REAL OPTIONS IN ENGINEERING DESIGN, OPERATIONS, AND MANAGEMENT

Edited by
Harriet Black Nembhard
Mehmet Aktan

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Preface

Chapters 1 through 3 provide an introduction to real options and an overview of how real options came to be used as an analytical tool in engineering problems. Chapters 4 through 6 deliver a real options perspective on operations. Chapters 7 through 10 cover a real options perspective on design. Chapters 11 through 15 discuss a real options perspective on management. In particular, the last chapter shows how easy it is to use real options software for the business problems that may arise out of engineering considerations.

Many people have contributed to the production of this book. In addition to each chapter author, the editorial team at CRC Press including Cindy Carelli and Catherine Giacari has been enormously supportive.

We welcome comments on the book from readers.

Harriet Black Nembhard
Pennsylvania State University

Mehmet Aktan
Atatürk University

Editors

Harriet Black Nembhard, PhD, is an associate professor of industrial engineering at Pennsylvania State University. She is also the director of the Laboratory for Quality Engineering and System Transitions, which examines ways to improve decision making in operations for periods and points of change. Dr. Nembhard is the author or co-author of more than 45 research publications, has received research support from the National Science Foundation, and sits on the editorial boards of four research journals. Dr. Nembhard earned her PhD from the University of Michigan. She is an elected member of the International Academy for Quality (IAQ) and a member of the Institute of Industrial Engineers (IIE), and the Institute for Operations Research and Management Science (INFORMS).

Mehmet Aktan, PhD, is an assistant professor of industrial engineering at Atatürk University, Turkey. He received his PhD in industrial engineering from the University of Wisconsin–Madison, his MS from the University of Iowa, and his BS from Bogaziçi University. He is the author and co-author of several research publications in the areas of financial engineering, statistical methods, and human factors.

Contributors

Mehmet Aktan
Department of Industrial Engineering
Faculty of Engineering
Atatürk University
Erzurum, Turkey
maktan@atauni.edu.tr

Anteneh Ayanso
Department of Finance, Operations and Information Systems
Faculty of Business
Brock University
St. Catharines, Ontario, Canada

David N. Ford
Zachry Department of Civil Engineering
Texas A&M University
College Station, Texas
dford@civil.tamu.edu

Michael Garvin
Myers-Lawson School of Construction
Virginia Technical Institute and State University
Blacksburg, Virginia
garvin@vt.edu

Hemantha Herath
Department of Accounting
Faculty of Business
Brock University
St. Catharines, Ontario, Canada
HHerath@brocku.ca

Konstantinos Kalligeros
London, United Kingdom
kkalligeros@gmail.com

Vassilios N. Kazakidis
School of Engineering
Laurentian University
Sudbury, Ontario, Canada
vkazakidis@laurentian.ca

Min-Jung Kim
Harold and Inge Marcus Department of Industrial and Manufacturing Engineering
Pennsylvania State University
University Park, Pennsylvania
mzk148@psu.edu

Zachary Mayer
School of Engineering
Laurentian University
Sudbury, Ontario, Quebec

Johnathan Mun
Real Options Valuation, Inc.
Dublin, California
jcmun@realoptionsvaluation.com

David Nembhard
Harold and Inge Marcus Department of Industrial and Manufacturing Engineering
Pennsylvania State University
University Park, Pennsylvania
DNembhard@psu.edu

Harriet Black Nembhard
Harold and Inge Marcus Department of Industrial and Manufacturing Engineering
Pennsylvania State University
University Park, Pennsylvania
HBNembhard@psu.edu

Richard de Neufville
Technology and Policy Program
Massachusetts Institute of Technology
Cambridge, Massachusetts
Ardent@mit.edu

Ruwen Qin
Capital One Financial Service Inc.
McLean, Virginia
ruwen.qin@capitalone.com

Stefan Scholtes
Judge Business School
University of Cambridge
Cambridge, United Kingdom

Leyuan Shi
Department of Industrial and Systems Engineering
University of Wisconsin–Madison
Madison, Wisconsin
leyuan@engr.wisc.edu

Olivier de Weck
Engineering Systems Division
Massachusetts Institute of Technology
Cambridge, Massachusetts

Julie Ann Stuart Williams
Department of Management and MIS
University of West Florida
Pensacola, Florida
JAWilliams@uwf.edu

1 Introduction

Harriet Black Nembhard
Pennsylvania State University

Mehmet Aktan
Atatürk University

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In today's fast-paced business environment, flexibility provides potentially great strategic benefits to firms. Flexibility allows firms to compete more effectively in a world of substantial price and demand uncertainty, product variety, short product life cycles, and rapid product development.

