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CENTRE FOR HEALTH ECONOMICS

# Incorporating Option Values Into the Economic Evaluation of Health Care Technologies

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# INCORPORATING OPTION VALUES INTO THE ECONOMIC EVALUATION OF HEALTH CARE TECHNOLOGIES

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**ABSTRACT**

Despite uncertainty being intrinsic to economic evaluation of health care, existing techniques for handling uncertainty remain underdeveloped compared to the formal techniques commonly applied in the business sector. This paper develops an alternative approach to handling uncertainty in economic evaluation based on the quantification of uncertainty using 'option pricing' techniques. The central feature of option pricing is that investments are rarely 'now or never' propositions. The presence of uncertainty and the degree of irreversibility of a decision makes it clear that some flexibility in the timing of a decision is often a desirable characteristic with an economic value. We demonstrate how, with modification, option pricing techniques can be applied to the decision rules for economic evaluation, illustrating how the presence of even modest degrees of uncertainty can give rise to substantial changes in the investment criterion for economic evaluation. The paper concludes by identifying the key determinants of the 'option value', namely the presence and type of uncertainty; the ability to defer a decision; and the irreversibility of the decision. The relative significance of each of these key determinants on the decision rules for economic evaluation will depend on the particular characteristics of the technology under consideration.

## INTRODUCTION

Uncertainty is intrinsic to all economic evaluation. Indeed it can be argued that, in the absence of uncertainty, economic evaluation is trivial, obviating the need for highly trained and moderately well paid economists. Uncertainty in the economic evaluation of health care technologies is no less acute than in any other sector of the economy. Yet, while the business sector has developed a number of formal techniques for handling uncertainty in investment appraisal, methodologies for incorporating uncertainty into health technology evaluation are currently at best crude, and are at worst distinctly misleading.

The conventional approach towards handling uncertainty in corporate sector project appraisal is to use *expected* cash flows as the basis for net present value (NPV) calculations. The uncertainty implicit in the project is then reflected in an adjustment to the discount rate, using methods such as the capital asset pricing model. These methods rely on the existence of a competitive market in corporate finance, and are probably not relevant to health care evaluation. Moreover, the NPV approach has come under increasing criticism because it ignores a fundamental consideration that applies to many investment decisions: namely, the irreversible nature of the investment decision. In practice, once a commitment to invest (or abandon) has been taken, the investment becomes a sunk cost. In effect, the firm loses an important *option* as to when and whether to invest (or abandon). Like all assets, this option has an economic value, and an irreversible decision entails a loss of such value. The loss of an option should therefore be included as a cost of the associated project (Trigeorgis 1996).

This insight can explain why there often appears to be a good deal of inertia in the corporate sector's investment choices. In practice, many firms choose to invest only in projects that exceed the market's required rate of return by a considerable amount. Similarly, they tend to abandon a project only when its expected rate of return appears to fall well below the required market rate of return. A powerful explanation for such behaviour is that by delaying a decision the firm is in both cases retaining a valuable option – in the first case an option to decide at some time in the future not to invest; in the second, an option to continue operating – that would be destroyed by definitive action. In effect, the firm defers an apparently optimal decision, in the hope that better information will become available in the future.

In our view, this criticism of the corporate sector NPV approach also has important implications for conventional approaches to health care technology assessment. In practice, many health care decisions involve considerable uncertainty, often involving an irreversible commitment of resources. Yet in the rapidly changing world of health technology, there might often be powerful reasons to "wait and see", rather than definitively to accept (or reject) a new technology. The purpose of this paper is to explore the relevance of an options approach to health technology evaluation, and to discuss the implications for evaluation methodologies. The intention is to indicate how it is possible in some circumstances not only to indicate the magnitude of certain types of uncertainty, but also to quantify its impact on any economic evaluation.

The paper is organized as follows. Section 1 evaluates existing techniques for handling uncertainty in economic evaluation, exploring the roles and limitations of sensitivity and statistical analyses. Section 2 explores the use of an alternative approach, the 'options' approach. This section describes how uncertainty, irreversibility and the timing of the investment can have profound implications for the conventional investment rules. Finally, Section 3 examines the implications of the 'options' approach with respect to health technology assessment.

