REAL OPTIONS ANALYSIS
The challenge and the opportunity

Ian Robinson*

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Abstract

This paper introduces and illustrates the techniques of real options analysis. The subject matter is highly relevant to the actuarial profession since real options analysis places great emphasis on:

- the measurement of value in times of high uncertainty,
- the recognition of the value inherent in management's ability to respond to the unwinding of uncertainty over time, and
- the sometimes counterintuitive way of thinking about value when the financial outcomes of uncertainty are non-linear.

The paper concludes that actuaries will benefit from becoming familiar with the techniques and that the Institute should ensure the new Finance syllabus includes material on real options analysis as well as generally expanding the coverage of project valuation and equity valuation.

* Ian N Robinson, FIA, FIAA, ASIA, CrusoeConsulting, Sydney, Australia. Email: crusoeconsulting@bigpond.com.

THE BELIEVERS

'… a business strategy is much more like a series of options than a series of static cash flows. Advances in both computing power and our understanding of option pricing … make it feasible now to begin analyzing business strategies as chains of real options.'—Luehrman, Harvard Business Review, 1998

'The greatest rewards go to those companies that can create new business models in the context of changing technological and demographic trends. Often times, risk reduction becomes a competitive imperative in response to uncertainty. An options approach, on the other hand, invokes a new perspective-profiting from uncertainty. It gives you a chance to be at the edge of the future.'— Ash Vasudevan, Director, CommerceNet Investment Initiatives

'Within ten years, real option analysis will supersede standard net present value techniques in the valuation of capital projects.'

'A revolution in decision making'

'Early on, academics saw how option-pricing models could be applied to a variety of non-financial or real assets. And they saw that the real options approach could be a bridge between finance and strategy. After all, both disciplines attempt to obtain the highest possible returns on risky assets.'—Journal of Business Strategy, May 1999

'By quantifying the fuzzy realm of strategic judgment, where leaps of faith govern decisions, Real Options analysis fosters the union of finance and strategy.'—CFO, November 1999

'The breakneck pace of change and elevated uncertainty demand new ways of strategic thinking and new tools for financial analysis. Real options are at the core of such a strategic and financial framework.'—Mauboussin, Credit Suisse First Boston

'With an options approach, uncertainty has the potential to be your friend not your enemy.'—Paul Greenberg, Consultant, Analysis Group/Economics, quoted in Businessweek, June 7, 1999

THE SCEPTICS

'46% of North American firms that experimented with real options analysis gave up, perhaps because it is too rarefied a concept.'—Bain survey quoted in FT.com, October 18, 2000

'Real options pricing may indeed open investors' minds to a new way of thinking about companies. So far, however, it appears to be more useful as a way of rationalizing pricing than as a way of predicting it.'—BW Online, December 31, 1999

'Investors do not accept it [real options] as a valid argument. They have a hard enough time believing net present value [based on discounted cash flow] let alone Black-Scholes option pricing models.'— Erling Refsum, Biotech Analyst at Nomura, in FT.com, January 19, 2001

'Bombed out shares are not the only casualties of the recent tech sell-off. Real option pricing, which once promised a revolution in valuing high-growth companies, has stalled. Most City analysts do not want to know and the models have been quietly abandoned by some of their former advocates.'—Dan Oakey, FT.com, January 19, 2001

'Real options analysis is just decision analysis dressed in new clothes.'

'Traditionally, natural-resources companies have been among the most enthusiastic experimenters with real options, primarily because they can link the future value of their assets to traded commodities, for which market information is readily available. However, even some of these companies have found it difficult to implement options-based valuation.'—Sumit Paul-Choudhury, CFO Europe, July 1999

CONTENTS

ABRIDGED VERSION

In the interests of space, this is the abridged version presented to the IAAust Biennial Convention 2003. The only difference between it and the full version is that the latter includes the reference list and all appendices.

While for the purposes of the Convention, this was not considered detrimental, interested readers can obtain the full version from the author.

1. INTRODUCTION

1.1 Background

> '**Virgin Blue flags $5.4bn spree to spread wings with long-range fleet**.
>
> Virgin Blue's expansion as the second domestic airline is to continue with its announcement of a $5.4 billion deal to buy as many as 50 new aircraft. While officials would not name specific routes or destinations for the new planes – the delivery of which could be staggered over eight years – the move represents a major expansion for Virgin, which plans to fly international this year.' SMH 17/1/03

This recent by-line seems to suggest that Virgin Blue has acquired a valuable right to purchase additional aircraft as new routes prove to be profitable or not. It would be interesting to know (but probably impossible to find out) how Virgin went about evaluating this right. But one thing seems clear: Virgin Blue understands the importance of the *timing* of capital investment decisions and the value of maintaining *flexibility* to expand their fleet if and when routes come on stream and traffic increases—and this is in essence what real options and real options analysis (ROA) is all about.

But before we delve too deeply into this subject, let's first review where the actuarial profession has come to in its understanding and use of options theory generally.

While perhaps a little slow at first, the actuarial profession has always shown an interest in the theory of option pricing from the time of ground-breaking work of Black-Scholes-Merton in the late 1970s. Of particular note (and relevance to real options) is the seminal research of North American actuaries into solving the long-standing problem of applying Monte Carlo simulation to the valuation of American options[1]. In addition, a number of other actuarial papers have explored the general aspects of option theory and considered its relevance to actuarial thought[2].

Over the years, there has also been a series of papers which put the theory to work in traditional as well as contemporary actuarial fields including superannuation plan design and funding, life insurance policy guarantees and reserving, general insurance pricing and reserving, balance sheet management, fair valuation of liabilities and, most recently, executive options[3]. The common denominator of that research was, naturally enough, its focus on an entity's liabilities, ie on the contractual options held by members, policyholders, shareholders, clients and employees—the ever-familiar turf of actuaries. While such options are clearly not 'financial options' of the traded type (whether on an exchange or 'over-the-counter'), neither are they real options.

'Real options', as the term is commonly used, refers to the *strategic* options held by a firm and embedded within a firm's own projects, assets and opportunities. All strategic decisions are investment decisions since strategy implementation always requires the allocation of scarce capital or human resources. None of the actuarial research referred to has addressed this specific application of options theory even though it has been an area of intense international research (especially in the last few years) and, while slow at first, finding new application in a widening range of businesses.

Nonetheless, it has not been all quiet for the profession.

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[1] Professor Phelim Boyle of the University of Waterloo has authored numerous papers in finance and actuarial science literature including on options theory. He was the first to suggest that Monte Carlo simulation could be used to price options (see Boyle (1977)) and continues to be at the forefront of research in this area. See, for example, Boyle et al (2002). Also Tilley (1993) is acknowledged as being the first serious attempt at pricing American options using Monte Carlo simulation.

[2] See, for example, Blake (1989), Kemp (1997) and Smith (1996) in the UK; Sherris (1989) in Australia; as well as papers presented to the North American Actuarial Journal (NAAJ) of the Society of Actuaries and the International AFIR Colloquia (especially up to 1996).

[3] See, for example, Babbel et al (2002), Barker (1989), Britt (1991), Brookes et al (1989), Carrett and Wong (2002), Corby (1977), Munns (1993), Sherris (1994), Taylor (1989), Wilkie (1987) and Yang (1993).

ROA was introduced by the author to the Australian profession at a workshop of the 2001 Convention. However, while some occasional interest had subsequently been expressed by some actuaries and despite the occasional brief article both here and overseas[4] as well as a few other fleeting references to ROA as having potential application for the profession[5], ROA did not seem to gather any momentum within the profession. Interestingly Australian actuarial examiners have been less timid: there has been a major question on real options in each of the Finance subject examinations of the Institute for the last two years (see section 11.4).

In contrast, there have been at least three professional papers or presentations in North America which have considered some problems from a real options perspective: financial planning, property insurance, and the value of strategic plans of a life company[6].

Looking more broadly at the financial services and investment industry level in Australia, things have seemingly progressed little further. For example, McDonald (1989) hinted to members of the Securities Institute of Australia (SIA) about the possibility for options techniques to be applied to resource company valuation, and Marriott (1996) was the first to write a full article on ROA valuation for the SIA's professional journal, JASSA.

1.2 Purpose

Perhaps the apparent inertia of interest in ROA simply reflects a conclusion by actuaries that there is little opportunity for application of the techniques to the fields where actuaries are used to working. This presumes that actuaries have sufficient understanding of ROA concepts and techniques to form such a judgement. The author believes not.

The purpose of this paper is therefore to start the process of bridging the education gap for the actuarial profession in Australia and, hopefully, this will lead to new applications. With the profession ever more seeking to work in wider fields, the opportunities where ROA could be applied should increase—likewise the need for actuaries to demonstrate they are equipped to take on the new tasks offering.

The author believes a paper on ROA is entirely appropriate for a convention which carries the theme 'Shaping the future in a world of uncertainty'[7] as it places great emphasis on:

- the measurement of value in times of high uncertainty,
- the recognition of the value inherent in management's ability to respond to the unwinding of uncertainty over time, and
- the sometimes counterintuitive way of thinking about value when the financial outcomes of uncertainty are non-linear.

1.3 Structure and scope of paper

After this introductory section, section 2 of the paper explains the nature of real options and compares them with financial options. A couple of examples are included to portray how ROA is being actively used in major Australian businesses. In section 3, by means of a very basic numerical illustration, the paper draws out the key technical differences between real options valuation and other more familiar methods. Section 4 then considers the roles played by other techniques, such as sensitivity testing, in real

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[4] See Board 2001, Robinson (2001) and Shaw (2000)

[5] See, for example, Carrett and Stitt (2001,p12), McClean (2001), Mehta (1996, p29) and Sherris (1989)—the latter making perhaps the first reference to real options in actuarial literature, at least in Australia.

[6] See Daily (1998), Butsic (2001) and Sinha (2002) respectively. A paper by Childs et al. (2002), while not written by actuaries, is nonetheless well within the domain of actuarial interest as it considers the optimal switching decision for an employee choosing between a defined benefit or defined contribution superannuation plan.

[7] This is a virtual continuation of the 2001 Convention theme: 'Beyond uncertainty: managing the future better' and echoes the motto for the Institute: 'Certainty out of Uncertainty',

option valuation, and seeks to counter those who would suggest that such techniques are sufficient in their own right to dispel the need for ROA.

In section 5 the paper also deals with a concern often raised, namely the theoretical foundation for applying options pricing to assets distant from liquid markets. Section 6 then considers how one goes about the modelling of uncertainty in ROA making sure to distinguish between external market factors and factors internal to the firm, before providing a more realistic worked example in section 7 which makes use of some of the ideas presented earlier.

The paper then takes a forward-looking perspective beginning in section 8 with comment of when one should consider ROA, discussion in section 9 of the types of problems actuaries might encounter where ROA could be deployed, and some warnings in section 10 about the 'sell' job required for ROA. The paper concludes in section 11 with a proposition of what ROA has to offer beyond being a technical tool and discusses next steps. Section 12 provides a comprehensive list of references used by the author. A number of appendices have been included to provide additional resources.

1.4 Do not expect a 'cookbook'

Many readers may be disappointed to find that the paper provides little in the way of worked examples illustrating how to value real options (although sufficient background material and references have been provided to get started). The paper deliberately avoided becoming a valuation 'cook book' with these two thoughts uppermost in the author's mind:

(a) It has been suggested by Amram and Kulatilaka (1999b) (and others) that the rate of adoption of ROA over the years since its introduction has been slower than expected because of an over-focus by practitioners on technical aspects while neglecting the espousal of ROA as more about 'a way of thinking'.[8] They provide little useful coverage of the techniques but place significant emphasis on ROA as a tool for framing and thinking about problems. As a contemporary view formed with the benefit of hindsight, the author believes this is not unreasonable and will come back to it in section 11.

While it might be tempting for actuaries to focus on the methods and techniques, ROA involves much more than merely a mechanical application of a set of valuation techniques. It should be no surprise to actuaries to learn that, to be truly effective, ROA should be applied within a rigorous framework of information gathering, data capture and analysis, model building and assumption setting, through to report writing and communication—a topic again touched on in section 7.4.

Management gain most from ROA when the adviser can show how real options can be created, nurtured and harvested. This is normal professional practice.

(b) Detailed explanations of the variety of methods for solving the complex array of real options problems found in practice, while generally not difficult to grasp, require significantly more space than allowed for in a paper of this type[9].

The author is sure that actuaries would have no trouble coming to grips with what is largely is a mechanical application of well understood option valuation techniques to a different arena[10]. We

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[8] We also acknowledge the results of a management consultant survey (quoted in *The Economist*, 22 April 2000) which apparently found, inter alia, that 46% of North American firms gave up 'experimenting' with real options analysis. While first suggesting the reason was that it was considered 'too rarefied a concept', it was subsequently learnt on follow-up that executives were 'too busy making sense of the new economy and the implications of the Internet to have time for these tools' (including other fads).

[9] Interested readers should refer, for example, to Copeland and Antikarov (2001) and Mun (2002) for comprehensive worked examples. If the reader is interested in the stochastic calculus of real options, apart from works by Lenos Trigeorgis (probably the modern 'godfather' of real options research), or the research papers listed at, for example, www.realoptions.org or www.puc-rio.br/marco.ind, one could refer to the widely cited Dixit and Pindyck (1994) for a comprehensive coverage or earlier research.

think though there is more to gain at this point by focussing on those practical and theoretical areas where concerns, misunderstandings or even controversy may arise.

While the paper does not over focus on the specifics of ROA valuation techniques, it includes a couple of illustrations since they can go a long way in drawing out the differences and highlighting the strengths compared to the alternatives actuaries are more familiar with.

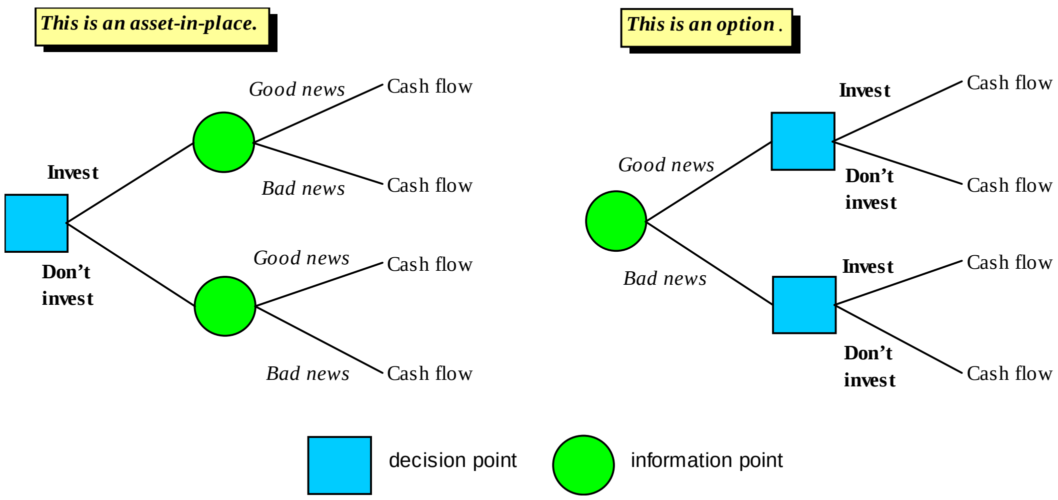
2. WHAT ARE REAL OPTIONS?

2.1 The basic concept

The origin of the term 'real option' has been attributed to Myers (1977) who first identified the fact that many corporate real assets can be viewed as call or put options[11]. A non-rigorous definition might be:

> *A real option is the right, but not the obligation, to acquire, expand, contract, abandon or switch some or all of an economic asset on fixed terms on or before the time the opportunity ceases to be available.*

Let us consider this idea a little more closely. Refer to the figure below.



Most investment decisions are treated analytically as if they were all-or-nothing (and irreversible) decisions, ie the decision whether to invest is made on the information available now. This ignores the reality that management generally has the flexibility to postpone its investment decision (ie a decision whether to 'exercise' the option) until new information comes to hand ('good news' or 'bad news'). The new information resolves or reduces the uncertainty sufficient to make a more reliable decision, ie management has a real option.

A real option is simply therefore an option held by a firm over an economic asset. The option may be clearly specified in a contract or, the more usual situation, have little in the way of formal structure. The asset may be owned already or under consideration for acquisition.

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[10] Copeland and Antikarov (2001) point out (p23) that the tools required to take full advantage of ROA are now available to all: more than sufficient personal computer power and capacity; lattice tree techniques are transparent and have largely supplanted stochastic calculus; methods for dealing with a wide range of complex real option problems are well-established.

[11] Brach (2003, Chp1) provides an interesting history of real options and of options generally.

Real options may arise naturally when firms are considering for example new plants, joint ventures, licensing agreements, and mineral exploration, or may be pro-actively created by management as part of a dynamic strategy program.

There are virtually endless manifestations of real options across all types of businesses, for example (the first two are classical examples often cited):

- a gold mine operator considering what gold price it makes economic sense to close the mine and at what price to reopen it;
- a pharmaceutical firm making staged commitments to the R&D of the a major new drug over a long period from its idea through to research, development, trialing, legal approval, production, and finally marketing;
- an energy company considering the optimum times to switch to and from different forms of energy production;
- a financial services provider considering an alliance with a distributor which requires significant capital commitments but the possibility of new growth opportunities;
- a government considering timber concessions for an old-growth forest in terms of both timber value and amenity value (wildlife habitat, flood control and visitation)[12]; and
- a government reviewing the optimal time to allow development of urban fringe in terms of the significant capital outlays required as well as the social and environmental impacts.

2.2 Decisions, decisions

The traditional investment decision rule is usually expressed as:

Invest now if $NPV_{NOW} > 0$

NPV_{NOW} refers to the net present value of full investment now after allowing for the cost of acquiring the investment[13].

The rule could be expressed in words as: 'Invest if the present value of expected cash flows is greater than the cost of acquiring the investment; otherwise abandon the investment.'

NPV uses a RADR (risk-adjusted discount rate) based on the expected return on marketable securities with similar risk to that of the underlying cash flows of the asset being valued—the 'opportunity cost of capital'. In practice, a suitable RADR would be determined exogenously, perhaps using CAPM or some hybrid. Importantly the RADR should, according for MPT (modern portfolio theory), allow only for *non-diversifiable market risk* (plus perhaps a margin to allow for non-tradeability of the asset). It should *not* allow for the technical or private risks associated with the asset or project which can be better handled with explicit probabilities[14].

But there is a problem with this rule—one that is generally overlooked or perhaps only acknowledged in an informal sense. Dixit and Pindyck (1994, p135) reconfirm earlier research which has shown that:

> 'This rule is incorrect because it ignores the opportunity cost of making a commitment now, and thereby giving up the option of waiting for new information…[T]hat opportunity cost must be included as part of the total cost of investing.'

A reformulation of the traditional rule to allow for opportunity cost would therefore be:

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[12] This is a major issue for the Brazilian Government, the Amazon Basin and the planet. See Rocha (2001).

[13] In the rules that follow, NPV is net of the investment cost of acquiring the asset, or option ('option premium'), or of exercising the option ('exercise price'). It is also assumed that cash flows to be discounted are positive.

[14] See section 6.6 for further comment on this matter

$$\text{Invest now if } NPV_{NOW} > \max(NPV_{DEFER}, 0)$$

$$\text{Defer investment if } NPV_{DEFER} > \max(NPV_{NOW}, 0)$$

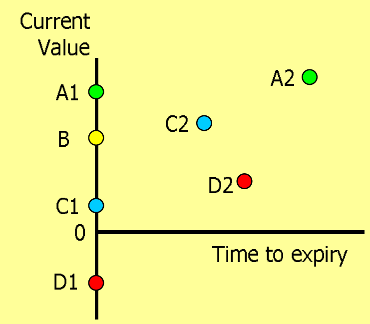
NPV_{DEFER} refers to the net value of the option to postpone investment until uncertainty is sufficiently resolved or the opportunity is due to expire[15].

The new rule could be expressed in words as: 'Invest today if the net present value (after allowing for the cost of investment) is high enough to compensate for giving up the option to wait for more information; otherwise defer (or abandon) investment.' This is equivalent to viewing the investment as a single American option with a right to exercise now or continue to hold.