The term "real options" was coined by Stewart Myers in 1977. He argued that the value of a firm includes the real assets in place plus the present value of options to make further investments in the future. These future investment opportunities are undertaken at the discretion of the firm, just as options on trade are exercised only when it is profitable to do so.

In other words, the real options approach seeks to quantify just how valuable flexibility really is. It takes into account the fact that most investments have managerial decisions and manufacturing uncertainty embedded within them. This method attempts to incorporate both the uncertainty inherent in business and the active decision making required for a strategy to succeed.

Fundamentally, an option is the right, but not the obligation, to take an action in the future. With real options the initial investment related to an asset buys the

potential opportunity to continue, expand, or abandon the use of the asset when it is favorable to do so, but does not carry the obligation to realize some losses when unfavorable conditions prevail. Managerial decisions lead to strategic and financial goals and they can follow different paths. They usually come in incremental steps. The real option at each step in the decision-making process is the freedom of choice to embark on the next step in the climb, or to choose against doing so based on the examination of additional information. An investment decision is rarely a now-or-never decision and rarely a decision that cannot be abandoned or changed. In most instances, the decision can be delayed or accelerated, and often it comes in sequential steps with various decision points, including "go" and "no-go" alternatives. All of these choices are real managerial options and impact on the value of the investment opportunity. Further, managers are very conscious of preserving a certain freedom of choice to respond to future uncertainties (Brach 2003). When executives create strategy, they project themselves and their organizations into the future, creating a path from where they are now to where they want to be some years down the road. But a plan cannot be formulated and followed mindlessly. It is intuitively understood that flexibility has value.

Real options may be categorized into three broad categories, as Copeland and Keenan (1998a, 1998b) described:

1. *Investment/growth options*. These include (1) scale-up options, where early entrants can scale up later through sequential investments as their market grows; (2) switch-up options, where speedy commitment to the first generation of a product or technology gives a firm preferential position to switch to the next generation of the product or technology; and (3) scope-up options, where investments in proprietary assets in one industry enable a firm to enter another industry cost-effectively.
2. *Deferral/learning options*. Also called study/start options, these are opportunities to delay investment until more information or skill is acquired. For example, a pharmaceutical firm uses real options analysis (ROA) to evaluate drug development projects, in which investments are made in several phases of experimentation with the drug compound before seeking regulatory approval and going to market.
3. *Disinvestment/shrinkage options*. These include (1) scale-down options, where new information that changes the expected payoffs can cause managers to shrink or shut down a project before completion; (2) switch-down options, where managers have the ability to switch to more cost-effective and flexible assets as new information is obtained; and (3) scope-down options, where operations are decreased or even abandoned when there is no further potential in a business opportunity.

The next issue that is critical to managers and financial planners is to understand and capture *precisely* the value of this flexibility. Achieving this with traditional financial tools, such as net present value (NPV) analysis and discounted cash flow (DCF) methods, is difficult because the value of switching depends on the current status, and once you have switched, the value of switching depends on your new status and the

switching options that it has. NPV and DCF cannot keep track of those interdependencies. In financial terms, a business strategy is much more like a series of options than like a series of static cash flows. Options analysis can deliver extra insight. Simple option pricing for exchange-traded puts and calls is fairly straightforward, and many authors present the basics lucidly (e.g., Hull 2008; Luenberger 1998). Real options build upon these ideas to quantify opportunities that are not financial instruments.

An excellent and practical reference is *Real Options Analysis: Tools and Techniques,* 2nd ed. (Wiley Finance; Mun 2006). Chapter 2, written by the author of that book, gives the reader an overview of many of the issues, criticisms, and viewpoints surrounding the use of real options in practice.

From an engineering perspective, manufacturing flexibility has been one of the key drivers of further work in real options. The origins of this work are discussed in Chapter 3. For other references on real options from a more theoretical point of view, we recommend Amram and Kulatilaka (1999), Trigeorgis (1999), and Copeland and Antikarov (2001).

The goal of this book is to present the state of the art in real options for engineering design, operations, and management. Therefore, Chapters 4–14 of this volume investigate a wide spectrum of fieldwork as follows.

