Risk-adjusted Valuation of R&D Projects

R&D management has historically been very much the art of creating value by managing an extraordinary degree of risk. The quantitative tools needed to transform practice from what has been an art to an analytical science have evolved rapidly in the last two decades. (1) We outline another step forward: integrating decision and risk analysis, real options, and stagegate methodologies.

F. Peter Boer[*]

OVERVIEW: The decision-tree approach to the valuation of R&D projects is mathematically identical to a probability-adjusted sequence of real options, when systematic (or market) risk is set to zero. Besides adding confidence to the calculation, this observation allows a clean separation of the value contribution of the option to abandon contained in a stagegate approach plus the additional value gained from market risk (as measured by volatility). One consequence is to enable the risk-adjusted valuation of R&D projects on a compact and familiar set of variables: net present value, initial investment, and the estimated cost, duration, and probability of success for each R&D stage. An estimate of the value of the project at the completion of each successive R&D stage is also a useful output of the method.

Every industrial R&D project plan envisions a payoff. In financial terms, the payoff can be represented by the project's Net Present Value in the year it is commercialized. But that payoff is inevitably diminished by what might be called "The Three Horsemen of the R&D Apocalypse," I. the time value of money; II. the risk of

[1] Boer, F. Peter, "Financial Management of R&D 2002", *Research-Technology Management,* July-August 2002, pp. 23-35.

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technical failure; and III. the cost of the R&D program itself. Given the value-destroying potential of these three factors, senior management will wish to determine whether its continuing R&D investment in R&D is creating value, and, if so, how much. A linear approach to this judgment is inevitably flawed, since it does not include the value of management's flexibility to respond to changes in the marketplace or in the technology outlook.

This paper presents a unified approach to the valuation of an R&D project that integrates three analytical tools: Discounted Cash Flow, Decision Trees, and Real Options. (2) The value calculation is basic, once the input parameters have been established. By extension, the sum of the values of its individual projects defines a minimum value for the R&D portfolio. The method presented below is especially well suited to run in the context of a stagegate management system.

Why might this be important? The Discounted Cash Flow approach is well established, and beloved of finance executives, but is known to systematically underestimate the value of R&D projects (and other intangible assets). The Decision Tree approach, sometimes labeled "Decision and Risk Analysis" captures the substantial value of the Option to Abandon. It quantifies *unique risk* and creates value by structuring R&D programs into a series of go/no-go decision points that exploit the option to abandon (3).

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[2] Books on Real Options include Trigeorgis, L., *Real Options: Managerial Flexibility and Strategy in Resource Allocation*, Cambridge, MA, MIT Press. 1998; Amram, M. and Kulatilaka, N., *Real Options, Managing Strategic Investment in an Uncertain World*. Boston, MA, Harvard Business School Press, 1999; Copeland, T. and Antikarov, V., *Real Options: A Practitioner's Guide*, New York, Texere LLC, 2001, Newton, David, Paxson, Dean, Howell, Sydney, Cavus, Mustafa, and Stack Andrew, *Real Options: Principles and Practice.* New York, Financial Times Prentice Hall, 2001; Mun, Jonathan, *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions,* New York, John Wiley and Sons, 2002.

[3] Boer, F. Peter, *The Valuation of Technology: Financial Issues in R&D*. New York, John Wiley & Sons, 1999, pp. 290-297.

This fact has been one reason for the widespread adoption of stagegate methodology, although the rationale has hitherto been largely qualitative (4).

The Real Options approach has generally been treated independently from Decision Trees. It captures value from the management of *market risk,* risk that cannot be diversified.

<u>In reality, the two approaches are additive, compatible, and form a powerful combination</u>. Technically, the Real Options method is more appropriate for valuation of R&D project plans than Discounted Cash Flow, because plans are options, not assets (5).

This paper describes how Decision Trees and Real Options can be combined into a single calculation (Decision Tree/Real Options), reducing valuation to two steps: Discounted Cash Flow followed by Decision Tree/Real Options. After the Discounted Cash Flow step has been performed to obtain a best estimate of business plan value, Decision Tree/Real Options then captures full value from both unique and market risk. In effect, we create a compound option based on multiple options to abandon, which also incorporate the value of call options capturing market risk.

Who can benefit from this analytic approach? Very broadly speaking, it fits situations with high risk, exposure to volatile markets, longer time horizons, and progressively increasing development costs. In addition to industrial R&D, venture capital, petroleum exploration, and screenplay development fit the profile. The methods are particularly useful when a historical data base is available regarding the odds of project success, as in the pharmaceutical industry or in the development of new specialty

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[4] Cooper, Robert G., *Winning at New Products; Accelerating the Process from Idea to Launch, 2nd Ed.* Reading, MA, Addison Wesley, 1993. A recent brochure from Stage-Gate, Inc. claims that 70% of U.S. companies have adopted this method.

chemicals. If the calculations are valid, those using them will invest in opportunities that competitors will pass up, a potentially enormous competitive advantage.