The new rule could also be expressed in the equivalent form: 'Defer investment if the net present value of waiting is higher than investing now.' This version confirms the 'truism' that, even an asset or project with negative net present value can be valuable so long as managers can postpone investment until conditions are more favourable.

The extra value that the deferral option provides for (after allowing for the cost of acquiring it) is $NPV_{DEFER} - NPV_{NOW}$. One could view this as the value of flexibility that deferral gives or, alternatively, the value of information which resolves uncertainty during deferral[16]. Actually, managers have always known about this rule, if only in an intuitive or informal sense.[17]

Readers might observe that one could view investment timing decisions as no more than investment alternatives to be considered alongside other distinct investment alternatives under consideration which are competing for the same limited resources of the firm—see side-bar. While this is correct, even if there were no other alternative investments under consideration, an opportunity to invest now always includes an option to defer the decision[18]. Further, most quantitative analysis by management ignores or pays at best only informal regard to the 'shadow' time dimension that is embedded in all investment decisions. Of course whether the actual value of deferral is material or not depends, amongst other things, upon the balance between the value that new information can bring to the investment decision, the risk of pre-emption by competitors, and any foregone cashflows[19].



Investment alternatives A1, B, C1 and D1 are all 'now' decisions, each of which (except for B) have deferral alternatives. While D1 has negative value and should be rejected immediately, its deferral alternative (D2) has positivevalue which is even greater than C1. If capital resources were sufficient, and assuming each project was of similar scale, we would choose (in order), A2, C2, B, D2.

One of the major aims and benefits of ROA is therefore to encourage management to shift from a one-dimensional approach of analysis which focuses largely on the value of investing now, to a two-dimensional approach which incorporates both analytical and strategic consideration of the time value of waiting.

Further, Trigeorgis (1993b) emphasises that 'expanded NPV', as he calls it, is more than just a matter of timing an investment decision in reaction to unfolding events; it also embodies

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[15] Note that NPV_{DEFER} could be less than zero after deducting the *cost* of acquiring the deferral option from the *value* of it (which must be at least zero).

[16] Using option terminology, this could be thought of as 'time value' where the 'intrinsic value' is NPV_{NOW}. In option theory, time value must always be greater than zero. It follows that, if valued correctly, actions that create options should be value accretive. Likewise, an action which exercises an option 'kills' the option and crystallises its value by transferring it from the option to the underlying asset.

[17] Section 10.4 provides further commentary on the informal methods commonly used by management.

[18] A proposal of marriage provides a social analogue: Even if the proposer had no other 'prospects' in mind, they would still have the option to defer proposing until they were felt surer of their decision (and perhaps the likelihood of acceptance!)

[19] See section 8 for further comment on these aspects.

management's *flexibility* to both reactively and proactively alter its operating strategy (eg defer, expand, contract, abandon a project) in order to adapt to unfolding events and capitalise on favourable future opportunities or to mitigate losses:

> 'Management's flexibility to adapt its future actions in response to altered future market conditions expands an investment opportunity's value by [actively] improving its upside potential while limiting downside losses relative to management's initial expectations under passive management.'

To round out the point, Trigeorgis expresses (p203) the formulation of NPV_{DEFER} in these terms:

> Expanded (strategic) NPV = static (passive) NPV of expected cash flows + value of options from active management

As we shall see, the actual valuation techniques underlying ROA are based on the observation that a company evaluating an existing asset or potential investment is in much the same position as the holder of a financial option, such as those written on shares, bonds or commodity prices. The holder of a financial call option on, say, the price of gold can exercise that option if the price rises above a pre-agreed level, but does not have to if the price falls. Similarly, the owner of a gold mine may have a licence to begin mining, but is not obliged to do so, if explorative tests prove favourable over the next three months and the price of gold is attractive at the time.

2.3 Comparison with financial options

After consideration of the definition in section 2.1, it would be easy for one to form the view that real options are little different from exchange traded financial options. In terms of the generic character of their respective payoffs, they are indeed very similar and that is the reason why financial options valuation techniques, already well researched and accepted, are readily extendible to the valuation of real options. But there are significant differences as highlighted in Table 1 and Table 2:

Table 1

STRUCTURAL DIFFERENCES BETWEEN FINANCIAL AND REAL OPTIONS

Description	Financial Options	Real Options
History	Have been traded for several decades	Have always existed if not recognised as such Techniques to identify and value them are a recent development (post-financial options)
Complexity	Simple to exotic contractual forms	Often very exotic forms including compound options, ie options on options
Underlying asset	Usually shares or bonds which themselves are securitised claims on other assets.	Economic asset (or project) generating free cash flows Unique to firm and usually not well defined
Terms	Months (or a few years in some forms). Fixed exercise prices and expiry dates. Exercise can be implemented with delay. Transaction costs simple.	Can be months but most usually years to many years (perhaps even unlimited) Usually not one certain date when option opportunity is extinguished. Cost of exercise may be stochastic. Exercise may take time risking missing the opportunity. Transaction costs may take different forms.
Tradeability	Very liquid markets (except OTC options) Historical market prices are observable	Little or no liquidity. All situations are different. No observed market price history (of identical asset)
Values involved	Units in thousands or perhaps millions of dollars	Millions to billions of dollars

STRUCTURAL DIFFERENCES BETWEEN FINANCIAL AND REAL OPTIONS		
Description	**Financial Options**	**Real Options**
Pricing posture	Generally price takers, ie very limited scope for participants to influence options prices	A firm can directly influence at least the economic or fundamental value of real options it holds (although market information is required to price them). Competition and market demand can drive the value of real options

Table 2

VALUATION DIFFERENCES BETWEEN FINANCIAL AND REAL OPTIONS		
Description	**Financial Options**	**Real Options**
Type of valuation	Market value	Economic value
Model complexity	From very simple to exotic Can usually be solved or estimated by closed formulae	Most often complex to very complex Closed formulae may be possible but the binomial tree or Monte Carlo simulation are more likely to be utilised, either in a spreadsheet or specialised software
Estimating valuation parameters	Option parameters are readily observable, except for volatility which can be measured from historical data or deduced from current market prices of similar options	Most option parameters are more difficult to observe or estimate, especially volatility (see section 6.4.1)
Dimensions of uncertainty	Market	Public and private (see section 6.1)
Importance of 'greeks' (delta, gamma, theta, vega, etc)	Fundamental to understanding and managing the risks associated with portfolios of options	May be calculated but more likely to use standard sensitivity tests of key variables (see section 4.2)
Precision of valuation	High (theoretical) precision possible	Much less confidence about numbers

As de Ruiter and Janssen (1996) note, real options always need to be seen in the larger context of the firm, its business objectives and its strategic plans, whereas financial options are better seen as instruments to manage or hedge a firm's specific asset and liability risks. Real options are about creating real assets and optimising their net cash flow stream potentials; financial options are about managing the market risks associated with the prices of assets and liabilities.

2.4 Where is ROA being used?

Most articles and books on real options originate from the US. It should not be surprising that the examples of real options that are cited (and there is no shortage of them!) are quoted from that economy. ROA is a well accepted methodology in pharmaceutical and biotech industry, petroleum companies, telecommunications industry, energy suppliers, and oil or coal exploration—high risk industries with multi-million dollar budgets and payoffs perhaps many years distant. For similar reasons ROA is now finding favour, at least in the US, in an increasing number of areas such as the airline industry and IT project assessment[20].

So is this just all 'American pie'?—another passing fad? The author believes not, although we are undoubtedly some way from the critical mass required for its general acceptance, particularly in the Australian situation. Nonetheless there are some signs of a local groundswell as testified by the experiences of two major Australian businesses when applying ROA[21].

[20] See, for example, Tallon et al (2001) for the transcript of a recent conference debate amongst IT professionals.

[21] Readers may want to review these storylines again after reading through the whole paper.

BHP Billiton

BHP Billiton (BHPB) has been making concerted efforts to develop better ways to value technology and R&D investment since about 1994. ROA is the latest significant enhancement (added around the year 2000) to the wide variety of valuation tools that they use.

Many projects within the BHPB Technology and R&D portfolio are associated with substantial capital budgets and rewards, long lead times and multi-staged investments, and significant uncertainty and risk. Before the introduction of ROA, management often found that technology and R&D investment proposals, because of a suspected undervaluation bias when applying traditional DCF, were sometimes losing out to other shorter-term investments with more obvious paybacks. Management understood that traditional DCF ignored the ability of a well-managed R&D project to change direction through the course of the project as new information came to hand and as general circumstances changed. They were therefore very motivated by a desire to simply put technology and R&D projects on the same economic evaluation playing field as other projects.

Since then, BHPB has been exposed to and has adopted ROA process enhancements from the US. Further development of the ROA technique has occurred by way of 'educated trial and error' on projects, all supported by continual self-education.

BHPB uses spreadsheets as the basis for all technological-financial modelling; however, when probabilistic evaluation techniques such as Monte Carlo and Decision Tree Analysis are applied, these spreadsheets are complemented by other specialised software tools.

BHPB believes that one of the most important and often-difficult tasks in ROA is framing the problem correctly and being consistent with key stakeholder requirements. Some of the other difficulties encountered over the period of its introduction include:

- separating the strategic high level decisions from the lower level tactical decisions;
- understanding the order and timing of these strategic decisions;
- identifying the key risks and uncertainties;
- building models capable of dealing with complex dependencies;
- management with strong biases, or existing, value-destroying projects (and the risk that these may get in the way of the sound commercial decision); and
- communicating the methodology and results to senior management.

With experience and repeated exposure, many of these hurdles have been largely overcome. Even so, while real options thinking is now prevalent within technology management thinking and behaviour, other issues such as environment, community, safety, health, fit with corporate strategy, and capital availability remain highly relevant to the final decision.

Academic, research and consulting communities have been working hard for many years (mainly in the US) on developing ROA as a useful tool and discipline. BHP Billiton believes ROA's time is coming as it sees a significant ROA ground swell occurring within many of its businesses, and externally, with indications that people understand and recognise the benefits associated with ROA. While the difficulties of implementation referred to above are recognised, they are being dealt with. However, BHPB emphasises a significant commitment of time and resources is required if a serious attempt at implementation is to be pursued. For this reason, growth might not be as fast or as widespread as businesses might otherwise expect or hope.

CS Energy

CS Energy has several major risk factors outside their ability to control or manage through contracts including gas volumes, gas prices, electricity market prices, carbon trading mechanisms, and the ever-present potential for new competitors to enter their market.

After reviewing contemporary economic valuation literature, CS Energy felt that ROA may provide an effective way to analyse and better understand the interactive dynamics of such variables on its business.

With the assistance of consultants, CS Energy developed a proprietary software solution in conjunction with comprehensive spreadsheet modelling of assumptions. In fact the setting of assumptions and probabilities was probably the greatest difficulty confronted. Existing modelling practices were stretched due to limited availability of data and market experience.

The ROA analysis was part of a total project and strategy review to construct a 385MW gas fired power station worth about $280 million. The evaluation highlighted areas of major significance that CS Energy needed to focus on. It provided more comfort to projected outcomes, highlighted target areas for further strategic attention, and enabled them to rule out or minimise from further consideration a number of areas that had previously caused concern but which did not have the impact.

CS Energy feels that ROA clarified major issues, help focus subsequent project finalisation efforts, and gave 'comfort' that there were reasonable probabilities of a suitable range of outcomes. Even so, ROA was initially a difficult proposition to 'sell' to colleagues because of its newness. This was overcome with external help.

The experience for CS Energy has generally been positive and they would use ROA again, particularly if there were multiple sources of risk with consequential outcomes that were difficult to contract or manage away. They believe ROA has much to commend it notwithstanding the apparent lack of exposure and usage it seems to be getting in Australia. CS Energy believes that for the inherently more complex ROA approach to find more general usage and acceptance by businesses, the key will be education and communication—both of which will take time and effort by consultants and businesses users.

2.5 Taxonomy of real options

Real options exist everywhere and in all businesses. Nonetheless they can be difficult to identify. A labelling system which seeks to categorise real options can help both to identify them and understand their general characteristics. All writers on real options attempt to categorise real options using one label or another but there is little consistency. What is often not stated is that many if not most real options have features which span a number of categories.

Table 3 (next page) provides a summary and description of the wide range of forms that real options can take. Only one or two of them will be referred to in this paper. The books and a number of the articles cited in the reference list fully explore their option characteristics and the techniques for valuing them.

Up till now, we have considered a number of the qualitative aspects of real options and ROA. The next part of the paper begins to consider the fundamental quantitative aspects of ROA and how they modify and extend the more familiar traditional method of DCF.

Table 3

Form	Description	Intrinsic option form
Waiting, Deferral	Passive options which allow a firm to postpone the decision to commit to investment until sufficient new market information becomes available, ie reserving the right to play as events unfold, eg acquiring a speculative property in anticipation of changes in redevelopment regulations. Note these options do not necessarily come without some cost as the firm may need to maintain access to market information or hold a licence. The danger with this form of option is that a firm does not generally have an exclusive right to exercise the option – refer to section 6.7. (aka 'wait-and see', 'no-regrets', 'learning by being a spectator')	Call (new assets)
Learning	*Pro-active* options which allow a firm to make phased or staged investments to resolve *technical* uncertainty, eg R&D activity of pharmaceutical companies; mineral or oil exploration. (aka 'learning by investing')	Sequential compound¥ call options (new assets)
Growth	Allow a firm to open up potentially significant new down-stream opportunities. (aka 'staircase' or 'platform' options)	Sequential compound¥ call options
Expand	***Scale up*** Allow a firm to make follow-up investments in same asset/project if successful outcomes are achieved. Increase the capacity as demand comes on stream or market share grows, eg M&A activity in the financial services industry ***Scope up*** Allow a firm to extend its core competencies into new products or services, eg Amazon.com started with books and subsequently extended its scope into CDs, videos and other lines eg new distribution channels or markets	Call (on assets-in-place)
Contract, shrink	***Scale back*** Shrink or shut down a project part way through if new information changes the expected payoffs negatively. ***Scope down*** Allow a firm to curtail investment, perhaps by selling off part of the asset for a fixed price. Limit the scope of (or abandon) operations in a related area when there is no further potential in a business opportunity Sub-forms: (a) 'exit-and-reenter' an industry, product or market, (b) 'stop-start', ie shutdown or mothball an operation or product until more favourable circumstances return.	Put (on assets-in-place)
Abandon, Exit	Allow a firm, once a pre-defined barrier has been triggered, to seek completely new alternative uses of capital, perhaps only obtaining salvage value for the existing asset or project.	Put (on assets-in-place)
Switching	Allow a firm, for a fixed cost, to vary or suspend its inputs (supplier flexibility), outputs (product flexibility) or production methods (process flexibility) in response to changes in prices or demand eg coal or gas power source; farms changing crops. Alternatively they allow a firm to usemore cost-effective and flexible assets as new information is obtained.	Call + Put (on assets-in-place)

¥ Compound options (aka 'downstream options') are contingent on exercising earlier options eg phased investments, RandD. They come in two forms: (a) 'simultaneous compound options' where the underlying option and the option on it are alive simultaneously, eg a call option on the listed equity of a firm (see Munns (1993)), and (b) 'sequential compound options' where the underlying option is created when the option on it is exercised, eg phased investments of a learning option.

Another term often used is 'rainbow option' which is not so much a type of real option but rather refers to any real option which its value is contingent upon multiple and significant sources of uncorrelated stochastic uncertainty and which require separate modelling).

(Table partially based on a general classifications by Trigeorgis (1996))

3. A SIMPLE ILLUSTRATION

3.1 The situation

Let us now consider a simple example[22] of valuing a ‘waiting option’. We aim to illustrate the essence of the valuation technique of ROA, specifically:

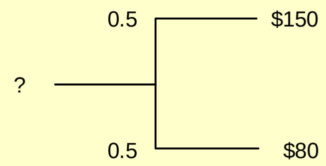
(a) the similarity with financial option valuation, at least at a fundamental level;

(b) how it extends traditional DCF valuation techniques into areas where actuaries are perhaps less familiar with; and, importantly

(c) how traditional methods of valuation fail to calculate the value of management flexibility correctly.

We have the choice of investing \$95 now to produce Widgets with an uncertain cashflow stream with an annual average of either \$15pa or \$8pa (with equal probability) commencing at the end of the *second* year[23], or, for a fee of \$10, the right to wait a year when the outcome will be certain but the investment required at that time will be \$100[24]—analogous to a simple European call option.

	Now	One year
Choice 1:	\$95	
Choice 2:	\$10	\$100



We also assume the firm’s RADR (risk-adjusted discount rate) suitable for valuation of the cash flow stream *after* they have commenced is 10%pa[25]. The NPV @10% of the annual cash flows in one year’s time is therefore calculated as \$150 and \$80. The risk-free rate is 5%pa, and we ignore tax.

How should we proceed?

In addition to the information above, we also know from observation of market traded securities that we can construct a synthetic security with payoffs and risk which are perfectly correlated with the cashflows of the asset (although at 1/5th the size: \$30 and \$16) and which has a market price of \$20. From the data we can also discern that the equivalent RADR of the synthetic security *before* the cash flow streams have commenced is given by:

$$= (0.5 \times 30 + 0.5 \times 16) / 20 - 1$$

$$= 15\%$$

3.2 Traditional DCF approach

The traditional DCF method assumes one commits now, ie that the decision is all-or-nothing based on what is known now[26].

The NPVs of the alternatives are:

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[22] Based loosely on an example by Copeland and Antikarov (2001).

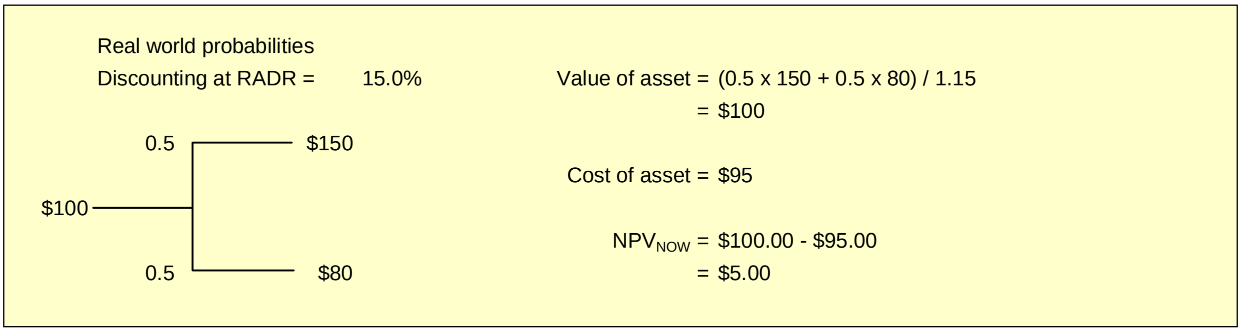
[23] This avoids the slightly complicating element of value leakage during the option period.

[24] Note also that the proposed investments of \$95 or \$100 are not the *value* of the investments (which is to be derived), but rather the *cost* or *exercise price* of the investments, ie what the ‘seller’ agrees now is appropriate payment at the time.

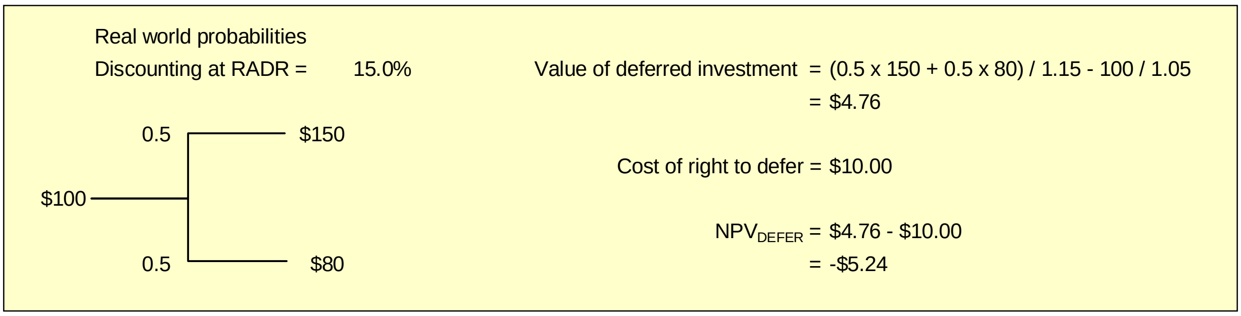
[25] See comments in section 2.2 regarding the selection of the RADR.