MANUFACTURING OPERATIONS

A manufacturing firm may delay, expand, contract, switch, or abandon a manufacturing project. Chapter 4 uses several scenarios that are valued over multiple periods.

QUALITY IMPROVEMENT

Chapter 5 presents a real options framework to value a quality improvement program and to determine strategic decisions about the program. A multinomial lattice technique is used to value the expected benefit potential of the quality improvement program.

PRODUCT OUTSOURCING

Chapter 6 investigates the value of outsourcing flexibility considering volatile currency exchange rates between client and vendor countries. The strategy is selected among supplying and/or producing at the home country, and outsourcing offshore.

ARCHITECTURE/ENGINEERING/CONSTRUCTION

The limited adoption and use of real options by practicing managers in the architecture/engineering/construction (AEC) industry remain an important challenge. Chapter 7 describes a risk-rich managerial practice in which real options can add value but are not fully exploited. This setting is used as a basis for identifying and describing specific barriers to widespread real options adoption and use by practicing project managers. These barriers are used to suggest tools, methods, and approaches that may reduce those barriers.

IMPROVING THE DESIGN OF ENGINEERING SYSTEMS

Flexible designs can deliver benefits because their underlying architecture enables managers to adapt projects to circumstances that develop. Owners can thus cut losses by avoiding undesirable outcomes, and increase gains by taking advantage of new opportunities. Chapter 8 focuses on the development of valuable flexibility in designs.

MINING SYSTEMS PLANNING AND DESIGN

Large multifaceted capital projects in the mineral resource industry are often associated with diverse sources of performance uncertainty. The introduction of flexibility into the planning process is required to counter the downturns and provide the ability to exploit the upturns that can develop over the life of a mining production system. The methods to assess the risk associated with a particular mining process and the flexible alternatives considered are discussed in Chapter 9, and a methodology is applied to case studies from underground mines in Canada.

ENGINEERING SYSTEMS DESIGN

Chapter 10 examines how designers can create real options in flexible systems, and how they can compare or even optimize the flexibility among alternative design solutions. A necessary element in this process is the consistent comparison of the risk exposure achieved by alternative designs, flexible or not.

WORKFORCE CROSS-TRAINING

Workforce cross-training involves a dynamic investment on workforce flexibility. Chapter 11 proposes a real options framework that models the cross-training policy as an approximation of an American call option using binomial lattices. Value stems from the merit of dynamic cross-training compared with the deterministic case using traditional discounted cash flow techniques. The work is discussed in the context of a volatile production system characterized by product dynamics, labor dynamics, task heterogeneity, and workforce heterogeneity.

SUSTAINABLE PRODUCT QUALITY MANAGEMENT

Chapter 12 considers a company that has the flexibility of producing both ordinary and more sustainable "green" products, and is striving to improve its overall quality. It presents a model to evaluate the optimal strategies that will maximize the expected profit using real options analysis. It illustrates the use and sensitivity of the model for desktop computer production, and discusses future sustainable product quality attributes and their product life cycle management implications for the electronics industry.

NANOTECHNOLOGY

Nanotechnology increasingly shows potential in research and development, as well as some commercial applications. The U.S. government has spent over $1 billion in promoting nanotech initiatives. Chapter 13 explores the opportunities and challenges associated with making good decisions for nanotechnology investments from the perspective of real options.

PHARMACEUTICAL DEVELOPMENT

New drug development has uncertainty at every project phase. Chapter 14 explores a method for deciding upon the optimal timing for partnerships between labs and investors. In the proposed model, the decision to invest in a new drug development as an aspect of a pharmaceutical company's consideration is represented as exercising a call option. A decision to sell ownership of a new drug is considered as a biotechnology company exercising a put option. The optimal timing depends upon a number of specific investment factors.

After these forward-reaching applications are presented, we conclude with chapter 15, which demonstrates how to model real options using the Super Lattice Solver (SLS) software tool.

We hope that this book expands the understanding of real options in the engineering domain and inspires a broader consideration of research impact through the real options decision-making lens.

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2 Real Options in Practice

Johnathan Mun
Real Options Valuation, Inc.

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Business conditions are fraught with uncertainty and risks. These uncertainties hold with them valuable information. When uncertainty becomes resolved through the passage of time, managers can make the appropriate midcourse corrections through a change in business decisions and strategies. This chapter gives an overview on how real options incorporate this learning model, akin to having a strategic road map, whereas traditional analyses that neglect this managerial flexibility will grossly undervalue certain projects and strategies. It also introduces the concepts in implementing real options, as well as a balanced perspective on what is really needed to do so.