Part I: Setting Up the Calculation

Framing the Problem

While it is not the focus of this paper, it must be realized that the most important, and time-consuming, step in the valuation of technology is to understand the business situation and frame the option credibly.(6) The successful practitioner must draw not only on his own expertise and industry experience, but on dialog with experts: R&D managers, marketing execs, economic evaluators, and licensing specialists. Their perspectives will help frame the problem and the issues; and when the numbers are at variance with expert opinion, it is especially useful to identify and analyze the assumptions which are driving that variance. The framing step is where value is created, but it is facilitated by user-friendly analytical tools, such as those we describe, where strategic alternatives and economic adjustments can be readily evaluated.

External/Financial Inputs

The combined method requires three financial (external) inputs. The first is the Risk-free Interest Rate, typically considered to be the return on Treasury bills. The second is the Cost of Capital for the party funding the project. There are a number of methods for estimating Cost of Capital, such as the Capital Asset Pricing Model (7). These are described and discussed in a variety sources, and will not be described further

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[5] Boer, F. Peter, *The Real Options Solution; Finding Total Value in a High-Risk World,"* New York, John Wiley & Sons, 2002, pp. 137-163.
[6] Amram, M. and Kulatilaka, N., *Real Options, Managing Strategic Investment in an Uncertain World*. Boston, MA, Harvard Business School Press, 1999, pp. 90-98.

here. As a practical matter, you can get the former rate from the newspaper and the latter by checking with the CFO or his staff. We use 5% and 12% for these two rates respectively in our examples.

The third external parameter is the volatility (σ) to be assigned for the options part of the calculation. Technically, it should be the annual standard deviation of the value of the security underlying the option. For a financial option based on a stock, volatility parameters are published in a financial data bases, such as the one provided on-line by the Chicago Board Options Exchange (http://www.cboe.com). For a real option, the underlying security is the present value of the business plan. Estimating the appropriate volatility is a matter of judgment. I have considered using the observed volatility of stocks in the industrial sector in which the business plan operates (8), the observed volatility of the parent company, the volatility of a time series of prices in a commodity to which the business plan is linked (such as natural gas), and (my favorite) the volatility of the cash margin of the product to which the business plan is linked. Because there is no absolute answer, and historical volatilities themselves seem to move in range, it is wise to estimate the sensitivity of the final result to the volatility parameter (6). In this context, sensitivity analysis simply means running a (most likely) base case, an upside case reflecting an optimistic/favorable estimate of the parameter at issue, and a downside case using a pessimistic/conservative estimate.

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[7] Brealey, R.A. and Myers, S.C., *Principles of Corporate Finance, 5th Ed.* New York, McGraw-Hill, 1996. pp. 183-188.
[8] Nichols, Nancy A., "Scientific Management at Merck: An Interview with CFO Judy Lewent", *Harvard Business Review*, January-February 1994, p 91.

Business Inputs

While, within the scope of this paper, we are not directly concerned with the steps by which a business plan is calculated, and we need only two of its outputs: the Net Present Value and the Initial Investment. The present value of the underlying security in the options calculation is the sum (Initial Investment + Net Present Value). (9)

Nevertheless, the business plan is of the utmost importance to an accurate calculation. Garbage in, garbage out. It depends on an accurate model of revenues over the timeframe of commercial operation; estimates of many categories of fixed and variable costs, estimates of fixed capital requirements (plant and equipment), and allowances for working capital and taxes. An extended discussion of how to write a pro forma business plan is available in the author's book, *The Valuation of Technology*(10). It is also useful and relatively simple to determine the range of uncertainty in Net Present Value by running sensitivity calculations, or Monte Carlo analysis(11) of the business plan model. This estimate can then be carried over to calculate uncertainty in the Risk-adjusted Valuation, for example by using the calculated standard deviation of Net Present Value in the Discounted Cash Flow step to define a normal distribution for Net Present Value in the Decision Tree/Real Options calculation. .

A useful convention is to define the final year of the R&D project to be Year 0 of the Business Plan: Capital Investments, Start-up expenses, and possibly Revenues can

[9] INV (initial investment/strike price) is a necessary component of the Black-Scholes algorithm, but does not enter the Decision Tree calculation directly. Strangely, the RO calculation will appear to be independent of INV, because it values the difference between the price of the underlying security and the strike price. The apparent paradox resolves quickly when one remembers that Net Present Value was itself very much a function of INV in the preceding Discounted Cash Flow calculation.

[10] Boer, F. Peter, *The Valuation of Technology: Financial Issues in R&D*. New York, John Wiley & Sons, 1999, Chapter 9.

[11] Crystal Ball [TM] software from Decisioneering, Inc., Denver, CO.

begin in Commercial Year 1. Hence, Net Present Value is referenced to Year 0 of the Business Plan. It must thereafter be discounted to the present by the estimated duration of the R&D program.

An inevitable issue that will arise is how to account for R&D costs. One way is to incorporate pre-commercial R&D costs as the front end of the business plan itself. I do not recommend this approach, because it treats the project like a "rifle shot" and forfeits the benefits of the option to abandon. The better way to account for <u>pre-commercial</u> R&D is to introduce it in the Decision Tree step.