[26] Readers may view the DCF solution proposed as naive given we know in advance that investment would not proceed if the value reduced to \$80. Remember though that the illustration is meant to be an analogue for what valuers (including actuaries) typically do in practice, namely value the expectation or ‘best estimate’ of a continuous spectrum of possibilities, without any regard to how later decisions, in response to unfolding events, will limit the downside risk.

Invest now



Defer decision to invest



In this example, the *value* of the deferred investment is less than the *cost* of acquiring the right to defer (ie $NPV_{DEFER} < 0$). So it seems, based on this analysis[27], the value of flexibility to defer investment is:

$$= NPV_{DEFER} - NPV_{NOW}$$
$$= -5.24 - 5.00$$
$$= -10.24$$

According to both the traditional and revised investment rule, one should invest now ($NPV_{NOW} > 0$). Deferring investment appears unattractive.

But this cannot be right. Why? Flexibility cannot have negative value or, to put it another way, information which resolves uncertainty and which can reduce the likelihood of a poor investment decision must always have positive value. For example, market research is always worth undertaking up until the point when the benefit of the additional information gained equals the marginal cost (or opportunity cost) of acquiring it.

As we shall see, both DTA and ROA correct this particular weakness in traditional DCF.

3.3 Decision tree analysis (DTA)

DTA was originally developed as a way to map decisions and their uncertain consequences against (most often) subjective probabilities—see section 4.4 for further background.

DTA, when applied to real options, attempts to be more rational than traditional DCF by anticipating that, on deferral, the investment described earlier would only take place if the known outcome were $150, ie DTA attempts to incorporate management flexibility as the temporal uncertainty is resolved. The calculation therefore anticipates that no investment would be made if the NPV at the time of the decision were negative.

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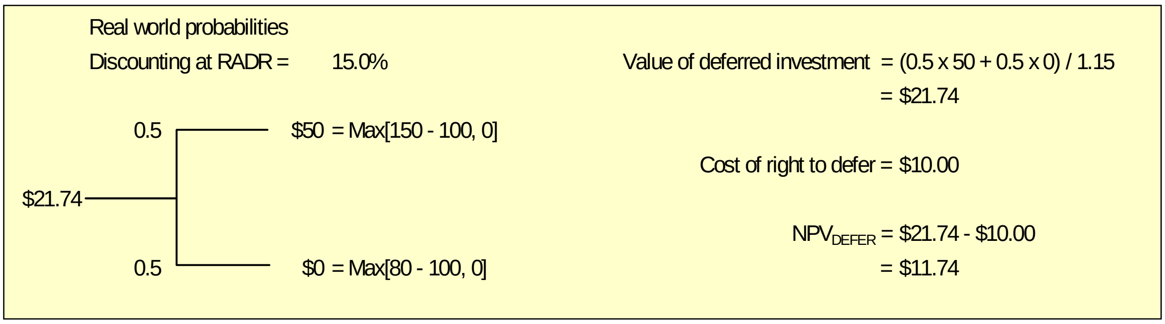
[27] Note that the cost of the investment is discounted at 5% because there is no market uncertainty associated with it.



Under a DTA approach, already the value of the deferral option is shown to be *greater* than the cost of acquiring the deferral option ($NPV_{DEFER} > 0$), and the additional value of flexibility to defer investment is now:

$$= 11.74 - 5.00$$

$$= 6.74$$

According to the revised investment rule, management flexibility has positive value and one should—*contrary to the DCF analysis*—delay investment for a year ($NPV_{DEFER} > NPV_{NOW}$). Note that this does not mean that investment *should* take place in a year but merely on the information available now, the optimum decision would be to defer the irreversible decision for one year. It is quite possible that ultimately the investment will still not be made.

Note that if we were to attempt to achieve the same result using traditional DCF, we would have needed to artificially (ie without any objective basis) reduce the RADR to -1.7% [28]. (Could the reader explain *that* to management?!)

But as many ROA writers point out, while DTA is a more logical approach and an improvement over traditional DCF, it is fundamentally flawed in one key aspect: the RADR (in this example, 15%), while appropriate for valuing cash flows with the same risk characteristics and payoff profiles as the securities upon which it was derived, is inappropriate when the cash flows are not so correlated. In other words, DTA violates the 'law of one price'. [29] This will become more evident when we consider ROA in the next section.

Further DTA (and traditional DCF), by using a single RADR, ignores the possibility of changing risk (or assumes it away) over the life of the investment – as in the case of options over each successive period of their term to expiry. A single RADR does not properly capture management's ability to react to a changing environment, changes in risk over the life of the asset or project, or interdependencies that exist between current and future decisions.

As a consequence, we abandon the traditional DCF/RADR and DTA approaches (except for the underlying asset itself if its payoffs are sufficiently 'linear') in favour of the option valuation approach described next.

But before we do, we need to digress for a moment to consider the fundamental valuation approach of financial economics.

3.4 Portfolio replication and risk-neutrality

In preparation for the next step of the illustration, it is now shown that we could have obtained the same result in section 3.2 for traditional DCF by means of the method of *portfolio replication* using the

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[28] (0.5 x 150 + 0.5 x 80)/(1 – **0.017**) – 100/1.05 = 21.74

[29] Alert readers will note that the cost of the investment ($100) has been discounted at 15% whereas earlier it was discounted at 5%. Which is correct? Neither—except coincidentally. Actually it is always impossible to set a correct *ex-ante* RADR (see section 5.2).

principle of the 'law of one price' and the no-arbitrage assumption. The method of portfolio replication allows us to value a set of cashflows by constructing a portfolio made up of a holding of risk free bonds and of the underlying asset such that this portfolio produces the same set of cashflows as that being valued[30].

If we have Δ units of the risky security (priced at $20 each) and *B* units of a risk-free security (current value = $1), then the replicating portfolio would produce the following pay-offs after one year:

$\Delta \times 30 + B \times 1.05 = 150$

$\Delta \times 16 + B \times 1.05 = 80$

Solving these equations gives Δ = 5 and *B* = 0. The current value of the asset is therefore $100 (= 5×$20) as before. This should not be surprising given the way the problem was framed.

The important point to note though is that, by this alternative means, we have bypassed the intermediate step of calculating the RADR; the only interest rate used was the risk-free rate (and even that does not effect the end result for linear payoffs). The method of portfolio replication may seem a little convoluted compared to applying the RADR but we will soon see that it is the only way to derive a market consistent valuation when payoffs are non-linear.

Finally, there is yet a third approach we could have taken which produces equivalent results as the portfolio replication method but more efficiently: the *risk-neutral valuation method*[31]. Using the method in Appendix 1, risk-neutral probabilities can be derived and deployed to provide an equivalent solution as follows:

$u = 30 / 20 = 1.5$

$d = 16 / 20 = 0.8$

The risk neutral probability for the 'up' movement is:

$$\pi = \frac{1 + r - d}{u - d} \quad = (1.05 - 0.8) / (1.5 - 0.8) = 0.357$$

The NPV of the asset is therefore:

$= [\ 0.357 \times 150 + (1 - 0.357) \times 80\ ] / 1.05$

$= 100$

The risk-neutral approach differs from the traditional DCF approach by shifting the risk adjustment from the denominator (where it is embedded in the RADR) to the numerator (where it is embedded in the risk-neutral probabilities). The numerator is then referred to as the 'certainty-equivalent cash flows' since discounting is at the risk-free rate[32].

The use of risk- neutral probabilities with lattice trees may provide a computationally easier alternative to portfolio replication, particularly since, under the types of assumptions usually made for the up and down movements in the value of the underlying asset, they do not require recalculation of the Δ and *B* values at each node in the tree. The main problem with the risk-neutral approach is that the concept of risk-neutral

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[30] For those not familiar with the technique of replicating portfolios and the building of binomial lattice trees, Appendix 1 provides a general introduction. In any event note that the method is independent of 'real world' probabilities and risk preferences.

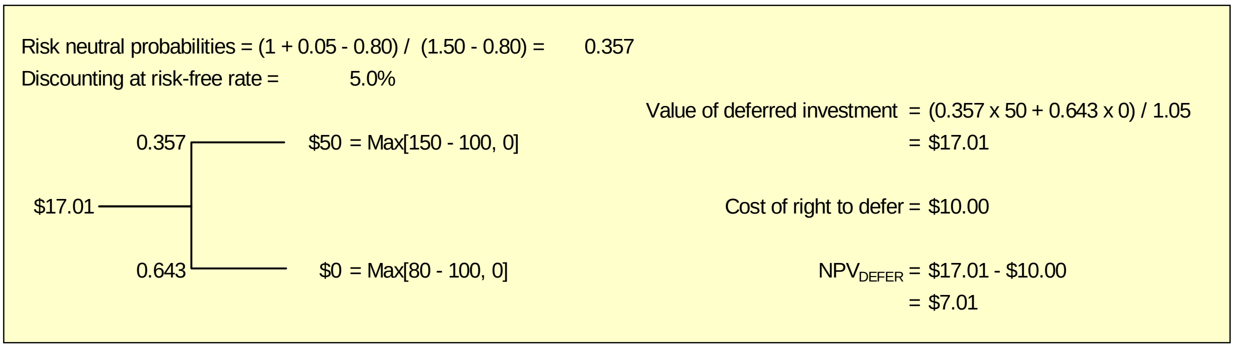
[31] Appendix 2 contains a brief explanation and a non-formal reconciliation of the risk-neutral approach used in financial economic theory with the real world approach actuaries are generally more familiar with. For a formal proof using price deflators, refer to Jarvis et al (2000, App.C).

[32] The certainty equivalent cash flow could also be expressed as the expected cashflow (with real world probabilities) less an adjustment for risk.

probabilities is hard for many to accept because it is not immediately obvious that it is equivalent to the replication method[33].

3.5 ROA approach

The essential idea of valuation under the ROA approach is to merge the idea of portfolio replication with DTA to produce a result consistent with market pricing. This is now demonstrated (using the risk-neutral probabilities in this case):



The value of flexibility to defer the investment is therefore:

$$= 7.01 - 5.00$$

$$= 2.01$$

If we backsolve in the DTA approach, we find we would have needed to use a RADR = 47.0% to achieve the same result[34]. (Backsolving in the DCF approach indicates a required RADR of 2.5%.) This tells us two things:

(a) Again, as for DTA, there is no objective means by which such a RADR, a valuation input, could have been derived; and

(b) The respective results and the decisions that flow from DTA and ROA valuation may be significantly different if the RADR can move as much it has in this example.

Of course, we could have used the portfolio replication method directly as follows:

$$\Delta \times 30 + B \times 1.05 = \max[150 - 100, 0] = 50$$

$$\Delta \times 16 + B \times 1.05 = \max[80 - 100, 0] = 0$$

Solving these equations gives $\Delta = (50 - 0) / (30 - 16) = 3.571$ and $B = (50 - 3.571 \times 30) / 1.05 = -54.422$ (ie sold short). Applying these ratios to the value of the securities we obtain the current value of the deferred investment:

$$\text{Value of option} = 3.571 \times 20 + (-54.422) = 17.01 \text{ (as before)}$$

The following table summarises the results so far:

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[33] The author suggests that understanding is also not assisted with the term ‘risk-neutral probabilities’. They are not probabilities as we would normally understand them (except for hypothetical risk neutral investor) even though they may appear to act like probabilities. There is in fact nothing stopping them being negative, although it can be shown this implies arbitrage is possible.

[34] (0.5 x 50 + 0.5 x 0) / (1 + **0.470**) = 17.01. This high rate reflects the high risk associated with the *return* on the option (not the option *value*—see Appendix 2)

	Invest Now	Defer Investment		
		DCF	DTA	ROA
Net value of investment	5.00	-5.24	11.74	7.01
Value of flexibility	-	-10.24	6.74	2.01
Required RADR	15%	15%	-1.7%	2.5% (DCF) 47.0% (DTA)

The conclusion is that, where material real options exist, a DTA approach is necessary in order to get a 'correct' order-of-magnitude result, and an ROA market consistent approach is worth the extra effort in order to get a 'correct' market consistent result.

3.6 Stochastic values

In the example above we assumed that there were only two states that the asset value could take in a single discrete time step. A more realistic assumption is that the asset values change randomly over time (perhaps with 'shocks' now again), ie a stochastic process[35]. This is of course the situation considered in the valuation of financial options where it is assumed that the market price of the underlying asset follows a stochastic diffusion process. If asset price movements follow a Geometric Brownian Motion process, then the Black-Scholes closed formula can be used for European options without dividends.

The standard deviation of the expected return in the simplistic two-state example above is 35%[36]. Let us assume that the asset value is lognormally distributed with the same standard deviation[37]. Using the Black-Scholes formula for European call options with $S = 100$, $K = 100$, $\sigma = .35$, $r = .05$, $t = 1$ we find the value of the deferral option, before deducting the cost to acquire it ($10), is $16.13 (cf $17.01 in the two state approach above).

The Black-Scholes equation (or modified and extended versions) is a powerful, simple way to calculate the value of real options in many situations. But as noted by the Strategic Decision Group (refer web site references), an enormously complex strategy problem can rarely be boiled down to a few factors:

> 'Directly using the [Black-Scholes] formula is wrong because of failed assumptions: a single exercise date; all uncertainty resolved by the time a decision is made to exercise; uncertainty in projected cash flows represented by a log-normal distribution; Lack of markets, ability to replicate. Better tools and methods are available including spreadsheets, lattice trees, Monte Carlo simulation, mean reverting returns etc can go at least some of the way to satisfy most of these concerns. Use them!'

In practice there are a number of ways to derive the real option value of which a closed formula derived using stochastic calculus is one. While closed formulae for more complex real options situations are available[38], actuaries would probably be more comfortable with using the transparent and familiar binomial lattice tree method, perhaps supplemented with Monte Carlo simulation[39]. Closed formulae are nonetheless useful to provide a check on numerical methods such as the binomial tree, even if only a simple form is used to bound the results.

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[35] Informally, a stochastic process is one that is at least partially random and involving a time dimension eg asset growth.

[36] $= (1.5 – 0.8) [\ 0.5 \times (1 – 0.5)\ ]^{1/2}$ — See Appendix 2

[37] This is only an approximation since $d \neq 1/u$. Lognormality of asset value means the log of the asset values (or equivalently the log of the asset returns) has a Normal distribution with a standard deviation of 35%.

[38] See, for example, Mun (2002) for a description of some of the most useful ones.

[39] Binomial tree valuation of options uses 'backward induction'. We will demonstrate the binomial tree in another example in section 7.3. It is also possible to use finite differences, another backward induction method, to derive option values. See Cortazar (2001) for an introduction of finite difference and other methods.

Table 4 provides comments on some practical considerations when considering closed formula or binomial lattice tree methods[40].

Table 4

Nature	Closed formulae	Binomial tree
Accuracy	Give a semblance of accuracy	Can be just as accurate but may require significant computer power to achieve it
Implementation	Easy to implement using standard functions in a spreadsheet	May be complex to implement in a spreadsheet perhaps requiring use of VBA (macros), Add-ins or else custom off-the-shelf software
Derivation	Very difficult (if not impossible) to derive	No knowledge of stochastic calculus required
Communications	Very difficult to explain	Transparency, ie easy to explain
Flexibility	Very specific to problem (limited model flexibility)	Highly adaptable to a wide variety of problems

With binomial lattice trees the modelling can quickly become unwieldy, especially if the different branches of the tree do not recombine, ie $d \neq 1/u$. The direct portfolio replication approach has the advantage over its indirect risk-neutral probability alternative in that the former has more general application, for example when volatility changes over time.

3.7 Changing volatility

Before leaving this section, it is instructive to consider the effect of increasing the volatility of the underlying asset (market volatility unchanged). We can do this easily by multiplying the 'up' movement by, for example, 1.1 and dividing the 'down' factor by 1.1. While the volatility of the possible states increases from 35% to 46%[41], the expected return also increases from 15% to 18.9%[42]pa, since we are assuming that the asset value does not change[43].

The summary table appearing in section 3.5 changes as follows[44]:

	Invest Now	Defer Investment		
		DCF	DTA	ROA
Net value of investment	5.00	-5.24	17.34	11.65
Value of flexibility	-	-10.24	12.74	6.65
Required RADR	18.9%	18.9%	-3.0%	1.7% (DCF) 51.0% (DTA)

[40] Methods have been developed to build 3-jump (trinomial), 4-jump (quadranomial) and even 5-jump trees that approach lognormality—see Boyle (1988, 1989). Boyle points out that the trinomial tree, at least for one state variable, appears to be significantly more efficient than the binomial (the accuracy in their testing of the 3-jump method with 5 time intervals was comparable to the binomial method with 20 time intervals).

[41] $= (1.5 \times 1.1 - 0.8 / 1.1) [0.5 \times (1 - 0.5)]^{1/2}$

[42] $= (0.5 \times 1.5 \times 1.1 + 0.5 \times 0.8 / 1.1)$

[43] When the expected volatility of asset prices increases in this 2-state model, the expected cash flows must also increase. Further the asset's beta and thereby its CAPM risk-adjusted return must also increase. The net result is that the asset price does not change. This is not to be confused with the general market expectations which can change without any change in market volatility or the discount rate. In this case asset prices will change.

[44] Detailed calculations are available from the author on request.

The thing to notice is that, as expected, the value of the real option under both the DTA and ROA methods has increased corresponding to the expected increased volatility. Further, the traditional DCF method of measuring the value of deferral, as wrong as it is anyhow, is not affected at all! This occurs because the increased volatility is perfectly offset by the increased RADR with no adjustment for the asymmetry of the payoffs.

4. ALTERNATIVES TO ROA?

4.1 The sceptic asks

"So what's the big deal?", some readers may be asking. "Is ROA genuinely something new? Isn't ROA just traditional valuation techniques dressed up in new clothes? For example, DTA has been around for a long time. Isn't ROA just DTA adjusted to ensure it obeys the 'law of one price'? Or isn't ROA merely options theory applied to a broader range of option problems?"

The answer to the last two questions is: "In a narrow sense—Yes."

Our sceptical reader continues: "Further, if we have to allow for management flexibility, wouldn't traditional DCF with some suitable sensitivity or scenario tests thrown in handle the problem well enough? Doesn't Monte Carlo simulation fill the gap?"

Similarly it is admitted that the answer to these suggestions in many, or perhaps even most, valuation problems that actuaries confront might be is: "Yes—for the most part, but perhaps less so in future."[45]

The paper now reviews the elements referred to in these questions, namely sensitivity and scenario testing, Monte Carlo simulation, and decision tree analysis. We look at what they are intended to do and not do and where ROA goes further.

4.2 Sensitivity and scenario testing

Sensitivity tests can be to used to *bound* the uncertainty and possible financial outcomes associated with individual parameters used in ROA valuation, particularly the volatility measure which is the most difficult to estimate. It is a useful technique for testing the significance of various assumptions made and may help a firm understand the drivers and impact of risk in meeting its objectives, thereby assisting in the identification of areas for further risk management.

The major weaknesses of sensitivity testing, in any valuation situation, are that it does not take account of interdependencies of variables, and it rarely considers the (statistical) confidence level of the sensitivities.

The 'greeks' (delta, gamma, theta, vega, etc), while the bread-and-butter of financial options markets for understanding point-in-time sensitivities and fine tuning holdings of portfolios of options, have limited application in ROA. The usefulness of the greeks depends directly on the ability to readily synthesise various combinations of standardised derivative instruments—clearly circumstances not pertinent to real options.

Scenario testing extends sensitivity testing by considering entire potential future scenarios with particular emphasis on the internal consistency of each set of parameters. It also has application when there are too many key parameters to apply sensitivity testing. It is a more rigorous approach where the scenarios can differ widely particularly if in a non-linear manner such as ROA problems.

Nonetheless both sensitivity and scenario testing still leave the decision maker with a range of results with no ready means for choosing amongst them. They also cannot objectively handle the optionality embedded within the problems ROA seeks to address.

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[45] In fact there are few key tests which any apparent real option valuation problem must pass before one would consider drawing the ROA tool from the valuation 'kit bag'. We will look at these more closely in section 0.