2.1 WHAT ARE REAL OPTIONS?

In the past, corporate investment decisions were cut-and-dried. Buy a new machine that is more efficient, make more products costing a certain amount, and if the benefits outweigh the costs, execute the investment. Hire a larger pool of sales associates, expand the current geographical area, and if the marginal increase in forecast sales revenues exceeds the additional salary and implementation costs, start hiring. Need a new manufacturing plant? Show that the construction costs can be recouped quickly and easily by the increase in revenues the plant will generate through new and improved products, and the initiative is approved.

However, real-life business conditions are a lot more complicated. Your firm decides to go with an e-commerce strategy, but multiple strategic paths exist. Which path do you choose? What are the options you have? If you choose the wrong path, how do you get back on the right track? How do you value and prioritize the paths that exist? You are a venture capitalist firm with multiple business plans to consider. How do you value a start-up firm with no proven track record? How do you structure a mutually beneficial investment deal? What is the optimal timing to a second or third round of financing? Real options are useful in valuing a firm through its strategic business options.

Real options are also useful as a strategic business tool in capital investment decisions. For instance, should a firm invest millions in a new e-commerce initiative? How does a firm choose among several seemingly cashless, costly, and unprofitable information technology infrastructure projects? Should a firm invest its billions in a risky research and development initiative? The consequences of a wrong decision can be disastrous or even terminal for certain firms. In a traditional discounted cash flow model, these questions cannot be answered with any certainty. In fact, some of the answers generated through the use of the traditional discounted cash flow model are flawed because the model assumes a static, one-time decision-making process, whereas the real options approach takes into consideration the strategic managerial options certain projects create under uncertainty and management's flexibility in exercising or abandoning these options at different points in time, when the level of uncertainty has decreased or has become known over time.

The real options approach incorporates a learning model, such that management makes better and more informed strategic decisions when some levels of uncertainty are resolved through the passage of time. The discounted cash flow analysis assumes a static investment decision and assumes that strategic decisions are made initially with no recourse to choose other pathways or options in the future. To create a good analogy of real options, visualize it as a strategic road map of long and winding roads with multiple perilous turns and branches along the way. Imagine the intrinsic and extrinsic value of having such a road map or global positioning system when navigating through unfamiliar territory, as well as having road signs at every turn to guide you in making the best and most informed driving decisions. Such a strategic map is the essence of real options.

The answer to evaluating such projects lies in real options analysis, which can be used in a variety of settings, including pharmaceutical drug development, oil and gas exploration and production, manufacturing, start-up valuation, venture capital investment, information technology infrastructure, research and development, mergers and acquisitions, e-commerce and e-business, intellectual capital development, technology development, facility expansion, business project prioritization, enterprise-wide risk management, business unit capital budgeting, licenses, contracts, intangible asset valuation, and the like. The following section illustrates some business cases and how real options can assist in identifying and capturing additional strategic value for a firm.

2.2 THE REAL OPTIONS SOLUTION IN A NUTSHELL

Simply defined, real options comprise a systematic approach and integrated solution using financial theory, economic analysis, management science, decision sciences, statistics, and econometric modeling in applying options theory in valuing real physical assets, as opposed to financial assets, in a dynamic and uncertain business environment where business decisions are flexible in the context of strategic capital investment decision making, valuing investment opportunities, and project capital expenditures.

Real options are crucial in the following situations:

- Identifying different corporate investment decision pathways or projects that management can navigate given highly uncertain business conditions
- Valuing each of the strategic decision pathways and what it represents in terms of financial viability and feasibility
- Prioritizing these pathways or projects based on a series of qualitative and quantitative metrics
- Optimizing the value of strategic investment decisions by evaluating different decision paths under certain conditions or using a different sequence of pathways that can lead to the optimal strategy
- Timing the effective execution of investments and finding the optimal trigger values and cost or revenue drivers
- Managing existing or developing new optionalities and strategic decision pathways for future opportunities