The treatment of <u>post-commercial</u> R&D costs is more straightforward – include in R&D all costs required to support the business plan. An R&D "tax" to support other corporate initiatives is not necessary, because these could be included in the pre-commercial phases of these other initiatives.

<u>R&D Inputs</u>

We require three R&D inputs per R&D stage (12 numbers for a four stage process). These are simply the estimated duration of that stage, the estimated after-tax cost of the stage (actual cost times [1 – tax rate]), and the probability of success defined as the probability of advancing through the stagegate to the next stage.

An example of a four-stage process is a "Conceptual" stage involving range-finding experiments, small-scale tests, and intellectual property development. It leads to a "feasibility" stage to produce larger samples, develop a scheme for an efficient manufacturing process, and to resolve issues related to customer acceptance. The "Development" phase would typically include yet larger samples, customer tests, advanced testing, and the operation of a prototype manufacturing process. "Early

Commercialization" or "Launch" requires teamwork between R&D and the business unit, and would include small-scale production, sales of modest amounts of materials to selected customers, adjustments to product specifications, and a requirement for continued R&D problem-solving. The R&D Department may be subsidizing all or part of the effort. Full commercialization means the R&D departments no longer call the shots, the business unit establishes a P&L (Profit and Loss Statement) and R&D moves to a support role.

The amounts at risk in this process increase considerably through each stage. In the Conceptual and Feasibility stages, the risk is internal and financial; the project may fail and be terminated. Exposure to risk will grow with each successive stage. In the development stage, the firm takes on additional risk by exposing the product to potential customers. Some reputation is also at risk. The Early Commercialization phase, where money is changing hands, presupposes the customer understands fully why the new technology adds value from his viewpoint. However, in a well-managed project, the overall level of risk typically (2) decreases. It is the combination of successively increasing costs and sharply reduced relative risks which powers value creation.

How are these parameters to be estimated? The short answer is to ask the research managers. The longer answer is a process of determining the objectives of each stage, which include not only a demonstration of the technology at the appropriate scale, but also all of the technical information required for the next stage to begin. This last point is particularly important when a technology transfer step is involved, say from laboratory to pilot plant. These needs can be reduced to timelines and resource commitments. Nearly all laboratories account for professional time at a man-year rate that includes overheads to cover laboratory fixed costs. Extraordinary costs, such as outside testing services, raw materials, etc. will need to be added separately.

The "probability of success" input raises more issues. It reduces a complex situation defined by multiple specifications to a single number. Will those responsible for deciding to advance a project be satisfied with substantially meeting the specifications, or will they insist on meeting them fully? Unfavorable variances from spec may translate into lower revenues, additional cost, or higher capital investment than contemplated in the original business plan. (An acceptable degree of variation may be predetermined by calculating the sensitivity of plan economics to scale, cost, and capital).

Once a basic definition of success is achieved, there are two ways to estimate it: 1) ask the experts, or 2) review the statistics. The expert approach should definitely include individuals who are not project champions or who otherwise have a stake in continuing the project. The statistical approach can work when the statistical base is adequate, and the comparisons are essentially apples-to-apples. A company should create a database on its past projects and determine what percentage of candidates has advanced to each next stage. Drug companies have excellent statistics of this type, and have generally published them quite freely. There are a few generic studies that can give a clue to the overall situation(12). In other situations, the database may be scanty, or projects so varied in character that apples are being compared to oranges. But even if agreement on probabilities or other R&D inputs cannot be reached, the method described below still enables sensitivity tests on profit based on all three R&D variables (duration, cost, and probability) at each stage.

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[12] Stevens, Greg A. and Burley, James, "3,000 Raw Ideas = 1 Commercial Success", *Research-Technology Management,* May-June 1997, pp. 16-27.

Part II: An Example

An R&D team at the fictional bioremediation business unit of Acme BioChemicals proposes to develop a new microorganism that its microbiologists have identified as having excellent potential to bioremediate refractory chlorinated waste.

Their business plan calls for two R&D stages over three years: a laboratory feasibility study; followed by a two-year field test. In Year 4, when technical risks have been eliminated, the technology will be commercialized at three superfund sites. The feasibility study will take one year, cost $500,000, and is given a 50% chance of technical success. The field test will take two years, cost $1 million, and have a 75% chance of success. Deployment of the technology at three commercial sites will require an investment of $5 million. The R&D team believes the technology, if successful, would offer customers a large cost saving versus the best alternative technology, while earning Acme an attractive return on investment. Specifically, Acme's economic evaluators estimated the enterprise would have a value of $8 million, giving a Net Present Value in year four of $3 million.

Unfortunately, because of the development costs and high unique risks the project has negative economic value when evaluated by a decision tree (Figure 1). The project has three possible outcomes: a 50% chance of failure after the feasibility stage, a 12.5% probability of failure after the field test (the worst outcome), and a 37.5% chance of success. Applying a 12% cost of capital, the project is a marginal loser, with a weighted Net Present Value of ($109,000).