Note that it is not being suggested that ROA should replace sensitivity and scenario testing any more than such testing avoids the need in some situations for ROA. Sensitivity and scenario testing are not valuation methods but rather techniques that complement ROA (and DCF) by enhancing the information content of the valuation method.

4.3 Monte Carlo simulation

Monte Carlo simulation extends sensitivity and scenario testing by replacing single parameters with probability distributions as well as more complex correlations between parameters than is possible in a deterministic model. One statistically models the key parameters and their interdependencies, runs many scenarios using these underlying distributions, and produces a distribution of outcomes[46]. Monte Carlo simulation therefore allows one to see the *probability* rather than just the *plausibility* of various cash flows streams and the NPVs that result.

The main difficulty of the technique is deriving probability distributions and correlations between parameters which are reasonable representations of reality. Further, in practice, the distribution of outcomes can be difficult to interpret or give a spurious impression of accuracy.

Possibly the most significant practical weakness of applying Monte Carlo simulation to options valuation is that it cannot, without sophisticated modification, be applied to American-type options (ie where exercise can occur before the expiry date). The reason is that, at a given point in time in the simulation, the exercise decision must compare the option's immediate exercise value against its continuation value. The continuation value is though a function of its value along all possible future price paths from that node on, and each path will present further exercise decisions with the same difficulty in resolving them. Significant research in recent years has provided a variety of means by which to overcome this technical weakness—refer to Appendix 3.

Nonetheless, Monte Carlo simulation is the only solution for valuing real options when

- the diffusion process for the market uncertainty is more complex than Geometric Brownian Motion;
- option payoffs are path dependent;
- the lattice tree simply becomes too unwieldy, particularly for the more complex options or when multiple sources of uncertainty need to be modelled separately (see section 6.4); or
- unlikely catastrophes or shocks are substantially different from expected value and have significant (perhaps unrecoverable) consequences.

It is also a useful technique to support ROA for:

- measuring volatility of the underlying asset (see section 6.4.1); and
- plotting the distribution of real option values, comparing with plots of standard NPV values, and indicating confidence intervals[47];

As a starting point for those unfamiliar with the types of models used, Appendix 3 provides simulation formulae for random walk and mean-reverting processes.

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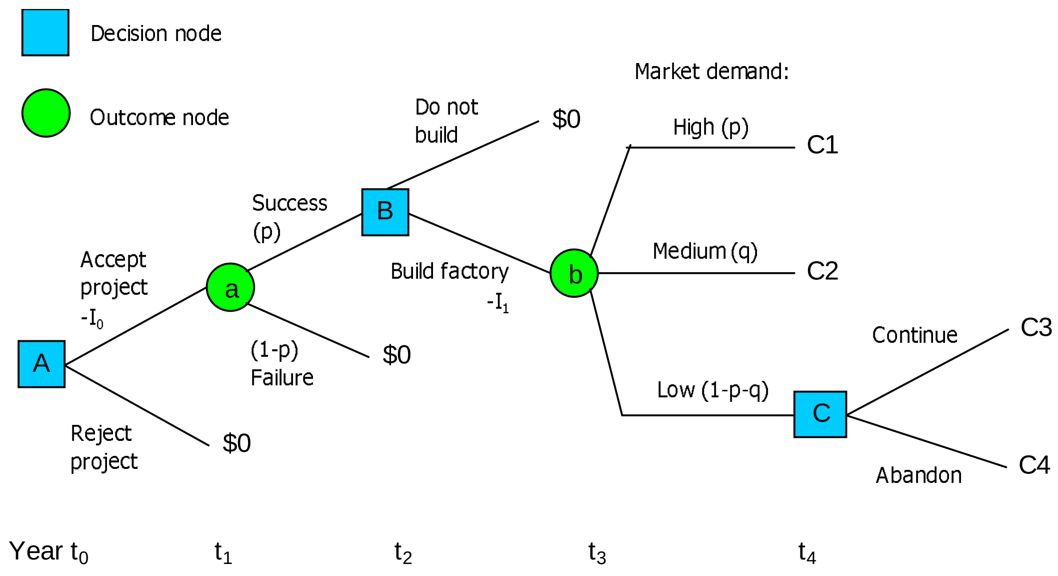
[46] Monte Carlo simulation requires a mathematical defined distribution. Non-parametric simulation could also be used in which one draws samples from a frequency table which has been based directly of empirical results, ie no attempt is made to estimate or hypothesise the moments or mathematical shape of the distribution. Winston (1999) shows how to undertake non-parametric simulation to calculate risk neutral probabilities and thus option values for any arbitrary distribution.

[47] See Sick (1997) for an illustration of this technique.

4.4 Decision tree analysis

Decision tree analysis (DTA) is a visual analytical tool that understands that decision makers operate in a dynamic world and it therefore tries to capture the flexibility of decision makers to respond to events as they unfold. They can be applied to any decision situation including those involving money, time and uncertainty (although unsophisticated users often take no account of the time value of money). A decision tree typically takes the form illustrated below.



Source: Nutter (2001,p8)

DTA can take account of the firm's flexibility to respond to events as they unfold an d new information becomes available. It enables the value of flexibility to be encapsulated into a single number. DTA can also be used in combination with any of the other methods just discussed to bound the uncertainty in parameter estimation.

It is said that DTA focuses on 'detail complexity', ie it tends to consider great detail in the cash flow models and many uncertainties, but relatively little in the way of dynamic decision making. DTA models can easily become highly complex and incomprehensible, a so-called 'decision forest', as attempts are made to make the model more realistic by adding states and decision points, decreasing the time between decision steps and extending the time horizon. ROA on the other hand focuses on 'dynamic complexity': the evolution of a few complex factors and the most significant uncertainties over time that determine the value of investment and cash flows. Whereas a decision-tree may become overly complex, real options can distil strategic thinking and decision making into a tractable framework by focussing on a few, key dynamic processes.

But more importantly, and as pointed out in the earlier illustration, the fundamental flaw with DTA as a valuation tool is that—unless adjustments are made—it does not apply the 'law of one price'. In other words, the presence of real options changes the risk profile of certain branches which implies different discount rates. Unfortunately, DTA does not show how to choose the discount rates[48]. It is therefore prone to introducing new modelling inconsistencies and distortions relative to the valuation of the underlying asset—however 'correct' (or otherwise) that in itself may be. Nonetheless, it has to be acknowledged, whether one is using ROA or DTA, that in many situations the same investment decisions will be made. The problem is that one cannot know (ex-ante) *which* situations. So while ROA may require a little more effort, the author believes it is warranted when market risk is prevalent.

DTA does have two distinct strengths which ROA retains:

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[48] As noted earlier (footnote 29), and explained in section 5.2, it is impossible to derive correct *ex-ante* RADRs.

- DTA provides an excellent device for visually representing and communicating real options dynamics
- DTA is the basis for development of binomial lattice trees which are, in essence, decision trees with recombining branches.

A relatively recent innovation is the application of influence diagrams to ROA. These were originally devised as a front-end to decision trees but have been developed to become a tool in their own right. According to Lander and Shenoy (1999), influence diagrams can produce the same results as decision trees but with the added advantage that they represent decision trees in a more descriptive, intuitive, and compact manner than decision tree or option-based models, particularly when there are multiple uncertainties and many time periods[49].

5. THEORETICAL BASIS FOR ROA

5.1 How sound is the basis for ROA?

By this time, it is anticipated that a number of readers, while perhaps understanding the conceptual basis for ROA and seeing that it may hold some promise, may nonetheless be feeling uncomfortable about applying valuation techniques developed from financial economics theory[50] for traded derivatives to non-traded real assets. This is a common concern and the author believes it warrants a digression before we delve too much further into practical issues surrounding ROA.

There are two separate, although related, matters to consider:

- the non-tradeability of the underlying asset and the appropriateness of applying methods derived for marketable securities; and
- the identification of a suitable market priced proxy for pricing the real option.

5.2 Non-traded assets

A common objection to the theoretical validity of the valuation methods used in ROA is that it assumes the underlying asset (or project) upon which the real option exists can be traded in a financial market. This concern seems reasonable given the development of options theory is centred around securities traded freely in stock markets. Nonetheless, it is believed the concern can be dispelled quickly by referring to three sources.

Firstly, in his Noble Prize lecture, Merton (1998) goes to some lengths to demonstrate that replication-based valuation (including the Black-Scholes formula which is derived from it) can be used for pricing a derivative security *even though replication is not feasible because the underlying asset is rarely traded (and therefore its price is not continuously observable)*.

Secondly, Arnold and Shockley (2002), going back to fundamentals, and making use of the minimum of assumptions demonstrate that the fundamental assumption of both DCF and ROA valuation methods is valuation by arbitrage, ie arbitrage-free opportunities exist and that they both assume 'complete markets'[51]. They go on to conclude:

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[49] The paper referred to also provides a critical review of decision tree and binomial tree modelling.

[50] We will make the assumption that readers of this paper are not of the school of thought that maintains that none of the ideas emanating from financial economics theory are of any practical worth!

[51] In complete markets, the cash flows of a new asset can be recreated in financial markets without impacting the equilibrium rates of return on existing assets Dixit and Pindyck (1994, p152) also note that without the assumption of complete markets (aka 'spanned markets'), there is no theory for determining a 'correct' risk adjusted discount rate. For example, CAPM would not have *any* scientific basis.

(a) DCF is invariably taught in business schools before options theory is introduced because it is simple and options pricing is complex. In so doing, shortcuts are made which hide, perhaps forever, the real economic explanation and the limitations of its application.

(b) There is no way to know the correct discount rate for the more general situations that options pricing techniques can deal with, without first doing the arbitrage valuation, ie the discount rate can only be known *after* the valuation has been completed by other means.

(c) Option pricing techniques work in a broader set of situations than DCF, ie *DCF is a special case of options pricing*[52] when the distribution of payoffs are linear and symmetrical and when the investment decision is 'now-or-never', ie time to expiry is zero and investment now is irreversible.

Lastly, Sherris (2002) proves the same point as Arnold and Shockley, namely that the arbitrage-free assumption is the only assumption necessary for both financial economics and DCF models, and concludes (p26):

> 'Actuaries who argue against the use of financial economic models are actually arguing against discounted cash flow models!'

More importantly, given the relevance to this paper, Arnold and Shockley also draw the following corollaries from point (c):

(c.1) ROA valuation is perfectly valid in any situation where DCF is applied *without needing to make any further fundamental assumptions*. That is, they are both derived from the same common foundation.

(c.2) Regardless of theoretical merit, if one is *willing* to apply DCF to an asset, the implicit fundamental assumption that has been made is sufficient to apply ROA valuation to the asset—*even if the asset is not traded*.

Our profession has been founded and built on our ability to apply DCF to a whole range of assets and liabilities for which no market exists. In fact it could be said that it was necessary to invent the method of DCF entirely because of the absence of a market pricing system for most assets or liabilities!

The author is satisfied that the issue of non-tradeability of assets should no longer be an issue for debate amongst practitioners in the field. There are both powerful theoretical and practical arguments to say it is not relevant. Even if the concerns did have theoretical merit, it has never hindered actuaries from solving commercial problems involving options as evidenced by the list of practice area papers cited in the introduction to this paper. Why should it bother us now?

5.3 Replicable securities

Non-tradeability nonetheless begs the question: How does one price the underlying asset? After all, market discipline is supposed to provide an objective means to solve valuation problems. ROA valuation therefore seems to rely on finding a suitable market priced security which is sufficiently correlated to the riskiness of the underlying asset being valued (for example, gold prices for a gold mine), even if the asset itself were not tradeable. The assumption here is that the volatility of commodity is same as that of the asset without flexibility.

Such an approach rarely works in practice for two reasons:

- The sources of uncertainty of the asset are many, not only the commodity price; and
- For the types of real assets commonly considered for ROA, such securities simply do not exist. It is often said that underlying assets of real options are 'distant' from the markets[53].

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[52] Options theory is itself a special case of state price deflators which requires no assumptions about the distribution of asset returns or the utility or risk preferences of investors.

Copeland and Antikarov (2001, p24) suggest that development of ROA was for a long time hindered by the belief in the need to identify a correlated security. We now know this belief was false.

The generally accepted way to avoid what otherwise seems a show-stopper is to initially derive the value of the asset-in-place but without the options and using traditional DCF methods including an appropriate RADR and then—and this is the crucial step—make the assumption that *this is the best unbiased estimate of the market price of the asset (without the options) if it were a tradeable*. The valuation of the option over the asset is then carried out using option valuation techniques such as lattice trees, closed formulae, and simulation. It also follows from this approach that best estimate of the volatility of the cash flows of the asset can be obtained from consideration of the underlying asset itself.

This approach means of course that the valuation of real options cannot dispense with the usual modelling of cash flows and the discounting of those cash flows. Existing models, spreadsheets and other computational tools must be retained. In the author's view, the key advantages are:

- it greatly simplifies the application of ROA
- it allows volatility to be estimated from the asset itself
- it ensures that the asset with and without options is valued consistently
- it builds on rather than discards traditional approaches and therefore makes reconciliations and communication of results more transparent.

The assumption behind the approach[54] is no weaker or stronger than that actuaries have been comfortable to use to value the underlying asset (without the options) in the first place. Indeed financial options are priced using relative valuation techniques on the premise that the market prices the underlying asset efficiently and correctly. To the extent that the market 'gets it wrong', so too are the options valued incorrectly—but at least consistently incorrect. Likewise to the extent that a DCF valuation of the underlying asset is "incorrect" because of the way cash flows are modelled or parameters set, so too will the valuation of the real option.

While there may be alternatives approaches to the one described here, in the author's view, there seems little practical point or need to look elsewhere. It gets answers which can be rationalised, explained and used effectively.

We will now shift from the theoretical to the practical in terms of how one sets what is the most awkward of the required assumptions for ROA, namely the measurement of uncertainty and in particular the volatility measure.

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[53] We should remind readers that, if one is applying a DCF/RADR or ROA approach to the valuation of an asset which is normally distant from the markets, we are implicitly assuming that management is able and willing to act on market signals. If not, one should use the risk free rate for present valuing the underlying asset.

[54] Referred to by Copeland and Antikarov (2001, pp94-95) as the 'Marketed Asset Disclaimer'.

6. MODELLING UNCERTAINTY

6.1 Types of uncertainty

Uncertainty or risk[55] can be classified into two general forms, namely 'public' and 'private'.

Public risk

Public risk is associated with factors *external* to the firm. A firm has little or no ability to control or influence the absolute level of the risk and therefore cannot reduce or eliminate it—a firm can generally only take a *reactive* posture.

Under this heading the author finds it useful to distinguish between:

- *market risk*, which includes general shifts in technology, economic factors (interest rates, inflation, exchange rates etc), government policy and regulation, consumer demand, geopolitics, environmental issues, societal and demographic issues and trends;, and
- *competitor risk*, which refers to the actions of competitors or their responses to the firm's own actions.

Public risk cannot be diversified away, that is extra assets exposed to the risk merely increases the firm's aggregate exposure to the risk. Note that a firm can *shape* its own *exposure* to market risk through use of derivatives or creating real options.

ROA distinguishes itself from other valuation methods by how it deals with market risk although competitor risks cannot be ignored.

Private risk

Private risk is associated with factors *internal* to the firm.

A firm may be able to control or influence the absolute level of the risk associated with its assets and their embedded options—and therefore option value—by application of its management skills and knowledge.

As pointed out by Leslie and Michaels (1997), this does not just mean taking a posture of *reactive* flexibility—flexibility that a firm also holds likewise with financial options to invest, wait, divest, switch etc—but includes a firm's *proactive* or *strategic* flexibility 'to take action in ways that will enhance the value of the option once acquired'. Leslie and Michaels go on to discuss a way for management to 'pull the levers' of option value, most of them already done instinctively.

Under this heading the author also finds it useful to distinguish between:

- *technical risk*, which includes financial risks, and which refers to the strategic business activities of the firm such as R&D investment, marketing research and advertising strategies, new distribution channels and markets
- *structural risk*, which refers to operational, compliance and cultural risks, and which can usually only be managed by direct means such as procedures manuals, training, and perhaps even the CEO's golf scorecard! [56].

Unlike public risk, private risks can be reduced by diversification of negatively correlated risks, eg across opportunities, projects, business lines, product lines, supply lines, markets etc; or by pooling

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[55] The more usual term 'risk' is used in this section in the same sense as 'uncertainty', ie general doubt about future outcomes.

[56] Eg rash decisions made after a bad game or bad projects approved after a hole-in-one (cited by Mun (2002))

of homogenous independent risks. The way a firm manages technical risk is varied but may include diversification or hedging instruments.

ROA is able to cope with technical uncertainty during the option period but its characteristic form, as we shall see, is different to that of market risk. Structural risk is relevant to ROA only indirectly, namely to the extent that it can impact management's ability to create, manage and optimally exercise options.

We have not yet referred to what could be termed 'actuarial' risks such a s mortality and morbidity rates, attrition and lapse rates. These risks are distinctly probabilistic in character, tend to span both the public risk areas (eg medical research, general health trends) and private risk areas (eg pricing and distribution practices). The risks are managed by pooling, pricing, reinsurance (really a specialised form of hedging), underwriting and rating practices, and claims management practices. Actuarial risks, to the extent that they are relevant only to the calculation of actuarial liabilities, do not appear to require special consideration in ROA work.

6.2 Conflicts in uncertainty

All forms of uncertainty can exist together, and usually do to varying degrees. Boer (2000) makes an important point about the interplay of market and technical risk, namely that whereas market risk *enhances* option value, technical risk *diminishes* option value (just as it does for the traditional DCF value). Therefore, one must take care to distinguish them when considering how a firm might seek to resolve the uncertainty and how the uncertainty should be modelled lest one obtains erroneous results.

Copeland and Keenan (1998) provide the following illustration where these two risks are working in opposite directions:

> 'Mining companies having to decide when to develop the properties they own and how much to bid for the right to develop additional properties. Such decisions often involve a combination of options: the option to learn about the quantity of ore present underground [technical uncertainty] and the option to defer development until ore prices [market uncertainty] are favourable.
>
> These two options frequently conflict. Immediate development sacrifices the deferral option, but provides information on the quantity of ore available. Deferring development allows the owner to wait until the price of ore is high enough to ensure profitability, but provides no information on the quantity of ore. At time, partial or exploratory development, allowing a company to learn something about its holdings while preserving the ability to hold back actual production until prices improve, may be a reasonable compromise.

The optimal decision as to whether one should wait, invest now in stages, or wait a little and then invest in stages will be determined by the balance of the weight of the respective uncertainties. ROA can help resolve these countervailing uncertainties. Section 6.6 provides a very simple illustration.

We will now look at market and technical risks more closely and how to model them before looking at the effect that the presence of competitors can have.

6.3 Market risk and real options

It is the treatment of market risk which is the fundamental technical difference of the valuation method behind ROA over other methods using a RADR such as DTA and DCF.

Option theory shows increased market uncertainty (as measured by the standard deviation) *increases* the value of the option. Therefore the existence of market uncertainty, all other things being equal, increases the value of a firm's future investment opportunities and its willingness to delay decision making until sufficient uncertainty is resolved[57].

The optimal strategy for the firm may be to *wait* or postpone full investment (ie stay on the sideline but perhaps acquire access to relevant industry information) until sufficient market information and therefore market uncertainty has resolved itself – a 'waiting option'. It would also seem to follow that since a waiting option is like an American call option, optimal exercise of the option would occur at the expiry date[58]. Further, if a waiting option has an unlimited life, it also seems to follow that the option should *never* be exercised! This might be true if it were not for the fact that, in practice, there is value leakage during the option period due to cash flows forgone or option holding costs eg licence fees[59].

In practical terms, a waiting option should be 'exercised' when the option is considered to be sufficiently 'deep-in-the-money', ie when it is considered that any further delay in investment will be value destroying[60].

6.4 Modelling market risk

While both market and technical uncertainty are important, traditional DCF, as generally applied, tends to focus more on the latter in consideration of the precision of the *expected* cash flows. Discounting is usually at a single RADR derived perhaps by a combination of objective and subjective means.

