of a transparent one-step process for comparing the risk-reward profiles of the projects in their R&D portfolio. It is invaluable for distributing scarce resources. However, risk-adjusted valuation has implications beyond research—for transaction support and for corporate strategy.

As an example of a transaction, a company may wish to weigh commercializing the fruits of its research directly, doing so in concert with a strategic partner, evaluating licensing its technology to a third party, or, in our global economy, some combination of these strategies. A valuation can be performed for each alternative course to find the solution that maximizes value. The analysis will inevitably guide the negotiating positions taken by those charged to reach a deal.

Another type of transaction is to spin off technology into a start-up, consisting of inventors, entrepreneurs, and financial backers. Valuation will be at the heart of this exercise. By calculating the buildup in value of the start-up company as it reaches each of a series of R&D milestones, it is possible to estimate the ownership at each stage for the founders and employees, and for the investors in each financing round. Will these be reasonable for all concerned?

A broader consequence is that these methods can be applied to an entire R&D portfolio to estimate the value that a company may have in its research pipeline. This value may be more than the sum of individual projects, for value may be added by diversification and economy of scale. From the point of view of a venture capital fund, the risk-adjusted valuation method will similarly track the buildup value of an investment portfolio. It will also make apparent how much further investment is needed to realize that value.

WHO SHOULD READ THIS BOOK

An important user community consists of those R&D executives and planners, at all levels, with a need to justify their recommendations regarding the investment of R&D resources. This task is an inevitable part of both the annual budget and various long-term planning exercises. Part of their audience will be persons with financial training who lack familiarity with R&D. In my experience, such people appreciate an effort to change the dialogue from a qualitative to a quantitative assessment of the financial impact of new technology, and from a "trust me" or "trust my instincts and experience" approach to a quantitative estimate of the risk elements.

A second user community will be R&D practitioners with a need or desire to upgrade their financial savvy. They may engage for a positive reason—they are high performers slated for increased responsibility—or for a negative reason—their ideas have too often failed to convince management and they need to improve their understanding of the business environment. For example, a newly minted PhD biologist may not understand why a project that earns a profit may still destroy value. But she will need to understand this paradox on her path to becoming vice president of R&D!

A third user community will be students enrolled in business courses that deal with technology investment and management. I have used variations of the case studies in this book in my courses at the Yale University School of Management, and believe there is ample material herein to support a half semester or more of such a course. Other material has been added to round out this book.

I have given many courses, and written two books, on the subjects of valuation of technology and real options. They have found an audience among each of these user groups. One feature that is new and valuable is that the software is now linked, so that what had been a three-step process (write a pro forma business plan, apply decision and risk methodology to it, add real options) is reduced to a single step.

STRUCTURE OF THIS BOOK

This book is structured as a series of situations or cases requiring analysis. A problem is posed, and the solution is outlined. In the process the methodology is illustrated and its features discussed. Some of the cases are designed primarily to illustrate methods. Other cases provide an R&D practitioner's perspective of what the issues feel like at each stage of an

R&D project. The book lends itself to self-study by a scientist, engineer, or manager who wishes to become literate in the tools of technology valuation. The Microsoft Excel templates on the accompanying CD-ROM, contain extensive comments as well as depict the solution (references to the CD-ROM are indicated by the CD icon in the margins). Readers can readily substitute their own numbers into any of my spreadsheets. If they feel the template misses important features of their business models, they can make fundamental modifications in the models to capture them.

The pedagogical philosophy I have chosen is not unlike the choices one has for learning a new computer program. There are two well-recognized alternatives: read the manual, or jump right in. Even though the latter approach usually implies resorting to the manual when one is stymied, in practice, many of us find it to be more efficient. Reading the manual is more meaningful after one encounters some of the pitfalls.

In my earlier book *The Valuation of Technology*,[5] it took eight chapters to prepare the groundwork for a pro forma business plan. In this book, we will "jump right in" in Chapter 4. This condensed approach has been tested in a new format I have developed for fast-paced one-day workshops, which now seem to be preferred by industrial customers to more comprehensive three-day courses. However, in this more concise format, some of the fundamentals must inevitably be glossed over. Readers are advised to fill any gaps in their understanding, since a credible answer will invariably depend on credible assumptions. These gaps can be filled in two ways: (1) through discussion sections in this book that address alternative approaches and pitfalls and (2) by reading the material referenced in endnotes, including sections of *The Valuation of Technology* that address these subjects in more detail.

Chapter 1 reviews the concepts of discounted cash flow analysis and the cost of capital using a biotechnology licensing case that requires a decision between a smaller cash payment now and larger payments later.

Chapter 2 deals with horizon value, an important, if somewhat complex, calculation. An example from the plastics industry is used to illustrate five methods for calculating this key parameter. Two are based on liquidation scenarios, two are based on comparisons with other ongoing businesses, and the last is based on an estimate of future cash flows.

Chapter 3 addresses risk. As noted earlier, R&D management is very much the art of creating value by managing an extraordinary degree of risk. The quantitative tools needed to transform R&D practice from what many considered an art to an analytical science have evolved rapidly in the past two decades.[6] The decision tree method for evaluating unique risk and the real options method for evaluating market risk are introduced with examples based on a bioremediation project and an investment in a new line of computers, respectively. Then a major step

forward is outlined: integrating decision and risk analysis, real options, and stage-gate methodologies, using the bioremediation case again. Subsequent chapters will incorporate all of these tools, which had hitherto been introduced separately, in combination. And they will be applied to quite different cases.