Even so, management has created value by adroitly managing the option to abandon after the uncertain stages. If the stages were combined with a commitment to roll out this technology in year four regardless - for example, by signing a fixed-price contract with a contract research laboratory, the expected reward would be 37.5% x $1.907 million, or $715,000, versus a certain cost of ($1.201) million, giving a far worse expectation of ($486,000). Mitigating the unique risk with the option to abandon adds a great deal of value but is of itself is not enough to justify the project.

Now let us factor in market risk. In our context, market risk means we don't really know the price we will be able to realize four years hence, and that it will be subject to factors that have affected the industry in the past. These could include supply and demand for remediation services, changes in regulatory climate, and the level of competitor activity. We have discussed a number of possible proxies for volatility, but less assume we choose the volatility of a proxy industry (6), which we have determined to be 50% based on the average annual volatility of the three leading publicly-traded bioremediation companies.

Restructuring the analysis in options terms (Figure 2), we can assume that stage two is a two-year call option to invest $5 million, the strike price to begin commercial operations. The underlying security for this option is valued at $6.442 million—that is, the present value of the strike price at the risk-free rate, $4.535 million, plus the discounted Net Present Value, $1.907 million, of a successful project. This option is worth $2.643 million by the Black-Scholes formula at a market volatility of 50%. When we correct for the unique risk implied in a 75% probability of success, the project value is $1.982 million.

Next consider stage one as a second option to enter stage two, for which the underlying security is the value of the stage two option, or $1.982 million. This option has as its strike price(13) the discounted cost of the field test, $792,000. Plugging into Black-Scholes gives a value of $1.234 million. But there's unique risk of 50% at this stage, so this option is worth $617,000. Its discounted cost is ($446,000), so the project has a positive value of $171,000.

Let's do the reality check (Figure 3) and assume zero volatility. The underlying security and the strike price are the same, and unsurprisingly Black-Scholes gives an option value for stage two of $1.907, exactly the Year 0 Net Present Value! Correcting by 75% for unique risk gives $1.430 million. Feeding this value into the stage 1 calculation computes a second option valued at $675,000. Correcting by 50% probability of success gives $338,000. Subtract the discounted project cost of stage one ($446,000) and the net value is ($109,000). This result is <u>identical</u> to what we obtained from the decision-tree analysis. Despite the fact that the numbers passed twice through the Black-Scholes equation in the second case, the result is accurate within the reasonable precision of the computer.

The difference between the Decision Tree and the Decision Tree/Real Options results is significant, $279,000, and suffices to make this project a winner. That vital difference was created by market volatility. It took a combination of serial options to abandon and the value of market risk to make this project a winner.

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[13] Recall the gross cost of R&D Stage two was $1.000M, which was discounted at the cost of capital (12%) to ($0.399) + ($0.356) = ($0.754). But this is the *net present value* of the strike price. The strike price is related to its net present value in the Black-Scholes algorithm by the risk free rate (5%) over the 2-year duration of this stage, yielding for the strike price ($0.754) x

Part III: Integrating Net Present Value, Decision Trees, and Real Options

Integrated software can make this seemingly complicated process much easier, and quite transparent. It will also allow a rapid determination of which project proposals are winners, and which need more work. In my book, *Valuation of Technology*, (14) I described a fictitious case where a research group proposed to develop a new polymer, "polyarothene." They estimated it would take 8 years of R&D to get ready for commercial operations, and that sales would rise from an initial year's $12 million, to $48 million five years after launch. Let us frame the issue:

The research department is proposing a project which will have a Net Present Value of about $91 million if successfully commercialized. However, to get there they will have to spend more than $11 million, and the researchers admit the chances of success are only about 10%. The CEO points out that the expectation of reward (10% x $91M) is less than the R&D cost, and that the Net Present Value of $91M eight years from now is only about $36M today. Research replies that, yes, the CEO is correct, but that this is still an excellent project using the option-based tools of risk-adjusted valuation, and could be justified even with much more pessimistic assumptions. Both parties are correct! – let's see why.

The business case assumptions for this problem are illustrated in the top tier of Figure 4 which shows the sales forecast, the proposed capital investment, and the estimated costs associated with the business. Assuming a 12% cost of capital, the net present of the business is $91.07 M (bottom left of Figure 4). We also calculate an initial

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$(1.050)^2$ = ($0.792.) This treatment of the R&D strike price is essential to creating the identity of Decision Tree with Decision Tree/Real Options.

investment of $35.27M (required for options calculations) based on the capital expenditure for a 48 million pound/per year plant plus first-year working capital requirements.

A word about terminal value (see Figure 4, lower left). It represents the value of a business in a horizon year, that is a year sufficiently distant that there is no point in doing further cash flow calculations. One of two things can happen; first, the horizon year may be one in which the company plans to liquidate the business. In this case, the terminal value will equal the working capital. Or if the fixed assets have some value too, perhaps they can be liquidated at cost less accumulated depreciation (book value). These conservative assumptions will give a minimum value for the business. The contrasting assumption is that in the horizon year, there is still a viable business (which could in principle be sold to a second party). In that case, the terminal value can be estimated as a multiple of income (using an industry norm Price-to-Earnings ratio) or as a multiple of pre-tax Cash Flow (EBITDA), or finally as a function of Free Cash Flow using the growth-in-perpetuity method (15). The last three methods should in most cases give similar results; here I used the Free Cash Flow answer for subsequent calculations.