In ROA, market risk is reflected:

(a) (if using a closed valuation formula or Monte Carlo simulation) in the volatility measure (σ) of the market price of underlying asset (or perhaps of a suitably correlated and sufficiently traded proxy); or

(b) (if using a lattice tree valuation approach) in the up and down movements of each branch, which in turn are based on the same volatility measure (see further comment in section 6.4.2).

Either way, under ROA, discounting is carried out at the risk-free rate appropriate for the period of the option[61].

Obviously, market uncertainty derives from many sources and, equally obviously, a valuation model will become more complex if one wishes to model some of these separately. While in some cases, it may be possible to derive a joint probability distribution, Winston (1999) shows a possibly more practical way around the potential problem by simultaneously risk-neutralising all sources of uncertainty in a Monte Carlo simulation of asset prices.

6.4.1 MEASUREMENT OF VOLATILITY

The volatility measure of the return on the underlying asset is the most difficult and therefore unreliable assumption to set. Copeland and Antikarov (2001, Chp9) fully acknowledge the problem and provide a

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[57] From the perspective of an individual firm this may seem fine but from the perspective of the economy as a whole it means there will be a general decrease in the amount of actual current capital investment. As noted by Copeland and Antikarov (2001), this result is consistent with macro economic theory which says if uncertainty increases in an economy, for example due to political unrest, investment activity would tend to decline. Investors will ascribe higher value to future investment opportunities and will invest sufficient merely to keep these open.

[58] Options theory shows that simple American call options not paying dividends are equivalent to European call options, ie the option price is the same.

[59] This is analogous to dividend paying American call options which are priced higher than their European call counterparts because optimal exercise will occur earlier.

[60] For those seeking an analytical solution to the timing of the investment decision, see Dixit and Pindyck (1994, Chp5) who derive the conditions that must be met for a solution to exist, and a detailed review of the solutions for a variety of commonly used stochastic processes.

[61] Allowance for inflation and tax on the cash flows of the underlying asset is best modelled explicitly. The author is aware that in at least one situation for an Australian business, the risk-free rate itself is adjusted for inflation as well as country risk.

detailed coverage of ways to tackle it. They quickly dismiss some earlier practices of working from 'known' volatilities of input variables eg price of gold for a gold mine, or of using the historical volatility of the firm's listed equity[62].

The first of the two methods they propose is to model the uncertainty of chosen variables with Monte Carlo simulation of their estimated statistical distributions using historical data. The basic idea is as follows:

(a) Value the underlying asset in the usual way ignoring flexibility (ie the embedded real options) and using the RADR that would usually be deemed appropriate for such a non-flexible asset.

(b) Derive σ_S by Monte Carlo simulation of the key market parameters in the model such as interest rates and inflation.

The simulation can be extended quite easily to capture autocorrelation of each variable (for example where mean reversion may be significant), as well as cross-correlation among variables – see Appendix 3. This can be achieved within a spreadsheet environment without recourse to macros or specialised add-ins.

The second method Copeland and Antikarov propose[63] which may be satisfactory in some situations, for example when empirical data is not available, is to ask management for, say, its 90% or 95% confidence lower and upper case estimates for the values of the asset at the end of, say, a year. With these confidence bands, a suitable probability distribution, and the current value of the asset and its mean growth rate, one can back-solve for the standard deviation. Naturally, the likelihood of errors due to subjective bias is high although there exist methods which aim to reduce this effect.

Whichever approach is used, it is always useful to undertake sensitivity tests of the volatility of the ROA results. In particular, if starting from a negative NPV (without allowing for embedded real options), the author suggests back-solving for the level of volatility that makes the NPV (with options included) positive—the 'cusp point'. It may turn out that volatility at all reasonable levels is not such a critical assumption for making an otherwise non-viable asset or project viable.

6.4.2 BINOMIAL TREE PROJECTIONS

As intimated in point 6.4(b), if we are using a lattice tree approach to projecting asset values we need a way to translate the volatility measure into up and down movements along the branches of the tree. The standard approach for binomial trees is to set $u = e^{\sigma\sqrt{\Delta t}}$ and $d = 1/u$. This assumption is possible if one is prepared to assume that the stochastic distribution of the change in values implied by the binomial tree approaches lognormality[64]. While such an assumption is made for convenience, the situations that actuaries typically confront are likely to require more sophisticated approaches. In such a cases, Monte-Carlo simulation must be used—see section 4.3.

The translation rule is in fact an approximation for achieving a binomial model which yields a mean return and standard deviation equal to the desired continuous lognormal parameters—although one usually good enough in practice. If a more accurate approach were desired, we could utilise the SOLVER function in Excel® in combination with Monte Carlo simulation to choose values of u, d and π for which the binomial model yields the desired lognormal mean return and standard deviation.

A word of caution though…

Binomial tree projections of asset values using this translation rule are strictly *risk-neutral* projections. In other words, they provide the intermediate results at each node in the lattice tree to enable the valuation of the option using the risk-free rate and using risk-neutral probabilities. Real world projections, perhaps to

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[62] Even if there were a justification for using this measure for, say a firm project, one would normally have to adjust for the firm's use of debt financing and its leverage impact on equity returns (since most projects are not financed by any part of the debt) – refer Mun (2002, p202) for further comment and considerations.

[63] Also proposed by Mun (2002)

[64] Cox and Rubinstein (1985), and similar references on options pricing, provide details.

calculate so-called 'value-at-risk', or to derive an estimate of when the option will be exercised and the likelihood of exercise, must still be carried out using real world probabilities and expected returns[65].

6.5 Technical risk and real options

Unlike the waiting option where exposure to market uncertainty already exists and the firm is seeking to delay a decision while waiting for the uncertainty to resolve itself (the only way it can), *acquiring* exposure to private uncertainty is the *only* way to gain the information about it and resolve it to the firm's economic advantage. That is, waiting will not work; separate effort is required. The strategic response is to speed up investment or make incremental or multi-staged investments to limit downside risk.

Staged investing, while not only protecting the downside, reveals information about costs, sales potential, problems and risks and has so-called 'shadow value' beyond its direct contribution to completion of the project. This is often seen in the form of *learning* options which are most prevalent when high capital expenditure is at stake.

For example, a firm may establish a branch office to create a beachhead in a new country in order to learn more about the specific market, the competition, and its laws. It may even market a pilot product or service to assess market resistance or acceptance of its brand. If successful, that is on resolution of the first level of uncertainty, it may make further investments in staff, training, products and marketing, each carefully staged after the uncertainty is sufficiently resolved. At any point, the firm can choose to abandon the investment already made but it is not required to make further commitments of capital. Another example is direct mail campaigns which are designed and managed to optimise the return on scarce capital resources and to limit risk of loss.

6.6 Modelling technical risk

The resolution of technical risk is much less likely to occur as a diffuse process as is usually assumed for market uncertainty. In traditional DCF, it is the practice to allow for technical risk by subjective adjustment to the RADR over and above non-diversifiable market risk.

In ROA, allowing for technical risk that exists *in the option period* is analytically more difficult than for market risk and as actuaries would usually provide for in DCF models. It could nonetheless be allowed for by[66]:

(a) identifying specific points of time in the binomial lattice tree when the uncertainty is expected to be resolved and attaching probabilities for the possible paths in the tree. (For a European style option this would only be at the exercise date – see example below);

(b) using a quadranomial lattice model to represent market and private uncertainty interacting together (perhaps with a correlation factor); or

(c) applying a 'jump' or Poisson stochastic process (in conjunction with a continuous diffusion process for market risk).

Technical risk is, by definition, not correlated to market price movements. Therefore cash flows subject *only* to technical risk should be discounted at the risk-free rate (whether under a traditional DCF approach or under ROA).

The side-bar below gives a very simple illustration.

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[65] The correct real world 2-state value of u is determined by solving $\sigma^2 t = (R - d)(u - R)$ where $\ln(R) = rt$ and r is the expected continuous return (after dividends). The value of the real-world probability associated with u is given by $q = (R - d) / (u - d)$. It is easy to show that as $R \rightarrow 1$, $\sigma\sqrt{t} \rightarrow \sqrt{u} - 1/\sqrt{u} \sim \ln(u)$. This is the reason that the translation $u = e^{\sigma\sqrt{t}}$ is often used in both the real world and risk-neutral worlds. The risk-neutral probability is given by $\pi = (R_f - d) / (u - d)$ where $\ln(R_f) = r_f t$ and r_f is the (continuous) risk-free rate.

[66] See Copeland and Antikarov (2001) for details of (a) and (b). See Dixit and Pindyck (1994) for details of (c).

Combining market and technical uncertainty

An oil company has paid \$1m for a four year lease on an oil field including an exploratory well. Its geologists estimate a 25% chance of finding oil in the field. If it finds oil, it will develop the field at a cost of \$18m (strike price), but the value of the oil in the fields is \$20m at current prices (ie in-the-money). The (continuous) risk-free rate is 5%pa and the historic volatility of oil prices is 30% (market risk).

The NPV without considering the option but allowing for the 25% chance of producing oil (private risk) is -\$0.5m (NPV_{NOW} = 0.25 x [\$20m - \$18m] - \$1m). Using the Black-Scholes European call option formula (and assuming certain success of finding productive oil), the value of the option is \$7.23m. Allowing for the chance of producing oil, the net value of exploratory option is NPV_{DEFER} = 0.25 x \$7.23m = \$1.81m which exceeds its cost of \$1m by \$0.81m.

Therefore the value of flexibility to either bring the well to full production after four years, or else abandon the well for a maximum loss of \$1m should results prove negative is:

$$NPV_{DEFER} - NPV_{NOW}$$

= \$0.81m–(-\$0.5m) = \$1.31m.

6.7 Impact of competition

The analysis presented so far in this section is sufficient for a firm which does not have to consider the potential actions of competitors, perhaps because the firm holds a monopolistic or dominant position. Typically though postponing investment until the future becomes clear can create a window of opportunity for competitors who are exposed to the same uncertainty. In other words, a firm may not have exclusive rights to exercise if competitors can pre-empt the firm's intent and thereby reduce or eliminate any option value that was presumed to exist.

Kester (1984), in perhaps one of the first general articles on the application of options thinking to real assets, refers to *proprietary* options (aka 'exclusive options') which, perhaps because of unique knowledge or patents held by the firm, lack of product substitutes, or natural barriers to entry (for example, control of resources, supply lines, markets, or land), cannot be duplicated by competitors. These are highly valuable.

On the other hand, *shared* options which are collectively held by the industry, such as cost-cutting projects or entering unprotected markets, are generally less valuable—unless if a firm is in a sufficiently stronger competitive position due to say, strength of brand or capital resources.

Management may need to be ready to exercise early when options are shared and this may require management to undertake additional strategies or acquire other options to give it the flexibility to act quickly as markets evolve, for example, investment in people, training, systems, channels.

Weeds (2002), in reviewing shared options in the context of game theory, also distinguishes between situations where 'first mover' and 'second mover' advantage exist, and where the advantage held by the first mover (or 'leader') may be temporary or persistent, ie sustainable, once the second mover (or 'follower') has reacted. Examples of options with first mover advantages include first-to-patent races, system wars, and entry into natural monopolies—any situation where delay is highly dangerous. The conclusion is that where a firm does not have a sustainable first mover advantage, then, despite first appearances, the value of options is probably near zero.

Weeds shows how being the second mover can sometimes be advantageous because of spillover benefits from the first mover, eg wars of attrition, and where the first mover has the capital resources to crack the market, create the awareness and demand which can be tapped by others, for example IBM created the PC which was rapidly cloned by other manufacturers wishing to 'ride the wave'. Weeds also distinguishes between situations where the benefits fall only to the second mover and where the first mover may also share in the benefits from the response of the second mover.

In an earlier paper, Smit and Ankum (1993) attempted to demonstrate analytically how the possibility of competitive pre-emption can erode the value of shared options and under what circumstances it can force early exercise of the option. They considered the situations of perfect competition, oligopoly, duopoly and monopoly. Like Weeds, they formulated a set of rules of thumb for shared options based upon the relative value of the immediate investment, the level of market uncertainty, and the relative market strength of the firm.

Figure 1 (based on Kester) helps to visualise some aspects of the types of rules of thumb that can be formulated in terms of the exclusivity of the option and the strength of market and competitor activity.

Figure 1

COMPETITOR RIVALRY	None	Absolute
Minimal	**OLIGOPOLISTIC (LOW IMMEDIATE NPV)** Threat of preemption, but market power of dominant firms increases their ability to appropriate the value of exercised options for themselves. Tendency to retain options until at least weaker competitors exercise. Even then preemption by weak competitors can benefit a dominant firm by providing useful market information.	**MONOPOLISTIC** Dominant firms able to fully appropriate option value for themselves. No risk of preemption. This applies where the firm has patents , licences or monopolies over supply, resources or markets. Options held until expiration.
Intense	**PERFECT COMPETITION** Little or no ability to appropriate the full value of an investment opportunity, at least for any sustainable period. Rapid exercise of options for defensive or preemptive reasons eg create cost advantage.	**OLIGOPOLISTIC (HIGH IMMEDIATE NPV)** No risk of complete preemption, but threat of value erosion due to competitor activity or opportunity cost of forfeited cash flows. Tendency for early exercise

EXCLUSIVENESS OF RIGHT TO EXERCISE

6.8 Modelling competition

The possibility of competitor responses suggests a possible application of game theory. While there has been recent research in this field, practical expedience would suggest employing explicit allowances such as reducing the term of the option, running off the value of the underlying asset over the term of the option by setting a 'dividend' assumption, or perhaps reducing the 'drift' rate (even making it negative).

In the face of intense competitor activity, the analysis by Weeds may be useful to judge the appropriate allowances. It may be concluded that the options are not 'real' at all. [67]. In practice the situations are often more complex. It will perhaps always remain difficult to come up with a reasonable set of analytical rules for sensibly adjusting the ROA valuation to properly reflect competitive dynamics.

[67] Perhaps they should be referred to as 'virtual' or 'Claytons' options!

7. A MORE COMPLEX EXAMPLE

7.1 Objectives of example

This paper has so far had little to say about the actual valuation techniques used. The simple illustration provided earlier was merely to introduce and compare the concepts underpinning ROA. This section includes a more realistic situation.

The example admittedly includes only a smattering of explanation. Nonetheless, readers who have read the paper closely up till now, particularly referring to sections 3.4, 3.5, 4.2 and 6.4.2 should have little difficulty reproducing the results[68].

The example is intended to illustrate, or at least hint at, a number of things:

- how compound options are valued
- the power of spreadsheets to handle an apparently complicated valuation problem with variable volatility and interest rates
- the ease of building a binomial tree (although in practice the time steps would be more granular to refine the accuracy of the valuation)
- how the optimal investment decisions are first made at the terminal nodes in the binomial tree and then by a method of backwards induction through each node to the initial node, the value of the option is derived[69]
- how strategic decisions might evolve over time as the uncertainty unwinds (higher granularity of time-steps will likewise refine this as well)
- the usefulness of sensitivity testing to extract more informational content

In practice, circumstances are typically more complex than this. Readers are again reminded that reference texts such as Copeland and Antikarov (2001) and Mun (2002) will go a long way in filling the technical gaps. The example was developed using nothing more than a spreadsheet and for many far more complex situations, even if simulation is employed, this is often all that is required (and without any recourse to macros). The lattice tree has been shown with arrows purely for illustrative purposes; in practice it would be collapsed for efficiency into a triangular shape of calculated cells.

7.2 The problem

A firm is contemplating entering a market with a significant new product offering in three phases:

Phase 1: *The firrm undertakes research at a cost of $100 and has the option to begin Phase 2 at a cost PV of $400 at the end of the year.*

Phase 2: *The firm establishes a beachhead in market and at sometime over the next 2 years will decide, based on market demand, whether to commit to beginning Phase 3 a PV cost of $750 if started in 2nd year plus another $50 if delayed until 3rd year.*

Phase 3: *The firm develops a full market presence (products, distribution channels, staffing etc) and would expect to earn net cash flows with a current PV of $1,000 estimated using a risk-adjusted discount rate based on existing ventures of this type and current demand.*

The one year zero coupon bond interest rates is currently 5% and is expected to increase to 6% in the 2nd year and then to 7% in the 3rd year.

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[68] The spreadsheet is available from the author on request.

[69] Readers unfamiliar with the technique could refer to any standard text on option pricing such as Cox and Rubinstein (1985).

The firm notes that total potential outlays total $1,153 in current value terms which is greater than the current estimated value of the venture but it is also noted that the potential value of the venture is subject to high market demand uncertainty with estimated volatility in the range 20% to 45%pa. The firm also believes market circumstances are such that it could expect volatility to reduce by perhaps 5% over the year.

Should the firm begin Phase 1?

7.3 The solution

The solution that follows provides a base estimate using the mid-point volatility together with sensitivity testing of the whole volatility range expected.

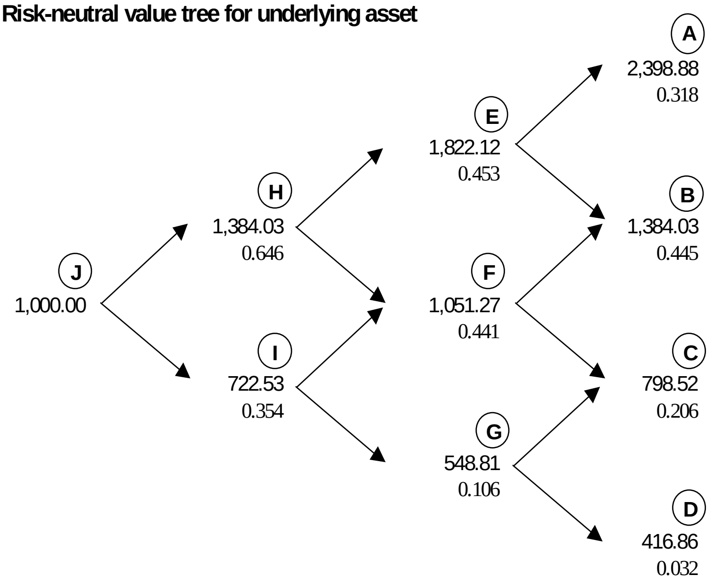
Sequential Compound Option

Low volatility	20%	pa	
High volatility	45%	pa	
Start-up cost	$100		$1,300
RADR	15%	pa	

	Phase 1	Phase 2		
	Yr 1	Yr 2	Yr 3	
Current PV of underlying (S) =	$1,000			
Investment cost to begin next phase (K) =	$400	$750	$800	
Years option is live (t) =	1	1	1	
Continuous risk-free rate (r) =	5%	6%	7%	
Volatility of underlying asset (σ) =	32.5%	27.5%	27.5%	pa
Binomial tree time step =	1.00	1.00	1.00	
Risk neutral u = exp(σ√t) =	1.384	1.317	1.317	
Risk neutral d = 1/u =	0.723	0.760	0.760	
RN probabilities π = (1 + r - d)/(u - d) =	0.495	0.539	0.557	
Real world u =	1.394	1.338	1.338	
Real world d = 1/u =	0.717	0.747	0.747	
Real world probabilities	0.646	0.701	0.701	

See Attachments 1 and 2 for meaning of terms

Risk-neutral value tree for underlying asset



A real world value tree has not been produced because it is very close to the risk-neutral tree - refer to factors above and text of paper.

Real world probabilities (from time 0) of reaching each node are shown beneath value of asset to left. The following probabilities can be calculated.