Strategic options do have significant intrinsic value, but this value is realized only when management decides to execute the strategies. Real options theory assumes that management is logical and competent and that management acts in the best interests of the company and its shareholders through the maximization of wealth and minimization of risk of losses. For example, suppose a firm owns the rights to a piece of land that fluctuates dramatically in price. An analyst calculates the volatility of prices and recommends that management retain ownership for a specified time period, where within this period there is a good chance that the price of real estate will triple. Therefore, management owns a call option, an *option to wait* and defer sale for a particular time period. The value of the real estate is therefore higher than the value that is based on today's sale price. The difference is simply this option to wait. However, the value of the real estate will not command the higher value if prices do triple but management decides not to execute the option to sell. In that case, the price of real estate goes back to its original levels after the specified period, and then management finally relinquishes its rights. *Strategic optionality value can be obtained only if the option is executed; otherwise, all the options in the world are worthless.*

Was the analyst right or wrong? What was the true value of the piece of land? Should it have been valued at its explicit value on a deterministic case where you know what the price of land is right now, and therefore this is its value; or should it include some types of optionality where there is a good probability that the price of land could triple in value and, hence, the piece of land is truly worth more than it is now and should therefore be valued accordingly? The latter is the real options view. The additional strategic optionality value can be obtained only if the option is executed; otherwise, all the options in the world are worthless. This idea of *explicit* versus *implicit* value becomes highly significant when management's compensation is tied directly to the actual performance of particular projects or strategies.

To further illustrate this point, suppose the price of the land in the market is currently $10 million. Further, suppose that the market is highly liquid and volatile and that the firm can easily sell off the land at a moment's notice within the

next five years, the same amount of time the firm owns the rights to the land. If there is a 50 percent chance the price will increase to $15 million and a 50 percent chance it will decrease to $5 million within this time period, is the property worth an expected value of $10 million? If the price rises to $15 million, management should be competent and rational enough to execute the option and sell that piece of land immediately to capture the additional $5 million premium. However, if management acts inappropriately or decides to hold off selling in the hopes that prices will rise even further, the property value may eventually drop back down to $5 million. Now, how much is this property really worth? What if there happens to be an *abandonment option?* Suppose there is a perfect counterparty to this transaction who decides to enter into a contractual agreement whereby, for a contractual fee, the counterparty agrees to purchase the property for $10 million within the next five years, regardless of the market price and executable at the whim of the firm that owns the property. Effectively, a safety net has been created whereby the minimum floor value of the property has been set at $10 million (less the fee paid). That is, there is a limited downside but an unlimited upside, as the firm can always sell the property at market price if it exceeds the floor value. Hence, this strategic *abandonment option* has increased the value of the property significantly. Logically, with this *abandonment option* in place, the value of the land with the option is definitely worth more than $10 million. The real options approach seeks to value this additional inherent flexibility. Real options analysis allows the firm to determine how much this safety downside insurance or abandonment option is worth (i.e., what is the fair market value of the contractual fee to obtain the option?), the optimal trigger price (i.e., what price will make it optimal to sell the land?), and the optimal timing (i.e., what is the optimal amount of time to hold on to the land?).

2.3 IMPLEMENTING REAL OPTIONS ANALYSIS

First, it is vital to understand that real options analysis is *not* a simple set of equations or models. It is an *entire decision-making process* that enhances the traditional decision analysis approaches. It takes what has been tried-and-true financial analytics and evolves it to the next step by pushing the envelope of analytical techniques. In addition, it is vital to understand that 50 percent of the value in real options analysis is simply thinking about it. Another 25 percent of the value comes from the number-crunching activities, while the final 25 percent comes from the results interpretation and explanation to management. Several issues should be considered when attempting to implement real options analysis:

- *Tools:* The correct tools are important. These tools must be more comprehensive than initially required because analysts will grow into them over time. Do not be restrictive in choosing the relevant tools. Always provide room for expansion. Advanced tools will relieve the analyst of detailed model building and let him or her focus instead on 75 percent of the value––thinking about the problem and interpreting the results. Chapter 16 of this book further discusses the Real Options Super Lattice Solver (SLS) software and how even complex and customized real options problems can be solved with great ease.

- *Resources:* The best tools in the world are useless without the relevant human resources to back them up. Tools do not eliminate the analyst, but enhance the analyst's ability to effectively and efficiently execute the analysis. The right people with the right tools will go a long way. Because there are only a few true real options experts in the world who truly understand the theoretical underpinnings of the models as well the practical applications, care should be taken in choosing the correct team. A team of real options experts is vital in the success of the initiative. A company should consider building a team of in-house experts to implement real options analysis and to maintain the ability for continuity, training, and knowledge transfer over time. Knowledge and experience in the theories, implementation, training, and consulting are the core requirements of this team of individuals.
- *Senior management buy-in:* The analysis buy-in has to be top-down where senior management drives the real options analysis initiative. A bottom-up approach where a few inexperienced junior analysts try to impress the powers that be will fail miserably, or it will be passed off as another business school fad and not applicable to "real life."