We have now carried out the first step of our two-step process; obtaining Net Present Value and Initial Investment. It is now time to take it through risk-adjusted valuation.

This calculation assumes four R&D stages, instead of the two used in the first example. Each stage is characterized by a cost, duration, and a probability of success, shown in the middle tier of Figure 4. To perform the options analysis, we also need the

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[14] Boer, F. Peter, *The Valuation of Technology,* pp. 214-233, 279-284. There are minor technical differences in the pro forma calculation as performed here and the method described in *VoT*.

risk-free rate, and an appropriate volatility parameter, shown among the financial parameters in the upper right.

On the lower right are the principal outputs we seek, the value of the project incorporating all R&D costs (the rifle shot value), the value of the project after the option to abandon is included (Decision Tree value), and the value of the project incorporating market risk (Decision Tree/Real Options value). Rather neatly, the contribution from each component of the calculation, that is from the option to abandon, and then from the inclusion of market risk, is quantified. In this case the Option to Abandon is worth $4.26M and takes the project from a loser (the CEO's rifle-shot model) to a winner, while market volatility adds only $0.04M. The latter is a result of this project being deep in the money – netting $91.07M of value on an investment of only $35.27M.

As an additional benefit, this method allows a calculation for the step-up in value that occurs as each stagegate is successfully passed – an important consideration when the team is weighing whether to proceed. These progressively increasing values are shown at the bottom right of the table. Value increases from a $1.86M idea before the conceptual stage begins, to $8.62M when it is successfully completed. The latter figure does not include sunk costs, in this case, the expenditure on the Stage 1 R&D program; these are easily added if management so prefers. But it does fully account for all future R&D costs and risks.

The new value is not intuitively unreasonable, since the R&D team has just overcome 2:1 odds and moved 2 years closer to the goal. Value correspondingly steps up again to $18.84M at the end of the Feasibility Stage, $27.68M at the end of

[15] Boer, F. Peter, *The Valuation of Technology*, pp. 115-120.

Development, and to (the Net Present Value of $91.07M at the successful completion of Stage 4. Obviously, this methodology is also very useful in evaluating technology investments, such as start up companies, since financing rounds are analogous to R&D stages, and dilution calculations will be driven by a pre-money valuation, plus the cash needs to finance the next stage.

Having performed the calculation for a base case, it is straightforward to plug other input values into the spreadsheet to determine the sensitivity of the answer to individual parameters, whether these be price, fixed capital, probabilities of success, etc. Alternatively, a Monte Carlo calculation (6) can be performed using a distribution of possible values for each selected input variable, to determine the full range of uncertainty (which may be very high for early-stage technologies).

For example, let us consider some pessimistic cases, to see what we can learn. First, assume we estimate we can realize a selling price only $0.86 cents/lb. instead of our previous $1.00. This represents a 28% hit to our previous gross margin. The Net Present Value of the project is still positive $37.23M, but the R&D costs and risks are not justified by Decision Tree analysis alone, giving a value of ($0.16M). But volatility, reflecting uncertainty in business conditions and pricing adds more value in this scenario, $0.19M, bringing project value into the black, $0.03M. We have learned that 86 cents a pound is the real chokepoint for this project.

Does adding Real Options to the economic analysis make a difference? Although the answer is "sometimes," it makes the most difference with respect to the toughest decisions. Since options algorithms are readily integrated into an analytical package, and their use is conceptually sound (since plans are options), there is little reason not to do so.

But achieving turbocharged valuations via Real Options will not be a universal result (despite the fact that market risk always acts in the direction of enhancing value).

An option that is deep-in-the money, that is, where the present value far exceeds the strike price, will receive little additional benefit from Real Options. This circumstance should not disappoint, since a deep-in-the-money option is a happy circumstance and should always be exercised. Deep-out-of-the-money options likewise will get only a small boost from Real Options treatment; but these are generally foolhardy projects that rightfully should be rejected or rethought. Projects that are at-the-money or slightly-out-of-the-money (zero or slightly negative Net Present Values) are the ones that have high Real Options value, and benefit most from being viewed through the real options lens. In other words, Decision Tree/Real Options is for making the close calls.

Just as importantly, a user-friendly, integrated software model for calculating risk-adjusted value can assist R&D planners in identifying sources of value in their projects, both in factors they cannot control, such as market volatility, and factors they can control, such as project timelines and resources. For example, does it make sense to increase project resources if it shortens the timeline and reduces first-stage project risk? Or are those resources best allocated elsewhere? In my view, the ability to dynamically program scenarios at the individual project level will be even more valuable than the answer to the question, ”What is our R&D portfolio worth?” But a quantitative framework for addressing both of these needs is rapidly coming within reach.

Figure 1: Project Outcomes by DCF/Decision Tree. The project has abandonment scenarios after Stages 1 and 2,and one successful outcome with a 37.5% chance of success. The expectattion value on the upper left is the weighted sum of the three possible outcomes.