Probability that firm will start Phase 2

Node H =	0.646
Node I =	0.00
	0.646

Probability that firm will start Phase 3 once Phase 2 is started

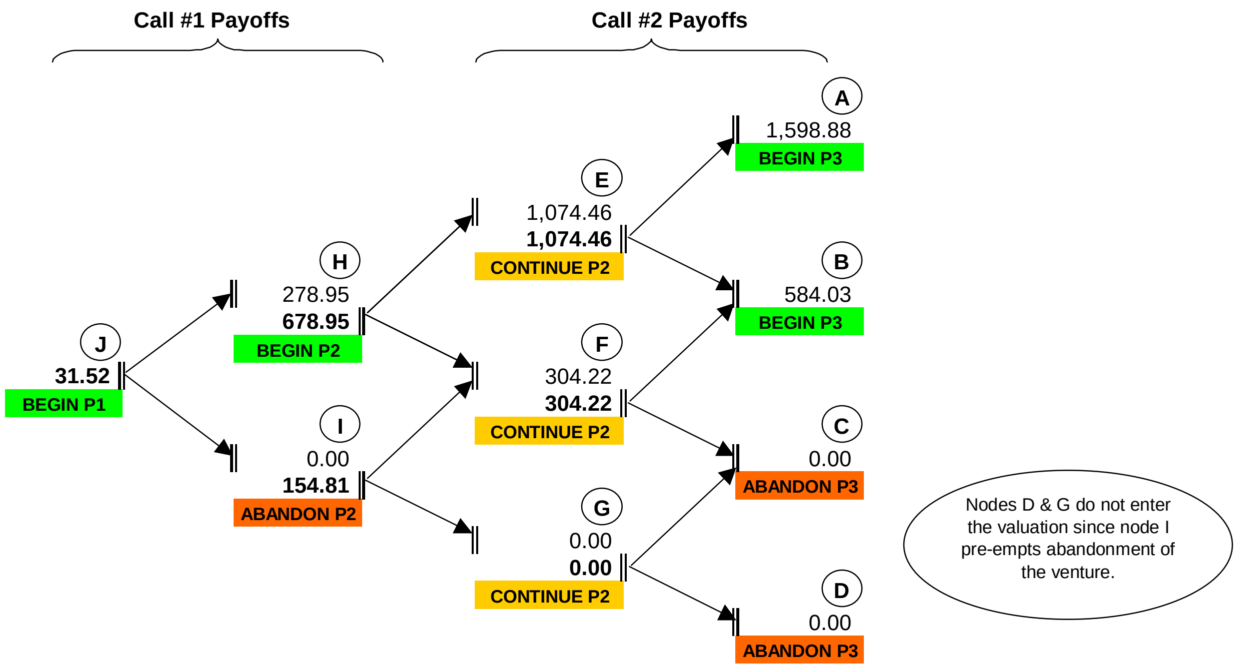
Node E =	0.701
Nodes F&B =	0.210
	0.911

Probability that firm will start Phase 3 once Phase 1 is started

0.588

Option value tree

Call #1 depends only on the value of Call #2



Cell A
Optimal value of decision at expiry = Max(Exercise value, 0) = = Max(2398.88 - 800, 0)

Cell E
Option value = (pi*Su + (1-pi)*Sd]/(1 + r) = [0.5574 * 1598.88 + (1 - 0.5574) * 584.03] / 1.07
Optimal value of decision at node = Max(Exercise value, Continuation value) = Max(1822.12 - 750, 1074.46)

Cell J
Option value = (pi*Su + (1-pi)*Sd]/(1 + r) - startup cost = [0.4950 * 278.95 + (1 - 0.4950) * 0.00] / 1.05 - 100

Sensitivity Testing

Volatility	$31.52	
20%	-$37	ABANDON
21%	-$31	ABANDON
22%	-$25	ABANDON
23%	-$20	ABANDON
24%	-$14	ABANDON
25%	-$9	ABANDON
26%	-$3	ABANDON
27%	$2	BEGIN PHASE 1
28%	$8	BEGIN PHASE 1
29%	$13	BEGIN PHASE 1
30%	$18	BEGIN PHASE 1
31%	$24	BEGIN PHASE 1
32%	$29	BEGIN PHASE 1
33%	$34	BEGIN PHASE 1
34%	$40	BEGIN PHASE 1
35%	$46	BEGIN PHASE 1
36%	$52	BEGIN PHASE 1
37%	$58	BEGIN PHASE 1
38%	$64	BEGIN PHASE 1
39%	$70	BEGIN PHASE 1
40%	$76	BEGIN PHASE 1
41%	$82	BEGIN PHASE 1
42%	$87	BEGIN PHASE 1
43%	$93	BEGIN PHASE 1
44%	$99	BEGIN PHASE 1
45%	$105	BEGIN PHASE 1

Some conclusions

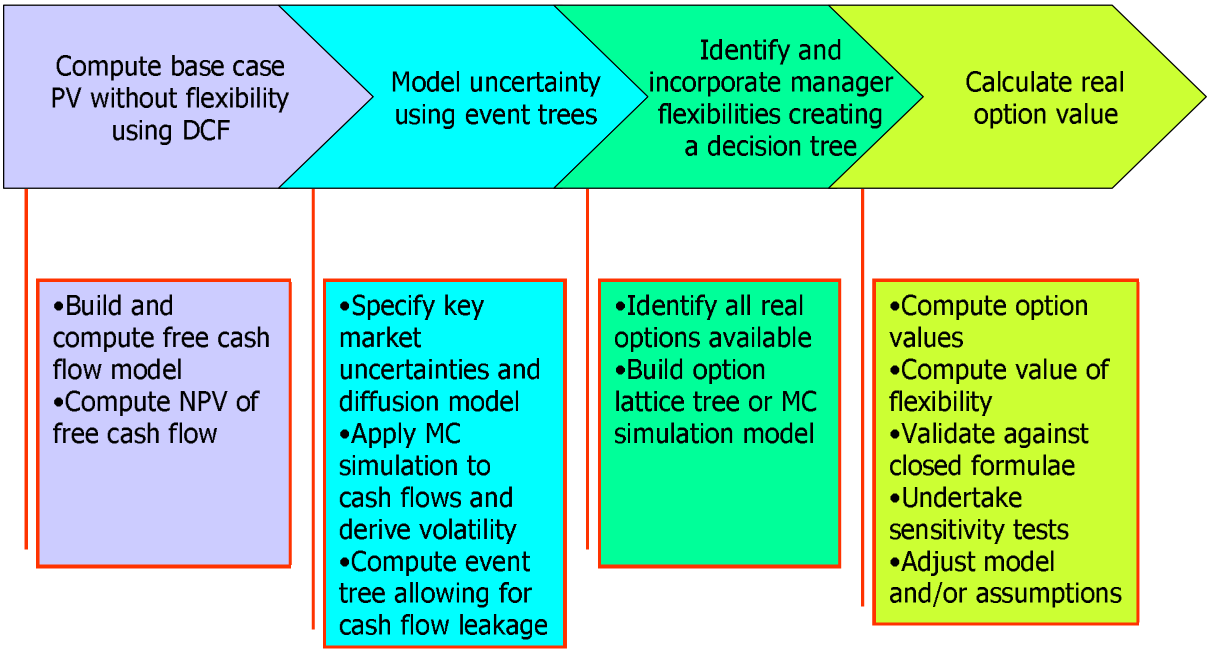
The value of option is $32 using a volatility mid-point in the expected possible range, 32.5%.

At this volatility, the likelihood of going to Phase 3 is 59%.

Nonetheless, based on the sensitivity tests, as long as the expected volatility is greater than 26%pa, it is worthwhile to begin Phase 1.

7.4 Valuation framework

The following diagram summarises the modelling steps suggested by earlier parts of this paper:



Adapted from: Copeland & Antikarov (2001)

Of course, this really only represents the analytical part of the real options approach. No analytical work can take place except within some form of general framework of problem definition, scoping, resolution, communication and feedback. Amram and Kulatilaka (1999a,Chp7) provide a framework for undertaking ROA with emphasis of the whole problem, both strategic and analytical. Their framework includes the following steps:

1) **Set up the decision frame**

   What are the key downstream decision points?
   What are the key sources of uncertainty that make flexibility valuable?
   What downstream investments might be required?
   What's the business payoff?

2) **Value the investment opportunity** (as per above)

3) **Review the results** (as per above)

4) **Redesign the project**

   Can the value be increased?
   Can the risk be reduced?
   Can the downstream investment opportunities be expanded?
   Does the project line up with risk/reward pricing in financial markets?

5) **Get ready to execute**

   What are the trigger points for the next decision?
   Who will have the authority and information to make the right decision at the right time?
   Can we live with project abandonment?
   What are the full costs of keeping these options alive?
   Do the future capital demands fit within the budget?

Many readers will immediately recognise that the Amram and Kulatilaka framework is essentially an application of what actuaries refer to as the 'actuarial control cycle'.

7.5 What we have not considered

There is a wide range of problem variations that ROA can be applied to as evidenced by the different forms that real options take—see Table 3. The illustration in this section, while hopefully illuminating to readers, has only hinted at how the techniques are applied.

For a truly comprehensive treatment the paper would have needed to cover and fully illustrate the technical aspects of such areas as:

- switching options, abandonment options, and exit-and-enter options;
- value leakage during the period of the option;
- variable volatility, interest rates, exercise prices and exercise terms;
- simulation to solve American-type options or derive asset volatility;
- the interaction effects of multi-option investments.

There is a huge and still growing body of research literature on all these and other aspects of ROA and which the reference list at the end of this paper represents only a starting point (although many of the most notable works are included). Most reference texts, while generally comprehensive, are pitched at the entry level and therefore do not provide a complete coverage of such topics.

8. WHEN ROA MAKES A DIFFERENCE

8.1 Introduction

The fundamental technical change that ROA has made is the break with the idea employed by other forms of traditional valuation (including DTA) that it is always appropriate to adjust for the riskiness of cash flows by means of adjustment to the discount rate.

Nonetheless, ROA is not a panacea for all valuation problems—far from it. Its usefulness in any situation depends on a number of elements in the valuation problem all coming together at the same time. To begin with, Dixit and Pindyck (1995) note that for any decision to have option value, three fundamental requirements must be met: (1) the decision is not a 'now-or-never' decision, ie it can be postponed; (2) the outcomes of waiting are both uncertain and losses could occur; and (3) once the decision to exercise or abandon the option is made, it is irreversible.

We will first look at the fundamental concept of irreversibility a little more closely before looking at the four main practical requirements that should be met before it is worthwhile to undertake ROA. That is, even if real options do exist, the additional effort of ROA may not be warranted:

- high market uncertainty
- high management flexibility
- low pre-emption risk
- indeterminate base NPV.

8.2 Investments are mostly irreversible

Dixit and Pinyck (1994, 1995) discuss in depth the importance of irreversibility to investment decision making. ROA does not apply when, in the unlikely situation, a decision to invest is reversible, ie that it can somehow be undone and the investment expenditures recovered should market conditions turn out worse than anticipated. Options to defer investment, for example, can only have value if the decision to invest (exercise) is irreversible, or substantially irreversible. Clearly, if one could recover invested funds at original value, then the ability via an option to limit downside risk has no significance.

The notion of irreversibility may seem at first to fly in the face of the fact that many or most assets will have (or will be expected to have) value greater than the cost of acquiring them. After all, one need only sell the asset to crystallise that value and recapture those costs. The problem though is in practice, when a firm wishes to sell an asset it will quite possibly not be at a time of the firm's choosing, perhaps following severely adverse changes in market conditions or a forced sale through reduced performance, increased running costs or general mismanagement of the asset. The prospect of recovering of even a substantial part of the full value of asset and associated investment costs may therefore be quite low. This applies particularly to firm specific economic investments such as marketing and advertising, single purpose shop and office fitouts, hiring and firing costs, but Dixit and Pindyck (1994, pp8-9; 1995) argue that it is almost universal.

The notion of irreversibility is often seen in the unwillingness of management to 'pull the plug' on non-performing assets. Nonetheless, using option theory, Dixit (1989) demonstrates how the entry price may be significantly higher than the exit price to allow for the fixed costs associated with closing and reopening (which also includes rebuilding the asset if its infrastructure has perished while closed). The gap between the two is wider than even standard economic theory of variable and fixed costs would suggest. The same situation arises when firms consider temporarily withdrawing from markets or laying off staff during economic downturns[70].

Another aspect of irreversibility is seen in tbe fallacious argument that 'sunk costs' (ie expenses already incurred to acquire, maintain or improve an economic asset) should somehow be recovered well beyond the point of no return[71].

8.3 When market uncertainty is high

An option holder does not lose from increased market uncertainty if things turn out wrong but gains if they turn out right.

When there is significant market uncertainty about the future, and material new information is expected to arise over the period of the option which will resolve the uncertainty, then the real option becomes more valuable. This information could be in the public arena, for example government policy, interest rates, and competitor actions, or internal to the firm and therefore under its control, for example results of research or pilot trials. This means that the time value of the options will be high relative to assets in place.

What is not stated (but perhaps implied) by writers on the subject of real options is that the market uncertainty that one is trying capture in ROA must, in the author's view, also be:

- ***Relevant.*** The possible future states of the underlying asset are (materially) exposed to the specific area of uncertainty.
- ***Resolvable.*** The specific uncertainty must be resolvable over time by some process of information discovery, ie there must be a reasonable likelihood of receiving new and material information over the life of the option.
- ***Measurable.*** There are many situations where uncertainty cannot be quantified in any meaningful sense (whether objectively or subjectively), where true ambiguity exists and where more sophisticated analytical tools of evaluation must be employed. Examples include entering emerging markets such as China, opportunities that arose at the time Germany was reunified, or the flow-on impacts, both economic and political, following the 11 September terrorist attacks in the US.
- ***Residual.*** ROA cannot be a replacement for research and analysis to measure *knowable* uncertainty, to identify its source, causes, and impacts, for example: demand/sales trends, performance of existing

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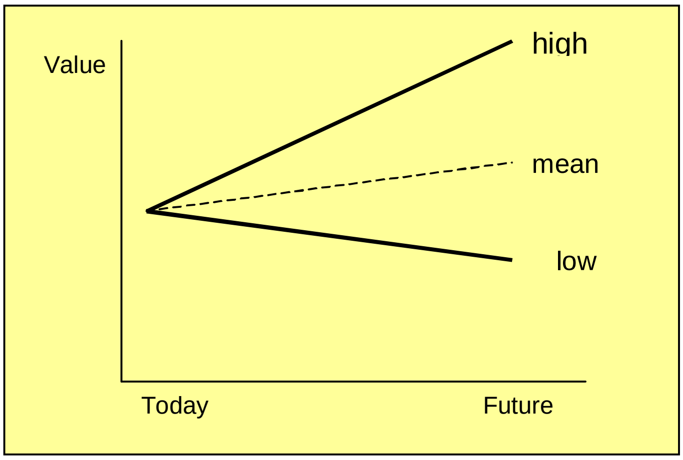
70 The term used to describe the failure of investment decisions to reverse themselves when the underlying causes are fully reversed is 'economic hysteresis'.

71 Sunk costs should be ignored in an economic valuation. What matters are those cash flows about which decisions can still be made, including the opportunity costs of tying up resources which could be better deployed. To illustrate, an economic asset may have current positive economic value although sunk costs may be higher. A decision about the worth of the economic asset should focus only upon its current economic value and that of the alternative uses of the economic asset and of other economic asset options; the sunk costs-no matter how high-are not relevant to any opinion of economic value.

technologies, competitor activity. Residual uncertainty is the type of uncertainty that only time and/or effort can resolve such as R&D of a new medical drug, changes in government policy and directions, success of a sequel to a block-buster movie.

The extent of market uncertainty can be visualised in the side figure[72], dubbed by some as the 'cone of uncertainty' but which is more familiar to actuaries as the 'funnel of doubt', a term first coined by Redington (1952).



If the future is clear enough, ie a single forecast is precise enough for determining strategy, then traditional DCF would typically be the analytical tool-of-choice; ROA would not be warranted. If the future were truly ambiguous, ie no basis exists to forecast the future, then ROA would be as misleading and inappropriate as any other commonly used analytical tool. In such cases other techniques should be considered[73].

8.4 When management flexibility is high

There are essentially seven kinds of management flexibility in regard to real options, the first five relating to assets-in-place or projects already commenced, namely: to expand scale or scope; to contract scale or scope; to abandon, to stop-then-start, and to switch. The other two relate to investments not yet commenced: to defer investment; to commence investment in incremental stages. Copeland has said that none of these different kinds of flexibility are captured in NPV:

> 'I've been teaching corporate finance at the graduate level for 30 years now—at UCLA, NYU, MIT, now at HBS—and I've come to the point of view that NPV systematically undervalues everything, simply because it fails to capture flexibility.' – an interview with Copeland (2002)

For real options to have material value and therefore for ROA to be worthwhile, management must have sufficient flexibility to respond to events as they unfold and as uncertainty is resolved. In practice, this means:

(a) management is entrepreneurial, ie it has the smartness and ability:

- to identify the strategic opportunities and/or thus create the options
- to manipulate the levers or drivers of option value

(b) management understands that timing is everything, ie it has:

- the instinct to recognise the optimum time to take advantage of the options, ie exercise them;
- the willingness and confidence to act at 'the right time'

(c) the firm has organisational and business structures in place to support and promote real options planning, ie management has:

- the authority to make and implement decisions—and without delay[74]

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[72] If share prices follow a Wiener process (limiting case of discrete geometric Brownian motion) as usually postulated in financial economics, uncertainty increases with time horizon but at a decreasing rate, ie volatility is $\sigma\sqrt{t}$. If they follow a mean-reverting processing, the uncertainty (as measured by the volatility measure) stabilises at a lower level the further one looks into the future.

[73] Courtney et al (1997) provide a useful framework for thinking about the different 'levels' of uncertainty that exist in any situation of strategy formulation and how to judge which types of techniques should be deployed to help make strategic decisions in the face of such uncertainty. They suggest some less familiar techniques such as latent-demand research, pattern recognition, and non-linear dynamic models.

- the budgets and capital resources to respond[75]

In short, management should not consider real option value unless it is willing and able to act on it.

Just because a firm has certain real options does not mean they will be intelligently exercised. The Strategic Decision Group (see web site references) point out that since there is normally no explicit contract to identify the option terms and conditions (as there is in financial options), it requires a rigorous management discipline to crystallise the real option value. This requires:

- Continuous focus on the stream of decisions. An option plan is a built-in obligation by the firm. A sure way to lose value is computing the option value, price accordingly, transacting, and then not following through.
- Treatment of uncertainty as a source of opportunity. Otherwise it may be feared and ignored and thus a potential competitive advantage may be lost.
- Allocation of resources and budgets to hold and execute the options. Acknowledgment of real options means simultaneously paying for things management may not want or need.

As has been said: 'Actions, not calculations, capture option value'.

8.5 When risk of pre-emption is low

In many types of competitive situations, any delay in investment may not be appropriate and option value may therefore be illusory. A firm usually does not have exclusive rights to exercise a real option and pre-emption by competitors may be value destroying.

For example product, technical, and marketing knowledge may be gained by waiting and learning from competitors who enter a market or develop and offer a product first. If the likely cost of later entry or recovery is too high (including being barred from entry), some form of option may need to be acquired eg licence, 'handcuffs' for sales force. One may need to exercise early if competitor actions threaten to decrease the option value unless it is captured immediately.

Section 6.7 provides further comments on the impact that competitors can have on option value and the circumstances when it is still appropriate to allow for option value.

Let us consider for a moment how this applies to emerging businesses, such as those leveraging off the Internet (the 'dot.coms'). For many of these businesses, the intrinsic value is the creative ideas of their owners and management—what the managers *might* do—rather than the assets, products and strategies in place[76]. These businesses are also characterised by high uncertainty associated with new technologies, markets, services and consumer responses. It has been said that such businesses are best valued using an ROA approach. From this perspective, one sees that ROA acknowledges better than traditional DCF that value is ultimately determined more by *intellectual* capital rather than *physical* capital, ie by the knowledge and creative skills of owners and managers of firms to make productive use of physical capital.

The bursting of the dot.com bubble perhaps suggests that the market, while seemingly 'valuing' the opportunities and options that were perceived to exist (and putting aside the emotional aspects driving the market), ignored the fact that most Internet players lacked exclusive rights to exercise their options. The

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[74] McDonald (1989) notes that if decisions get caught up in formal processes or red tape, the opportunity may pass too quickly to grasp.

[75] There also generally needs to be budget provisions in anticipation of the creating, nurturing, and harvesting the options. Acknowledgment of real options means simultaneously paying for things management may not want or need.

[76] Of course, ROA, like any form of economic valuation, does not promise that value determination will be synonymous with or a predictor of market valuation. In this regard, it seems that company analysts have so far considered ROA more as a way of *rationalising* market prices rather than a way of *predicting* them or estimating economic value.

reality was that most of those options were illusory and valueless. It may be that many analysts, who were using ROA to rationalise the high market prices at the time, were also overlooking the exclusive rights assumption embedded within the ROA method and therefore missed the warning signal.