Chapter 4 discusses a medical device, which is both a new-to-the-world invention and a new application. This circumstance is the most challenging and uncertain in both execution and planning. The case is illustrative of the thought processes and data required to make an initial decision as to whether to fund a big idea.

Chapter 5 discusses a new-to-the-world packaging material for which applications already exist. In this chapter, all the techniques introduced earlier (financial statements, decision trees, and real options) are integrated into a powerful model, allowing the planner to answer all the what-if questions, whether they regard timing, R&D risk, pricing uncertainty, capital investment, or an array of other business and financial parameters.

Chapter 6 explores another realm of technology valuation—the start-up company whose only asset is its R&D portfolio. How should such a company be valued? I show how the template used for valuing a project inside an established company can be transposed to estimate shareholder value at each milestone in the life of a start-up. If equity must be sold to finance subsequent research, the amount that remains for founders and earlier-round investors can be calculated based on the perceived value of the technology and the costs of proceeding forward. The case studies feature a biomed start-up and an instrument company.

Chapter 7 deals with a genuine technology breakthrough in the petrochemical industry. Process breakthroughs often have the economic effect of stealing most future growth from older processes, as well as replacing aging plants as they become uneconomic.

Chapter 8 addresses product improvements (in a textile application). Product improvement is for most operating firms the single largest category of R&D activity. This case involves the concept of how the value created is shared between supplier and customer, and offers a broad discussion of value in use.

The next two chapters deal with portfolios. Chapter 9 explores the concept of a balanced R&D portfolio, and the structural considerations that make balance an imperative. In this chapter, I relate my personal experiences in inheriting and transforming such a portfolio at W. R. Grace & Company, with an analysis of the outcomes of five key projects and the forces that drove these outcomes. This chapter also contains a discussion of the pros and cons of financial modeling.

Finally, Chapter 10 looks at the question of whether a portfolio can be worth more than the sum of its component projects, via diversification of risk and economies of scale. The answer is clearly yes. It presents a detailed case that applies financial portfolio theory to the R&D situation, followed by a critique of the strengths and weaknesses of this approach.

ORIGINS OF THIS BOOK

This book builds on what I have presented before (in two books and half a dozen articles) with new insights and expanded case material. Most of the cases derive from my personal business experience, but I have generally simplified detail, altered actual numbers, and in some cases combined aspects of two or more real situations into a single case. These changes were made for pedagogical reasons, to disguise actual firms, and to avoid disclosing sensitive data. More importantly, the cases encapsulate the spirit and feel of real problems.

My first book, *The Valuation of Technology: Business and Financial Issues in R&D*, was aimed at an audience similar to this one. It illustrated advanced techniques for assessing R&D risk (such as decision trees, real options, and Monte Carlo calculations) but in hindsight dealt with these subjects too briefly, all within a single chapter. This is a rich area and there is a need for an expanded and integrated treatment.

My second book, *The Real Options Solution: Finding Total Value in a High-Risk World* (John Wiley & Sons, 2002), explored the inferences of a key insight: that *plans are options*. This statement has important consequences for the methods by which opportunities, and hence companies that possess opportunities, should be valued. Its implications are still poorly recognized. However, in that book, I chose to make my case at a level aimed at the general business reader, rather than the planning professional. It led one reviewer to comment that he enjoyed the insights about value creation, but was looking forward to a second book containing detailed examples. Fair enough—here it is.

The decisive impetus for this book was the realization that I could seamlessly link decision trees to real options. R&D executives have increasingly relied on stage-gate methods for managing R&D processes,[7] and these models lent themselves readily to decision tree analysis. But in options terms, each successfully completed stage of a project could be considered as the purchase of an option to enter the next stage. Were these two viewpoints separate formulations of the risk equation or could they be integrated? When I realized[8] they were equivalent, a one-step analysis came into view and the backbone of a new book was before me.

In writing books, one needs to make editorial choices, and one of mine is not to offer another book about real options methods. A host of recent books cover this area more than adequately,[9] and I see my focus, based on my background as an R&D practitioner, as linking the existing methodology and software to the technology community and the R&D process, rather than in refinements in real options methodology. One of my biases is that the closed-form, "plug and chug," Black-Scholes equation is user-friendly and transparent, and allows the practitioner to focus on the other large uncertainties inherent in valuing R&D projects.

I also admit to being not particularly concerned by accounting arcana. For example, different classes of assets required by a project must be depreciated at different rates. Tax laws allow accelerated depreciation, which accelerates cash flow, an economic incentive, and in the process creates liabilities called deferred taxes. The application of tax strategies is highly situational and may have more to do with the firm than with the project. I believe good enough results for *decision support* can be obtained using average asset life and average effective tax rates, which can largely balance errors introduced by lack of accounting precision. However, when *transaction support* is the objective and legalities are in play, one must get the accountants involved, which in practice means to invite them to rework the pro forma business plan.

The R&D environment is in any case highly dynamic, since *every new data point affects valuation*. The data may be technical, or it may relate to customers or competition. If the new data is adverse, valuation goes down (costs are increased while rewards are reduced); if it is favorable, valuation correspondingly increases. Less obviously, when the data comes in about as expected, valuation also goes up, because risk has been reduced. Given this intrinsic variability in value along the time dimension, precision in methodology or accounting at any instant is of marginal worth from a strategic viewpoint.

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The true sources of the ideas in this book are my many colleagues in industry, academia, and government with whom I have shared experiences over four decades. They are too many to mention by name, but should they be reading this volume, my appreciation for the fun of working together on exciting business problems and novel technologies is deeply felt. My wife, Ellen, has been a wonderful source of inspiration for my writing activities, and her unstinting support is very much appreciated.

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