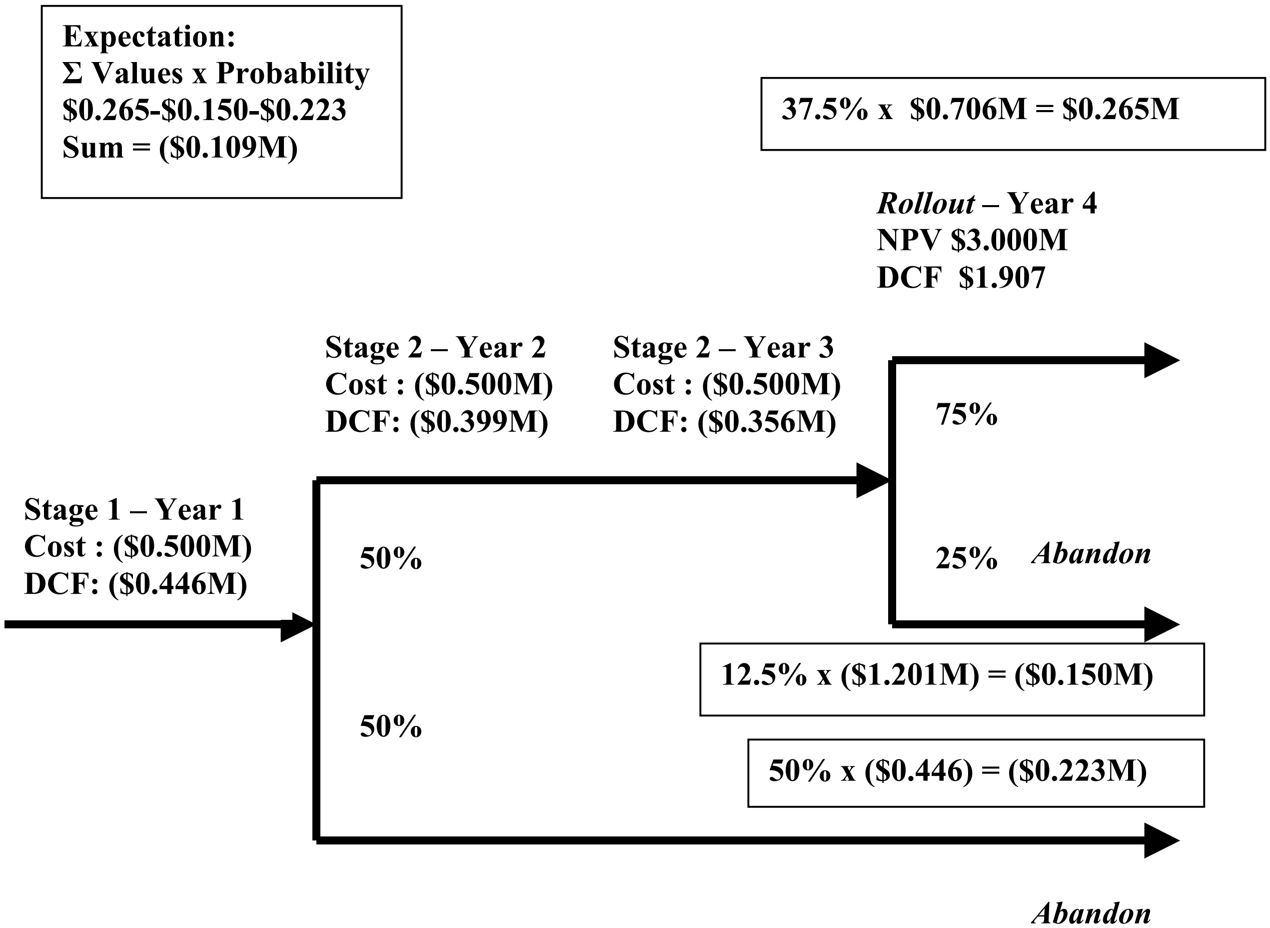

Figure 2. Project Outcome by Real Options Analysis. The Real Options calculation begins with value of a successful Rollout (top). This value is the underlying security for the Integration Study Option (lower right), which is in turn the underlying security for the Feasibility Study (lower left).