8.6 When base NPV is indeterminate

When NPV without consideration of real options is very positive, the extra work entailed in undertaking ROA would not seem to be warranted; one just goes ahead with the investment full steam. If NPV is very negative, it may be obvious that no amount of ROA is going to affect the decision not to invest. From an option's perspective, we could say that when the asset is 'deep-in-the-money' (or 'deep-out-of-the-money'), ie time value is negligible, then immediate exercise (or abandonment) is required.

On the other hand, when NPV (without consideration of real options) is close to zero, ie small relative to the size of investment, then, apart from reconfirming the veracity of the valuation model and the assumptions, one should consider whether there are real options which are being modelled incorrectly or perhaps not at all. If significant embedded options exist or can be created, then a borderline 'now-or-never' investment could become, for example, a clear decision to postpone investment or stage an investment. This is equivalent, from an options perspective, to time value being at a maximum when investment options are 'at-the-money'.

9. ACTUARIAL PROBLEMS

9.1 Where can actuaries use ROA?

Actuaries lack neither the technical skills or commercial acumen to be very effective contributors to ROA. The key problem remains though in identifying the possible areas of application. As a prelude to this, actuaries must be able to understand at least the rudiments of ROA, its strengths and weaknesses before their antennae will be tuned to the necessary frequencies to spot the opportunities. The author hopes that this paper has gone some way to this end.

Nevertheless, the paper would not be complete without some suggestions as to where actuaries could usefully deploy ROA. Three areas come to mind:

- economic valuations, particularly of firms
- strategy and project evaluation
- 'wider fields' such as energy, natural resources, environment

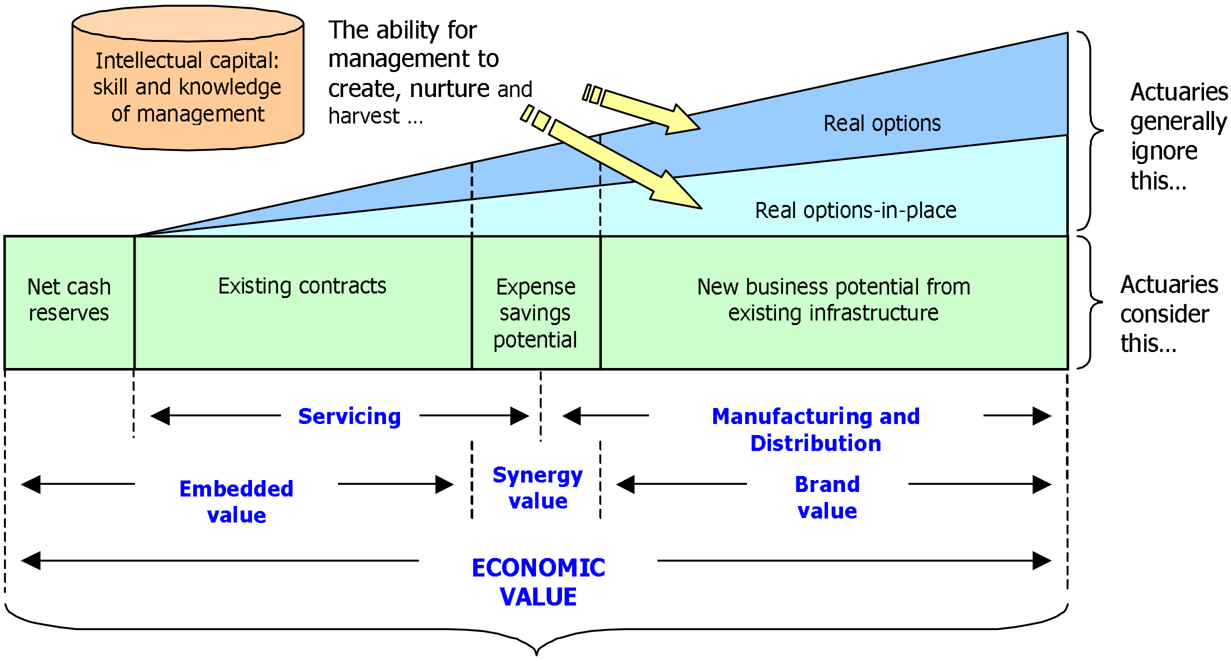
9.2 Economic valuations

The diagram below illustrates the economic valuation components of a firm from different perspectives.

The relative significance of each of the components would vary widely from a traditional retailer to a dot.com, from a green fields business to a mature business, and from a manufacturer to a consulting practice. For some, the components may not even exist (for example, consulting practices may have little in the way of cash reserves or long term contracts) or else may be negative (for example, cash reserves for a dot.com) or. While one could perhaps quibble with the accuracy of the labelling, the messages should be clear:

(a) From a whole-firm perspective, all components of the value chain may have embedded real options or the potential for management to create real options, but there is generally more real option potential in strategies focusing on new opportunities for revenue generation. This derives from a firm's intangible assets such as brand equity, corporate culture, employee skills, patents and trademarks, and marketing skills, as well its investment in R&D and training programs[77]. All of

[77] The performance measure EVA® treats such expenses as R&D and training as investments as distinct from operating expenses. While this is better than nothing, at best it is a crude way to allow for real option value since such expenses merely represent the *cost* of acquiring the options.



Different perspectives of value attribution

these provide the foundation for value creation but the 'flagstone' is the firm's stock of intellectual capital, in particular its ability to transforms ideas into real businesses.

Unfortunately for valuers, identification of these possibilities is more likely to be speculative and therefore harder to measure, not the least because of the long time dimensions involved. Phelan (1996) refers to one source that has estimated that between 56% and 125% of a firm's total value is comprised of strategic growth options that can only be realised beyond an eight-year forecast period. As Phelan states, the market at least believes the future opportunities generated by current investments are very valuable.

(b) Have actuaries considered significant strategic investment decisions already in place for the real options they contain? This could relate to strategic decisions for any of the value components of the business but most particularly in the infrastructure in place to capture new business, for example a strategy to enter a new market in incremental stages is a real option. There may also be real options to accelerate or delay the steps to enter the market depending upon how market conditions evolved or the success of the investment opportunity itself.

(c) When prices paid for acquisitions significantly exceed the actuarial 'appraisal value', are we seeing evidence of value that the acquirer 'knows' intuitively is there but has not been captured by the traditional DCF method of economic valuation? Should we be trying to measure it, particularly if clients are seeking a *market* valuation?

As a practical point and partial answer to this question, Nutter (2001) advises that we do not have to hunt for every real option that exists or could exist:

> '[F]or firms with a small number of very significant options, such as firms with a small number of strategically important patents, it is worth attempting to value the options in a firm's portfolio of options explicitly. For firms with a large portfolio of unspecified options, it may be practical to value the company by modelling only key features such as revenue and variable costs'.

Nutter reminds us (pp18-19) that option interaction and interdependencies generally reduce the total value of the portfolio, ie exercising one real option to invest may 'kill' another. Unless this is considered by a valuer, gross overvaluation of the portfolio is possible[78].

As an example of ROA in action in M&A, see Sinha (2002) who considers the real options framework as a way to rationalise the price recently paid by MetLife for a major acquisition and where public concerns were expressed that the price far and away exceeded the underlying value.

Boer (2002) provides an interesting history of how ideas for the valuation of firms have evolved post-WW2 and reviews the two most recent innovations—the intellectual capital 'solution' and real options—to solve the 'crisis in valuation: when market value didn't track economic value'. These trends led to the attempts to apply ROA to rationalise the apparent 'blue sky' embedded within certain market stocks, particularly Internet companies and their supporting technologies[79]. A general conclusion of much of this work is that the market, while having its periods of 'irrational exuberance', is rationally pricing Internet stocks, not so much for the *expectations* or *potential* of options that already exist in the firm (which ROA may be able measure), but for their option *possibilities* or even dreams, ie speculative options. Perhaps no analytical technique will ever be able to credibly measure the latter since they depend very much more on one's view of the ideas, plans, expertise and intellectual capacity of the firm's leaders and management[80]. In the words of Pindyck (1988):

> '[W]e find that in markets with volatile and unpredictable demand…much of the market value of these firms is due to the possibility (as opposed to the expectation) of increased demands in the future.. This value may result from patents and technical knowledge, but it also arises from the managerial expertise, infrastructure, and market position that gives these firms (as opposed to potential entrants) the option to economically expand.'

It really has little to do with levels of current cash flows, profits or cash reserves (except for the possibility that bankruptcy will occur before the ideas have a chance to reach fruition). One thing seems to be almost universally acknowledged by academia and analysts alike though: However tenuous the credibility of ROA to such situations, traditional DCF, at least in this field of valuation, has failed[81].

Finally, Pettit (1999), a proponent of EVA®, value based measurement, and real options, draws the following conclusion from his analysis:

> 'In the late 1990s, under the pressure of rising market expectations implicit in any long bull-market, companies face unprecedented demands for profitable, long-term growth. In most industries, and the market as a whole, market capitalisation is largely premised on profitable growth beyond the present value of all current operations – positive NPV investments that have yet to be discovered. In this environment, the value of intangible investments into organisational software – brands, processes, patents and intellectual capital – have become the most strategic investments an enterprise can contemplate. Financial policy must be updated and framed within the context of this new world – a financial policy consistent with, and supportive of, growth needs of business strategy, and the expectations of the market.

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[78] Trigeorgis (1993a) also finds that the incremental value of an additional option, in the presence of other options, is generally less than its value in isolation, and declines as more options are present. Therefore the impact of ignoring some or perhaps many options in the valuation of a firm or portfolio of options is most likely inconsequential.

[79] For example, Schwartz and Moon (2000) have looked at the market share prices of Amazon.com and Kellog et al (1999) considered a pharmaceutical firm with significant R&D. Nutter (2001) provides an easily read review of ROA and some of the attempts to use it to rationalise technology stock prices. Milano (2000) offers the Stern Stewart view on Internet valuation while Ashton and Mann (2001) 'debate' the real option value in market prices for Amazon, Yahoo, Nokia, Berkshire Hathaway and others.

[80] Mauboussin and Hiler (1999) write that the key value drivers of Internet stocks are neither obvious nor well understood. They identify four of them: business models (in particular the *sources* of cash generation), the so-called 'network effect' (economies of scale driven by demand, not supply), first-to-scale advantages, and real options.

[81] The real failure is the late recognition that DCF is a special case of the more general theory of options pricing and it is inappropriate to use it in situations where significant asymmetric payoffs are possible. See section 5.2 for a fuller discussion.

> Growth options, flexibility and options to defer, have all become necessary tools to manage and exploit the value of uncertainty and volatility. The financial measures, tools and management systems of the modern corporation have had to keep pace with the more complex and rapidly changing business environment. Whether managing global growth options, or the options implicit in a new business bid, executives apply much more rigorous and sophisticated analytics. The key to their successful use will be the extent to which they can be simply applied and communicated.'

The author understands that some consulting actuaries are already considering how to value brands and believes that ROA should provide additional perspectives and insights.

9.3 Strategy and project evaluation

The work of actuaries is generally associated with financial service providers, life and general insurance companies, banks, funds managers etc. These and other businesses need to constantly re-energise themselves just to at least 'stay in the pack'. They do this by a combination of practices such as rebranding or launching new products and services, diversifying into new products and services (or terminating poor performing ones), opening new distribution channels (or closing unsuccessful ones), entering new markets (or leaving problematic ones), forming alliances (or exiting failed ones), and deploying new technologies to access customers and for customers to access them. In some cases, usually because of the heavy capital costs of getting it wrong, the firm decides it would be prudent to 'test the waters'. This is another way of saying that firms already well appreciate the value of keeping their options open.

Firms may therefore have valuable options: to learn, to expand, to contract, or to exit. If we miss the value that may be hidden, it is quite possible the wrong investment decision will made when the firm considers these and other alternative uses of its capital and human resources.

Some actuaries already have a presence in corporate strategy and capital budgeting but what about strategies at the business unit level?

Point 9.2(c) above in relation to intuitive value is also relevant to the consideration of projects within a firm. Phelan (1996) quoted a 1991 survey of 93 of Australia's top 150 companies which found that 76% of respondents had accepted projects that did not meet the defined company benchmark. Of the 76%, a total of 94% cited 'strategic reasons' as the basis for their departure. Phelan concludes that it is clear that many companies have intuitively identified that DCF is deficient in its valuation of strategic projects.

Again it seems that there is much the profession could offer in this area too—if it were suitably equipped.

9.4 Non-traditional areas

There may be greater possibilities outside mainstream actuarial work for the application of ROA:

- ***Energy.*** Hinton (1997) has written about the opportunities for actuaries in energy markets concluding that:

  > '… using the methods developed in the insurance industry, actuaries can assist in designing and implementing strategies aimed at maximising expected profits while minimising and controlling risks'.

- ***Natural resources.*** Brown et al (1999) state that:

  > '…actuaries are well placed to make a contribution to developing valuation methodologies and frameworks that will improve the understanding of an appropriate value to place on natural resources and ensure the resources are used in the way that best benefits society.'

- ***Environment.*** Edwards (2002), responding to an earlier article and editorial on the environment, related her own consulting experiences in this general field and encouraged the profession to 'get involved'.

It so happens that the environment and resource sustainability are receiving particular attention for ROA in areas such as forestry, agriculture, fisheries, emissions and energy resources. A quick check of the

Internet will reveal the substantial amount of work being undertaken[82]. A recent conference in Germany on 'Option Valuation in Energy and Environmental Issues' had workshops with titles like 'Real option values and the adoption of energy efficient technologies' and 'Real options and the evaluation of power plants'.

Other examples which have long lead times, large capital budgets, irreversibility of costs and consequences, and significant uncertainty might be infrastructure such as highways and telecommunications, aircraft acquisition programs, and significant government purchase programs such as in defence.

Other professionals have successfully used ROA in all these areas. Perhaps, if it is not being done already, this represents an opportunity for actuaries to look, learn and apply some 'gardening skills' from our professional 'neighbours'.

Some readers may conclude now that merely by brushing up on their technical skills and with a smattering of understanding about the strategic setting of ROA, they can plough straight into this area. With this in mind, the author believes some cautionary points are worth making.

10. SOME CAUTIONARY NOTES

10.1 Do not underestimate the selling job

For many or perhaps most organisations, introducing ROA is taking a big step forward because real options is about embracing dynamics and uncertainty in strategic decision making. Depending upon where the firm's management is starting from in their use and understanding of DCF, as well as the actuary's professional competencies in the theory and practices of strategic decision making, this can be seen as a large leap, or much ado about nothing.

Copeland and Antikarov (2001), after reviewing a case study in depth, provide a number of useful pointers for those attempting to introduce ROA in their organisation, and which are paraphrased below:

Start simple. First employ it in a relatively simple situation with easily observable results and where management buy-in is minimal, ie where you believe ROA will provide clear evidence of its benefits for minimal risk

Get buy-in. Seek sponsorship from the highest possible level in the organisation and from potential users. Let them provide input and keep them informed.

Understand change culture. Understand the atmosphere in the organisation for change and its preparedness to adopt and promote new ideas. Be prepared for inertia.

Seek some help. Sometimes the combination of an internal champion who understands the business and an external adviser who may have the theoretical knowledge can make the difference[83].

Give intuition credence. Where possible, use ROA to confirm and support management intuition, rather than pointing out where intuition may have it wrong. Section 10.4 expands on a particular aspect of this.

Avoid the black box. Models should be transparent to management and consistent as far as possible with existing models (while recognising their limitations and assumptions). Decision trees and the Luehrman option space diagrams (see Appendix 4) are useful visual tools.

Reward risk-taking. ROA implies taking on greater risk than management may normally be comfortable with, especially it does not have a diversified portfolio of real options. Management need to know that

[82] Conrad (1997) was apparently the first to apply ROA to value forest resources based on social benefits. See also footnote 12.

[83] We suppose a couple of consultants could not resist slipping this one in!

they won't be canned for getting it wrong. This then strays into the area of alignment of remuneration structures with accountability.

Align with corporate finance. ROA decision making takes place in the operational and strategic ends of an organisation but managers are usually required to justify capital investment using cost of capital rules provided by the finance department (often centred around CAPM). Closer coordination is required including the framing and ongoing management of budgets.

It is useful to compare this list with the storylines of the case studies in section 2.4.

10.2 Do not overplay the numbers

There is a natural temptation for technocrats to dwell too much on refining a model and its assumptions. The author believes there are two potential risks associated with this:

Solving the wrong problem. ROA may uncover hidden value from initial business moves but it has been said that people are sometimes using option value to support poor initial moves. Management should therefore not apply the techniques without consideration of whether there may be a different way to secure the future option. For example, management could question whether it can undertake the suggested downstream investment more directly, or with some less expensive option eg leasing.

Therefore, once sufficient number work and analysis have been done—sufficient to form a reasonable appreciation of the dynamics and value drivers of the problem—it is important to shift one's mindset to an option creation frame.

Overanalysis-undercommunication. There is no point in refining a model to the nth degree and losing the communications battle. This is taken up by Luehrman (1997, 1998a, 1998b) in a series of articles on so-called 'option-space' and how a simple visual tool and some simplified analysis can go a long way to breaking communications barriers and achieving useful results. Appendix 4 provides a summary.

While Luehrman's proposition is driven by commercial imperatives, primarily the risk of losing the communications pitch through overanalysis, the author believes an important rider must be added: There is probably just as much risk of management making flawed decisions from oversimplification of the problem and its analysis.

In the author's view, perhaps the key to using a simplified approach effectively is not to focus on trying to get even a single rough value but rather on trying to establish the likely boundaries in which the 'correct' value is expected to lie. Still, the temptation we know will be to 'split the difference'.

10.3 ROA does not guarantee a good outcome

Someone who plays a hand of poker and wins the pot obtains a good *ex-post* outcome. Yet, the decision to bet on the hand dealt may or may not have been a good *ex-ante* decision, either because of the probabilistic 'value' of the hand or because of the financial circumstances of the player. More generally, a bad decision about any uncertain matter may lead to a good outcome and conversely a good decision may lead to a bad outcome. The quality of a decision must be evaluated on the basis of the decision maker's alternatives, information, values, and logic *at the time* the decision is made, and before the outcomes can be known.

Likewise a decision based on positive NPV after taking account of embedded real options does not guarantee success any more than a NPV (positive or negative) without recognition of embedded real options. ROA provides a 'fair' estimate of the economic value of an asset or project after taking account of management flexibility.

This point may seem obvious but the author believes it is open to misunderstanding or to giving false comfort to decision makers. It may be believed by some that ROA somehow assures that management will always make value accretive decisions at the optimum time. Of course it says nothing of a sort:

simulation and sensitivity tests still have a key role to play in portraying, for example, the uncertainty surrounding the assumptions made and the possibility that losses will be suffered[84].

10.4 Do not lightly dismiss informal methods

Management understand these three things: a firm's future investment options and alternatives may be more valuable than current investment proposals; capital resources are limited; and decisions taken today will lock an organisation into paths which may be difficult and/or costly to extricate itself from. A number of researchers and writers[85] suggest this is very much behind the common informal practices of managers who may set harder benchmarks for investment proposals such as very high hurdle rates, very short payback periods, or significant dollar margins over break even[86]. If so, are managers being rationale? Or, as McDonald, (1998) puts it, is it possible that firms can make investment decisions that are close to optimal by following simple the rules of thumb commonly used by firms such as those just mentioned?

Using the decision rules quoted in section 2.2, it is easy to see that NPV_{DEFER} could be allowed for in an informal way by adjustments to the traditional decision rule such as:

- Invest if $NPV_{NOW} >> 0$
- Invest if $NPV_{NOW} > 0$ using a RADR higher than the cost of capital
- Invest if payback period much shorter than normally required.

All these approaches may therefore be rational expedients to allow for the opportunity cost of 'killing off' what are perceived to be valuable future options. If so, the author believes management should be given credit for recognising that opportunity costs do exist and should be allowed for. In fact the analytical research by McDonald referred to above tentatively concluded that, for a wide range of project characteristics, the rules of thumb might still provide near optimal *ex-ante* capital budgeting decisions. Or, as Pindyck (1988) commented, 'Managers use the wrong method to get close to the right answer'.