2.4 CRITICISMS, CAVEATS, AND MISUNDERSTANDINGS IN REAL OPTIONS

Before embarking on a real options analysis, analysts should be aware of several caveats. The following five requirements need to be satisfied before a real options analysis can be run:

- *A financial model must exist.* Real options analysis requires the use of an existing discounted cash flow model, as real options build on the existing tried-and-true approaches of current financial-modeling techniques. If a model does not exist, it means that strategic decisions have already been made and no financial justifications are required, and hence, there is no need for financial modeling or real options analysis.
- *Uncertainties must exist.* Otherwise, the option value is worthless. If everything is known for certain in advance, then a discounted cash flow model is sufficient. In fact, when volatility (a measure of risk and uncertainty) is zero, everything is certain, the real options value is zero, and the total strategic value of the project or asset reverts to the net present value in a discounted cash flow model.
- *Uncertainties must affect decisions when the firm is actively managing the project, and these uncertainties must affect the results of the financial model.* These uncertainties will then become risks, and real options can be used to hedge the downside risk and take advantage of the upside uncertainties.
- *Management must have strategic flexibility or options to make midcourse corrections when actively managing the projects.* Otherwise, do not apply real options analysis when there are no options or management flexibility to value.
- *Management must be smart enough and credible enough to execute the options when it becomes optimal to do so.* Otherwise, all the options in the

world are useless unless they are executed appropriately, at the right time, and under the right conditions.

There are also several criticisms against real options analysis. It is vital that the analyst understands what they are and what the appropriate responses are, prior to applying real options.

- *Real options analysis is merely an academic exercise and is not practical in actual business applications*. Nothing is further from the truth. Although it was true in the past that real options analysis was merely academic, many corporations have begun to embrace and apply real options analysis. Also, its concepts are very pragmatic, and with the use of the Real Options Super Lattice Solver software, even very difficult problems can be easily solved, as will become evident in the next few chapters. This book and software have helped bring the theoretical a lot closer to practice. Firms are using it and universities are teaching it. It is only a matter of time before real options analysis becomes part of normal financial analysis.
- *Real options analysis is just another way to bump up and incorrectly increase the value of a project to get it justified*. Again, nothing is further from the truth. If a project has significant strategic options but the analyst does not value them appropriately, he or she is leaving money on the table. In fact, the analyst will be incorrectly undervaluing the project or asset. Also, one of the foregoing requirements states that one should never run real options analysis unless strategic options and flexibility exist. If they do not exist, then the option value is zero, but if they do exist, neglecting their valuation will grossly and significantly underestimate the project or asset's value.
- *Real options analysis ends up choosing the highest-risk projects as the higher the volatility, the higher the option value*. This criticism is also incorrect. The option value is zero if no options exist. However, if a project is highly risky and has high volatility, then real options analysis becomes more important. That is, if a project is strategic but is risky, then you better incorporate, create, integrate, or obtain strategic real options to reduce and hedge the downside risk and take advantage of the upside uncertainties. Therefore, this argument is actually heading in the wrong direction. It is not that real options will overinflate a project's value, but for risky projects, you should create or obtain real options to reduce the risk and increase the upside, thereby increasing the total strategic value of the project. Also, although an option value is always greater than or equal to zero, sometimes the cost to obtain certain options may exceed their benefit, making the entire strategic value of such options negative, although the option value itself is always zero or positive.

So, it is incorrect to say that real options will always increase the value of a project or that only risky projects are selected. People who make these criticisms do not truly understand how real options work. However, having said that, real options

analysis is just another financial analysis tool, and the old axiom of "garbage in, garbage out" still holds. But if care and due diligence are exercised, the analytical process and results can provide highly valuable insights. In fact, I believe that 50 percent (rounded, of course) of the challenge and value of real options analysis is simply *thinking about it*. Understanding that you have options, or obtaining options to hedge the risks and take advantage of the upside, and to think in terms of strategic options, is half the battle. Another 25 percent of the value comes from actually running the analysis and obtaining the results. The final 25 percent of the value comes from being able to explain it to management, to your clients, and to yourself, such that the results become actionable, and not merely another set of numbers. See Chapter 15 for getting started examples using real options software and additional resources for case studies, theoretical concepts, and other applications.