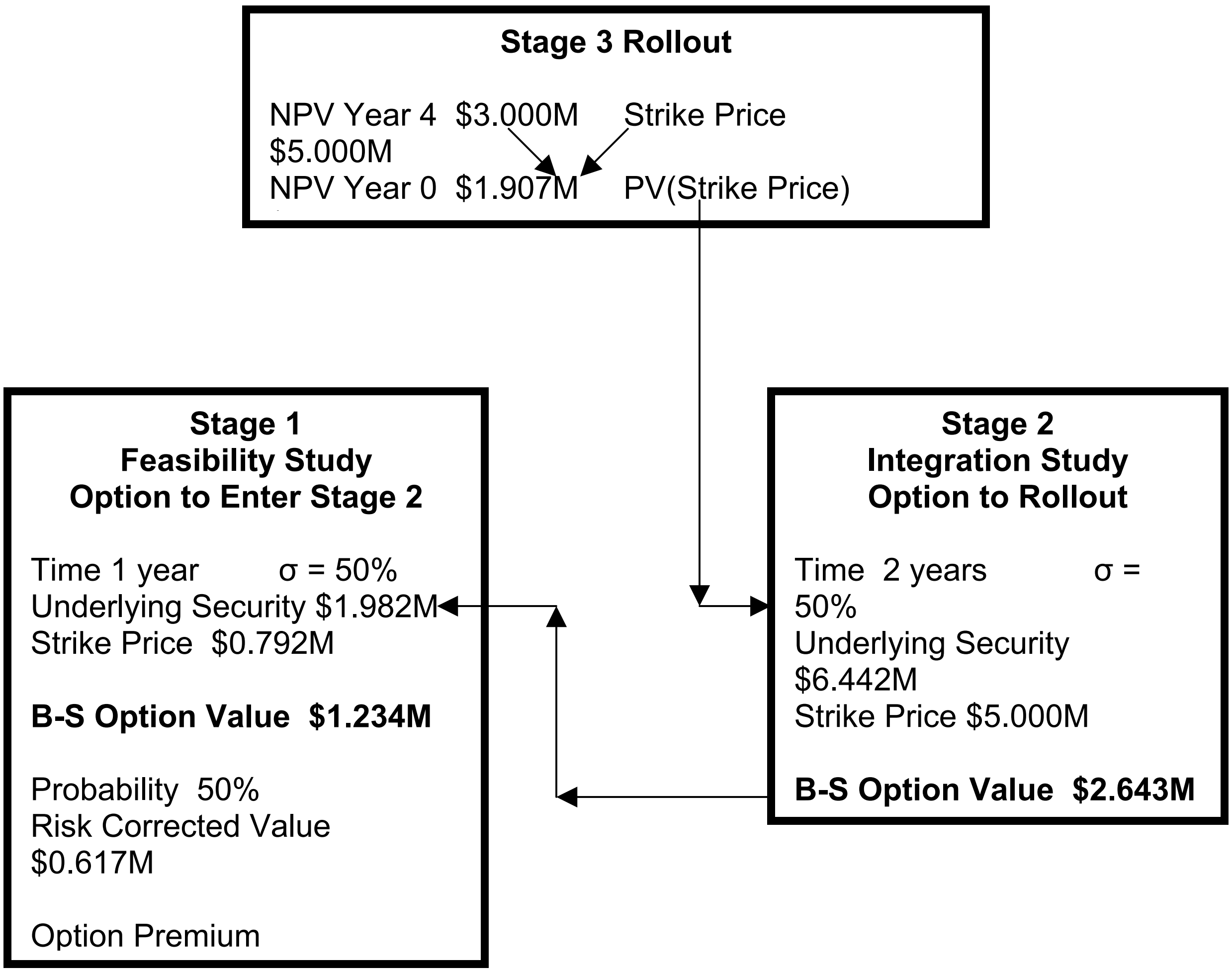

Figure 3. Project Outcome by Real Options Analysis – Zero Volatility. The dynamics are identical to Figure 2, with volatility set equal to zero. The result equals that of Figure 1.