The problem is, of course, by not explicitly valuing the future alternatives and options, one loses all transparency including an ability to better understand the drivers of value. This is similar to the relative merits of price-earnings valuations undertaken by equity analysts and appraisal values undertaken by actuaries.

11. WHERE TO NOW?

11.1 The promise of ROA

Although Black-Scholes-Merton and financial options came first in the 1970's, and the mathematical methods are the same, it must not be thought that ROA merely *adapts* traditional DCF and options theory to a new set of problems; rather it *extends* financial options theory. Why?

Consider the following:

(a) Referring to a number of writers on competition and strategy, Mauboussin (1999) states that strategic planning, as historically practiced, is really strategic *programming*: an articulation of strategies that already exist while advocating strategic *thinking* incorporates intuition and creativity—'Strategic

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[84] See Sick (1997) for an illustration of how this can be done.

[85] Dixit and Pindyck (1995, p107), Jagannathan and Meier (2002) and Mehta (1996, p29)

[86] This is apart from any ad hoc allowances for non-tradeability or other idiosyncratic risk of the investment, or from misunderstandings about the derivation or application of the RADR, a wish to be ultra risk averse, or perhaps myopic short-termism, ie a focus on the need for short term paybacks.

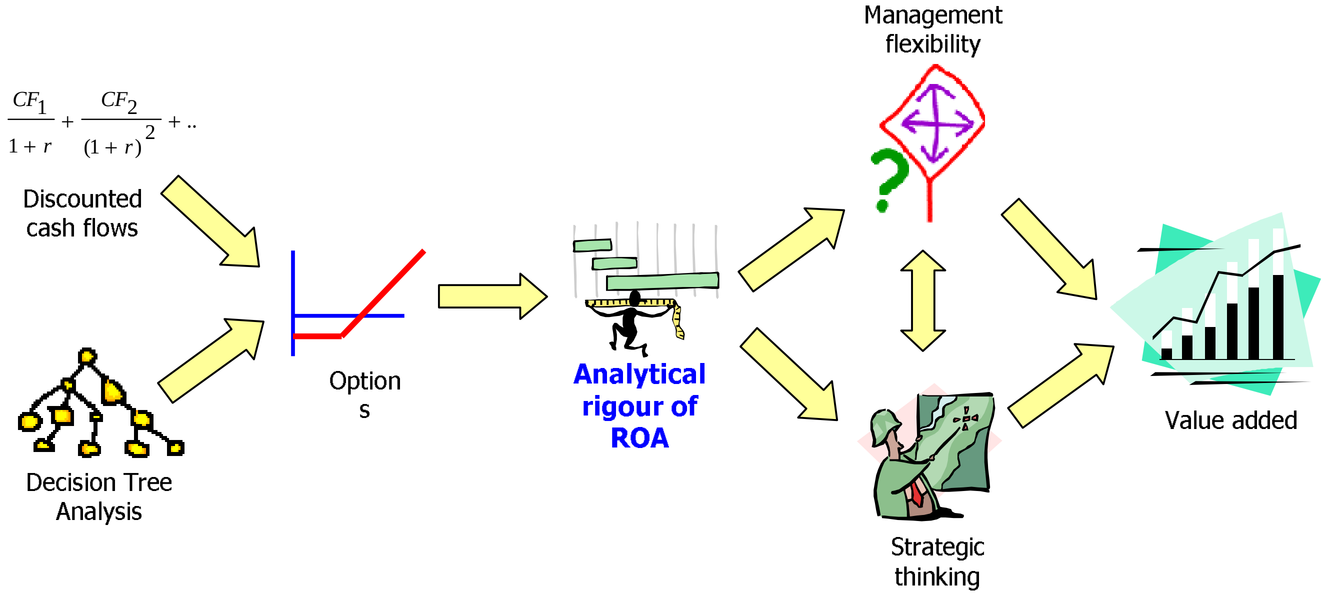
planning is DCF-based; strategic thinking is options-based'. [87] Sometimes this means that conclusions are at first counterintuitive, for example the greater the uncertainty associated with an asset, the lower its value but the greater the value of real options embedded in it[88];

(b) ROA, we have already seen, can show and explain where value may be hidden by normal DCF analysis, ie the value management often feel intuitively is there but the numbers just don't s ay it.

(c) We have already seen two examples of where management flexibility has value, for example to wait and see or to stage investments. ROA will also give pointers for where and when managers can create options or leverage value out of options; traditional DCF gives no such guidance (other than rudimentary guidance to invest now or never).

(d) For traditional DCF and DTA, RADR is an exogenous input based loosely indirectly for market prices of assets with similar risk and return profiles. A RADR binds together into a single number both the timing value of money (as represented by the risk-free rate) and *systematic* market risk (as reflected in the Beta and market risk premium of CAPM). In ROA, market risk is separately identified in the volatility measure. A practical aspect of rigour that an options framework introduces is the separation of time value of money and market risk. ROA integrates traditional DCF and DTA into a more tractable framework, but more importantly, rids DTA of its valuation flaw.

More generally, ROA offers the possibility of melding strategic thinking, management flexibility and analytic rigour, all using the well accepted and tested framework of traditional DCF and options theory.



In the end, whether one considers ROA as an evolutionary or as a revolutionary way of strategic thinking perhaps remains a moot point. The author proposes that ROA may at least, for some types of problem involving strategic thinking, help to bridge the gap between the analytical approach and the creative or intuitive approach.

Boer (2000, pp.227) reminds us though (citing Trigeorgis (1996)):

> 'Trigeorgis analyzes a business scenario in which the investor has five different real options – this is not a large number compared to real world managing. He demonstrates that each additional option adds more value to the

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[87] For a somewhat quirky but real situation, see Bughin (2000) who describes when a US television station had to manage the real option it held for timeslot of the Seinfeld series when ratings were initially poor.

[88] Busby and Pitts (1997) point out that 'In reality..most capital investments are a mixture of real options and non-flexible investments [running side-by-side], so countervailing effects of an increase in uncertainty will tend to cancel each other out'. This is the reason why traditional DCF valuation techniques may still provide reasonably robust economic valuations of a firm (which is conceptually a portfolio of investments-in-place and real options).

base case…However the complexity of the calculations also increases dramatically as multiple interacting compound options are included, and to my mind so does its distance from business reality. Hence, it would be illusional to conclude that rigorous options analysis is a substitute for managerial skill. The real conclusion is that with options included many projects are demonstrably better than [traditional DCF] alone tells us."

11.2 Areas for research

For those interested in ROA as a research frontier, here are a few examples which may excite some readers enough to undertake their own research.

Impact of taxation

This paper has not taken into account the impacts of taxation. In fact it is rare to find the effects of taxation considered in ROA and indeed options literature generally[89]. Nonetheless, taxation effects are usually both critical and complex elements within the businesses that actuaries typically work with. Neglecting taxation in ROA, as in any economic valuation, may therefore cause incorrect investment decisions.

At its simplest level, taxes are merely another cash flow item of the underlying asset in the projections. To the extent that there is a nexus between taxes (or any other items of cashflow) and the value of the underlying asset, the valuation should naturally need to model that relationship, perhaps in a similar way to how dividends are modelled in option pricing. The problems associated with Monte Carlo simulation have already been referred to in the paper; taxation increases the complications further particularly when, for example, there are timing differences between the measurement and payment of the taxes.

A particular difficulty and an area of common confusion for many valuation problems is the question of when and how to adjust the discount rate for taxes and to do so consistently with the allowance for tax (if any) in the cash flows. This is a large topic in its own right[90] and will not be taken up here except to note two things:

- Unlike financial options, real options are not discrete investments in their own right and therefore not subject to a treatment of tax separate from the underlying asset.
- Where the underlying asset generates taxable investment earnings either in the form of income or capital growth, then the risk-free rate used in the real option valuation (including that used to derive the risk-neutral probabilities) must include a suitable allowance for that tax.

The author suggests that proper incorporation of tax in ROA would be a very useful line of research for actuaries. Two possible starting points could be the discussion by Cox and Rubinstein (1985, pp271-274) who deduce the required modifications to the hedging ratio, risk-neutral probabilities and risk-free rate for financial options, and Niemann and Sureth (2002a) who analyse the integration of taxes under risk neutrality and risk aversion and who provide a useful list of references of earlier work in the field.

Game theory

Game theory, despite its early promise, has probably always struggled to establish a firm foothold in financial economic theory. Nonetheless it is beginning to make a contribution to our better understanding of the dynamics of strategy formulation and response to competitor activity, and therefore in ROA itself. The paper has already referred to the research of Weeds (2002) and Smit and Ankum (1993) in the application of game theory to real options. We are also now beginning to see books focussed entirely on this theme[91].

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[89] Niemann and Sureth (2002b) review the research that has been undertaken and consider how investment decision rules are impacted by taxation using the real options framework.

[90] The topic of the correct allowance for tax continues to generate academic research literature. For example, see Fernandez (2002) amongst many others.

[91] For example, *The Intersection of Real Options and Game Theory* by Grenadier (2001)

Genetic algorithms

Monte Carlo simulation in conjunction with genetic algorithms (GAs) has been proposed by Dias (2000) as a way to solve simulation of American-type options. The development of GAs was inspired by, not surprisingly, by Darwin' s theory about evolution.

> 'Genetic algorithms (GAs) and evolutionary computation have been around since the cybernetics movement of 1950s, but they have undergone a renaissance since the mid-1980s to the point where many walks of human endeavour are benefiting from this approach. For example, problems as different as jet engine design, electromagnetic antenna-absorber optimisation and design, analog and logic electronic circuit synthesis, structural optimisation and layout, factory and project scheduling, control system synthesis, music composition, image recognition, and automated programming have been successfully tackled.
>
> The mechanics of a genetic algorithm (GA) are conceptually simple: (1) maintain a population of solutions coded as artificial chromosomes, (2) select the better solutions for recombination (crossover) of the mating chromosomes, (3) perform mutation and other variation operators on the chromosomes, and (4) use these offspring to replace poorer solutions or to create a new generation altogether. Theory and empirical results demonstrate that GAs lead to improved solutions in many problem domains, and well-designed GAs can be guaranteed to solve a broad class of probably hard problems, quickly, reliably, and accurately.'
>
> Quoted from http://www-illigal.ge.uiuc.edu/index.php3

More general information is available at http://cs.felk.cvut.cz/~xobitko/ga

Fuzzy numbers

Because of the unquestionable difficulties of reliably assessing cash flows far into the future (as is usually required in actuarial modelling of assets with long economic lives), Carlsson et al (2001) propose a 'fuzzy numbers' approach as an alternative to stochastic methods which may fail to recognise how, for example:

- new technologies over time can dramatically change the life cycle of a large investment; or
- very large investments can sometimes become self-supportive in a way that generates significant new trends and thereby destroy historical time series patterns.

11.3 Proposals for education [92]

> 'To get others to come into our ways of thinking, we must go over to theirs; and it is necessary to follow in order to lead.' – William Hazlitt (quoted by Trowbridge (1998))
>
> 'One of the things I have discovered…is that the way I have been trained to think as an actuary inhibits my ability to think strategically. We are trained to think in a very logical way…This is a great approach for solving a wide range of problems. However, it is not a very helpful approach for strategic thinking.' – Howes (2002)

While there are numerous opportunities to attend workshops and seminars on real options valuation both in the US and other parts of the world, the author is only aware of one seminar held in Australia a couple of years ago which was devoted entirely to the subject. Nonetheless, the subject of real options is increasingly being included in postgraduate finance courses, both MBA degrees and other Commerce degrees (at least at a rudimentary level). The Securities Institute of Australia includes it as a component in their 'Advanced Valuation' subject.

Should the Institute's own syllabus now equip actuaries with knowledge of the subject?

Currently the education system for Part III of the examinations of the Institute is undergoing some extensive changes[93]. This provides the profession an opportunity to review the content of the existing investment and finance syllabus.

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[92] See Acknowledgments, section 11.6.

[93] The document *Proposed Strategy for Future Part III Education* (August 2002) available at www.actuaries.asn.au sets out the proposals in detail.

Instead of choosing two of five specialist level subjects, Part III is going to be restructured into four modules as follows:

- Module 1 'Investments' will be compulsory for all students. This aims to provide an adequate level of investment knowledge.
- Module 4 'Business Applications' will also be compulsory. This will be a non practice-specific module that allows students to use judgement in applying the knowledge and skills they have gained in the other three modules to simulated commercial problems[94].
- Modules 2 and 3 will each cover a particular practice area such as General Insurance, Life Insurance, Superannuation, or Finance. The existing specialist level subjects will be split into two parts, each examined separately with a single three-hour exam instead of the present situation of one six-hour exam.

The current Finance syllabus is broken down into 14 topics. One of these topics covers the elements of investment evaluation. There are three topics on corporate finance theory. The remaining topics cover capital markets and securities, as well as options and futures in some detail. It is unclear what material will be included in the new Module 1. Also, there is some degree of overlap between the current Investment Management syllabus and the Finance syllabus.

Real options should fit very naturally into the Finance syllabus under the new system. This is because much of the technical knowledge required to understand real options and to utilise the quantitative methods to value them are included in the current Finance syllabus.

For example it includes the various methods for investment decision making, including NPV, IRR, MISF, payback period, and discounted payback period. Further, most of the quantitative methods and techniques needed for pricing real options are covered in this syllabus, and in particular the following highly relevant material:

- basic stochastic calculus
- valuation of standard call and put options using the Black-Scholes formula
- the risk neutral valuation technique
- derivation of the Black-Scholes formula and formulae for other types of options
- the binomial tree, finite difference and Monte Carlo Simulation methods for numerical evaluation of option prices
- exotic options

As the following quote testifies, we also believe valuation of projects is an area where actuaries can most definitely add value and where our natural skills fit well with what is required. Other professionals have already moved into this area and are defining it as their own.

> 'Much of the work [of project evaluation] is based on precedent and, while actuarial techniques can add value, there is greater scope for actuaries to apply the professionalism of the actuarial methodology to what are often sound evaluation techniques… I believe that actuaries' unique grounding in the principles of compound interest gives them the ability to add real value.' – Interview with Michael Clark, June 1997 Actuary

In fact, the actuarial education system as currently structured, does not cover the valuation of ordinary equity adequately. It is briefly covered in one of the 14 topics ('Mergers and Acquisitions') of the current finance syllabus. This is a serious defect in the syllabus and one we as a profession should correct. Actuaries could and should be working in M&A and this requires a good understanding of what is involved in valuation of equities. This should be a natural area for actuaries to work in. It is recommended that the new Finance syllabus include material on both valuation of projects and opportunities, valuation of firms and other equity and specifically include material on real options.

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[94] We have heard this described as being like a 'mini-MBA'.

It is also recommended that the new Finance syllabus include material on real options analysis and expand the coverage of project valuation and equity valuation. This could be in the form of a new topic on 'Advanced valuation and real options analysis'.

11.4 Actuarial examinations

As a final observation, for the last two years, the examiners of the Institute's Finance subject have included a question on real options—despite it not receiving any specific coverage in course materials![95]

The 2001 question was inspired perhaps by the 'tech wreck' at the time and the number or general articles surrounding it which referred to real options (usually disparagingly). The Chief Examiner's brief report, on how students generally fared with the question, is illuminating but perhaps not surprising[96]:

> 'This was a real option pricing question, which is an area the students are not that familiar with. It required judgment, general reasoning and thinking skills. The students performed quite poorly as a group exhibiting generally poor logic. The question resulted in a very low pass rate, but still had good discriminatory power.'

The 2002 question required the numerical evaluation of a gold mine and the option to abandon it before all the gold reserves had been fully extracted, ie an American put option with value leakage during the term of the option. While the Chief Examiner's report did not make comment on this occasion, the pass rate was again notably poor[97].

11.5 Concluding comments

So will ROA forever remain in an actuarial backwater? Or is ROA an opportunity beckoning the profession? It is hoped that the paper has at least demonstrated that ROA:

- does not replace DCF but rather extends it to areas where it would otherwise fail
- properly accounts for market risk by separating time value of money and market uncertainty
- may help rationalise and support what might other be intuitively-based decisions
- can be utilised effectively using existing spreadsheet tools
- may help to identify and measure 'overlooked' value of a business

…but it requires:

- management discipline to capture the value measured
- actuaries to better understand the contribution of the management team to value creation

Copeland and Antikarov (2001) state they believe that ROA will replace traditional DCF as the central paradigm for investment decisions by the end of the decade. Copeland recently remarked, in response to the question as to why ROA is not more widely used if it is so good:

> 'New ideas take a long time to percolate through the management community. It took about 20 years for NPV to be accepted over simpler methods, like return on assets or payback, and it took the invention of pocket calculators to make it easy. Back in the 60s, there were no pocket calculators; it wasn't until the mid- to late '70s that most large companies were using NPV.

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[95] Both questions and model solutions are reproduced in Appendix 5 and they are available at the Institute's web site.

[96] Based largely on comments in section 9.2, the author believes the model solution (available on-line), while identifying important considerations for valuing stocks in this area, was perhaps too easily dismissive of ROA.

[97] The question was actually somewhat rigged to make the risk-free rate and the RADR the same. It was therefore not necessary to undertake a risk-neutral valuation using risk-neutral probabilities derived from the volatility measure. The model solution used a traditional 'actuarial' approach with annuity functions rather than a binomial tree. While the annuity method is perfectly sound in this case, it actually leads the student away from the usual and far more powerful and transparent method of binomial trees. The author has developed the binomial solution on a spreadsheet which is available to readers on request. The spreadsheet also shows how to provide for more granular periods eg monthly, do sensitivities, as well as break up the option value into its component drivers.

> The next revolution, the spreadsheet, in the '80s made it easier to do discounted cash flow analysis. In the '90s we' ve had PC-based programs that handle uncertainty pretty well, via Monte Carlo routines, making it much easier to implement real options. Real options are more complicated than Black-Scholes. So it takes time. It'll probably take another 10 to 15 years until real options are widely accepted as the tool to use because they' re more complicated.' – Copeland interview (2002)

He also noted in the same interview that:

> 'The leading textbook by Brealey and Meyers[98] now has a full chapter on real options. The previous edition had one page; the next edition will probably have a long chapter—or several chapters. In the next 10 years, I believe that all MBA programs will include ROA in the core curriculum.'

Ian Clark, an Australian-based real options consultant, believes it will all happen before 10 years:

> 'At present, options analysis is being used to supplement DCF methods. But it is gaining ground. It is appearing in university courses, and is part of the Securities Institute education program. Yes, it will eventually become the key tool in corporate finance. But in the end, methods like real options can only provide guidance, not a guarantee. It can give you a much broader picture of possible risks and rewards, but is no substitute for intelligence and sound judgement.' – Ian Clark, Partner, PricewaterhouseCoopers, as quoted by http://www.cpaaustralia.com.au

Time will tell. Those already working and advising in the area acknowledge that ROA has been a challenging area and will probably remain so for some time yet. Further there are those who counter that, while ROA should be used more by those who have the specialist skills and understanding, it will not become the premier valuation tool since it is too unwieldy to be accepted by mainstream valuers[99].

In the meantime, the author recommends that all actuaries—not just those about to commence their Part III studies—should undertake some form of self-education in order to meet this challenge. It will require a significant effort on the part of actuaries to learn the skills, apply them effectively, and translate results for the benefit of our employers, clients and their businesses. But then that's the business we're in!

The paper has only skirted the methods and issues; actuaries are encouraged to undertake their own exploration into the wealth of materials available from a variety of sources. The reference list should satisfy most initial needs. Wang (2002) also provides a comprehensive review of literature from economics, finance and strategic perspectives. While some actuaries may need to hone their spreadsheet skills, Appendix 6 provides a short summary of the variety of software tools that may assist.

11.6 Acknowledgments

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As always, any opinions, errors or omissions remain the responsibility of the author.

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[98] *Principles of Corporate Finance* (latest edition published 2000). This popular reference book, which has been in publication since 1983, is used by many US universities and business schools for a first course on capital markets and corporate finance.

[99] For example, see Mandon (2000) who also proposes a way that traditional DCF can be improved using multiple discount rates, although even he acknowledges the accompanying additional work and choices to made, as well as the associated pitfalls for the inexpert.