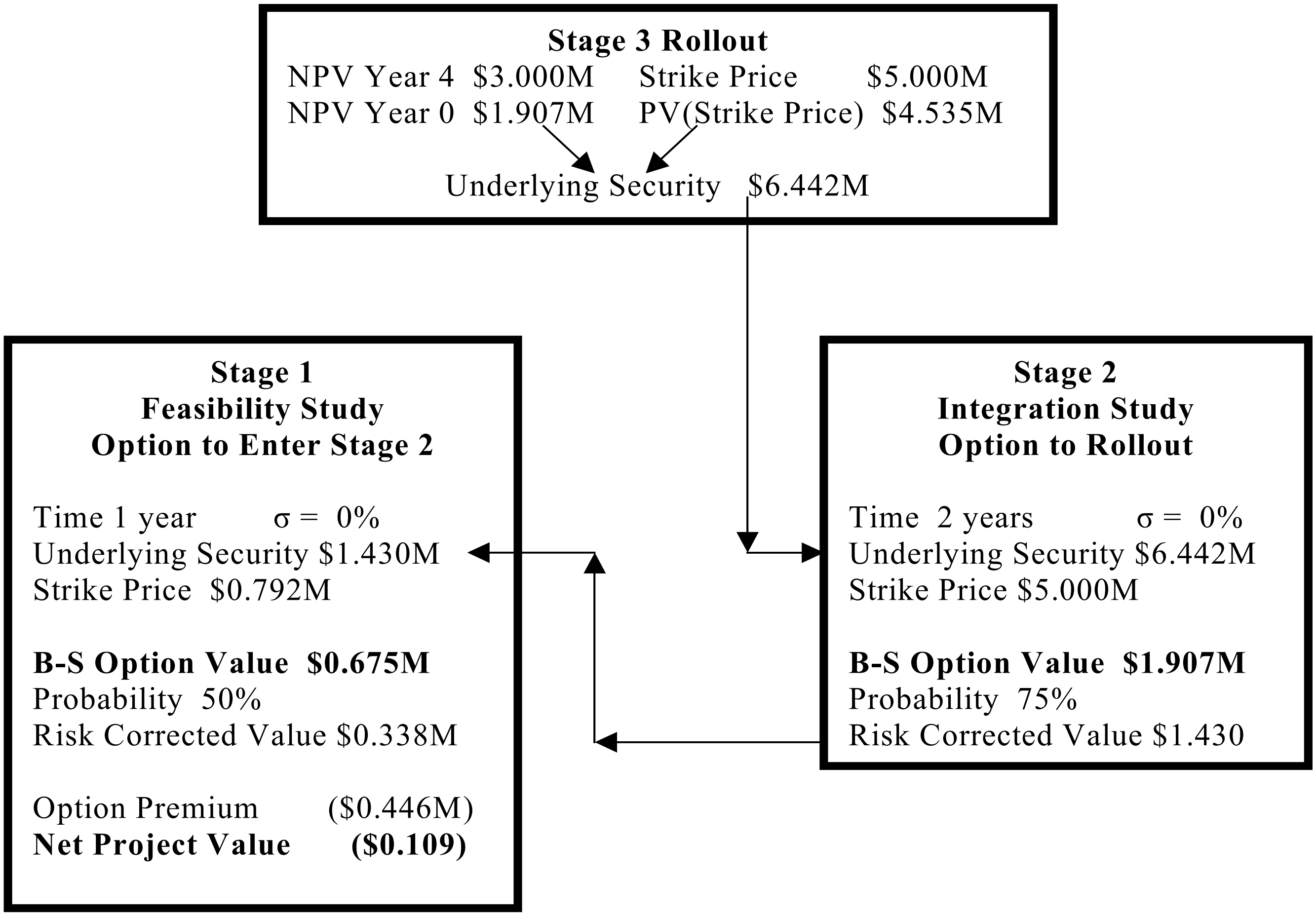

Figure 4. Integrated Valuation Model for an R&D Project. The top tier shows a sales forecast, capital requirements, and cost data for a proposed business, along with financial parameters. The second tier shows the R&D project estimates: cost, time and duration for each R&D stage. At the bottom left is the calculated initial investment and the value of the business plan using 5 possible assumptions about terminal value. At the bottom right is the current value of the project, and the value progression after each successful project stage.

Business and Financial Inputs			
Sales Forecast		***Price and Cost Information***	
Units Sold Yr 1 (millions)	**12**	**Sales Price/unit**	**$1.00**
Units Sold Yr 5	**48**	**Variable Cost/unit**	**$0.50**
Units Sold Yr 10	**100**	**Manufacturing Overhead/unit**	**$0.08**
Long- Term Growth Rate	**5.00%**	**Selling, Admin and R&D Expense**	**10.00%**
Capital Investment			
Initial Annual Capacity (M units)	**48**	***Financial Parameters***	
Initial Fixed Capital/unit	**$0.70**	**EBITDA Multiplier**	**7**
Incremental Fixed Capital/unit	**$0.50**	**Price-to-Earnings Ratio**	**12.5**
Asset Life (yrs)	**10**	**Risk-Free Rate**	**5.00%**
Working Capital		**Volatility**	**30.00%**
Days Inventory	**30**	**Tax Rate**	**35.00%**
Days Receivables	**36**	**Cost of Capital**	**12.00%**
Days Payables	**16**		

R&D Inputs			
Duration Stage 1 (yrs)	**2**	**Duration Stage 3 (yrs)**	**2**
Cost Stage 1($M)	**$0.75**	**Cost Stage 3 (M)**	**$3.00**
Probability of Success Stage 1	**33.33%**	**Probability of Success Stage 3**	**75.00%**
Duration Stage 2 (yrs)	**2**	**Duration Stage 4 (yrs)**	**2**
Cost Stage 2 ($M)	**$1.50**	**Cost Stage 4 ($M)**	**$6.00**
Probability of Success Stage 2	**50.00%**	**Probability of Success Stage 4**	**83.33%**
(Cumulative R&D Cost $M)	**$11.25**	**(Cumulative Probability of Success)**	**10.42%**

Pro Forma Business Plan Outputs ($M)		**Decision Tree(DT) and Real Options(RO) Outputs**	
Initial Investment	**$35.27**	**Current Project Value as Rifle Shot**	**($2.39)**
		Current Project Value by DT	**$1.86**
Net Present Value (NPV)		**Current Project Value by DTRO**	**$1.90**
Horizon Assumption	**NPV**	**Value Added by DT**	**$4.26**
Terminal Value = Working Capital	**$25.54**	**Value Added by RO**	**$0.04**
Terminal Value = Book Value	**$29.33**		
Terminal Value by EBITDA Ratio	**$84.14**	**Value Progression ($M)**	
Terminal Value by Price-to-Earnings Method	**$87.83**	**Current Value**	**$1.90**
Terminal Value by Free Cash Flow Growth Method	**$91.07**	**Value after Stage 1**	**$8.62**
		Value after Stage 2	**$18.84**
		Value after Stage 3	**$27.68**
Internal rate of return	**33.91%**	**Value after Stage 4**	**$91.07**