# 1. UNCERTAINTY IN ECONOMIC EVALUATION

All cost-effectiveness analyses produce estimates of the costs and outcomes of interventions in conditions of uncertainty.  This uncertainty will be associated with the data inputs, such as estimates of resource use, the probability of particular clinical events and the unit costs of resources; the methods of analysis used, such as the discount rate employed; and the extent to which the analysis can be generalized to routine clinical practice (Briggs *et al* 1994).  For particular inputs, the analyst may have a very good knowledge of what the true values are based on clinical trials and observational studies.  For other aspects of the study, however, the current level of certainty concerning the correct value may be extremely limited.

The degree of uncertainty in an evaluation will in part be determined by the quality of its data sources.  The debate that exists in clinical evaluation about the value and feasiblity of randomized controlled trials (RCTs), relative to observational studies (Black 1996), also takes place in relation to economic analysis. Increasingly, RCTs are being used as a vehicle for the collection of resource use and outcome data for economic evaluation (Drummond 1994). Although many consider the RCT to be the ideal design to measure key parameters in an evaluation (e.g. clinical effectiveness), decision making may require this data to be augmented by information from other sources and plausible assumptions about parameters that are hard to measure. For example, although an economic evaluation may demonstrate that a given technology is cost-effective in a particular context, or cost-effective based on an intermediate outcome, uncertainty about either the generalisability of the results or the link between intermediate outcomes and final health outcomes may affect the usefulness of the findings.  In these cases there is a clear role for modelling in linking intermediate clinical endpoints to final outcomes (e.g. life years saved) or generalising results to other settings (Buxton *et al* 1997). Hence, decision analytic models are commonly used as a framework to synthesise data from a range of sources and assumptions regarding unmeasured (or unmeasurable) parameters (Weinstein *et al* 1980; Thornton *et al* 1995; Dowie 1996).

Hitherto, two techniques for handling uncertainty have traditionally been considered relevant in health care evaluation: sensitivity analysis and statistical analysis. Table 1 summarizes the variety of methods that can be used in these approaches, which are now considered in turn.

**Table 1:**
**Existing approaches for assessing uncertainty in economic evaluation**

|  | Sensitivity Analyses | Statistical Analyses |
|---|---|---|
| Parameter Uncertainty | • One-way sensitivity analysis <br> • Multi-way sensitivity analysis <br> • Scenario analysis (inc.Max-min analysis) <br> • Threshold analysis <br> • Probabilistic sensitivity analysis | • Box method <br> • Taylor series method <br> • Nonparametric bootstrap method <br> • Fieller theorem method |

**Sensitivity analysis**

Until recently, sensitivity analysis has been used as the standard way of dealing with uncertainty in cost effectiveness analysis. The importance of employing sensitivity analysis to test the robustness of a study's conclusions has been well documented (Weinstein 1981) and is reflected in pharmaceutical guidelines which recommend both the incorporation of sensitivity analysis and the quantitative reporting of these analyses in pharmacoeconomic evaluations (Commonwealth Department of Human Services and Health 1995; Ontario Ministry of Health 1994; Canadian Co-ordinating Office for Health Technology Assesment 1994; Task Force on Principles for Economic Analysis of Health Care Technology 1995).

In a sensitivity analysis, some integral input (or inputs) in the calculation is changed by a meaningful amount or varied from worst case to best case, and the cost-effectiveness ratio (CER) is recalculated. The resulting difference in the ratio provides the analyst with an indication of how sensitive the results are to a substantial but not implausible change in that parameter. If the major results are insensitive to a reasonable variation in a parameter, then the analyst can be relatively sure that the conclusions are robust to the assumptions made about that parameter. In cases where variations in parameters cause wide divergences in the estimated CER, threshold analysis can be performed to identify critical values of particular inputs which cause the cost-effectiveness to change from dominant to non-dominant, or in the case of incremental CERs, the critical values which cause the ratio to exceed the maximum acceptable value. The decision maker can then make assessments of the relative likelihood of each scenario before deciding whether to implement the programme.

**Table 2: Cost-per-QALY estimates (£) for 7 medical procedures after sensitivity analysis of outcome and survival data**

| Procedure | Gudex's cost per QALY estimates (£) | Cost per QALY estimates (£) after sensitivity analysis of outcome and survival data |
|---|---|---|
| 1. Scoliosis surgery for neuromuscular illness | 194 | 108-28573 |
| | 592 | 238-26650 |
| 2. Shoulder joint replacement | 1413 | 1381-5839 |
| 3. Kidney Transplant | 2619 | 682-9244 |
| 4. Surgery for idiopathic scoliosis in adolescents | 8225 | 1545-12658 |
| | 9075 | 8741-9656 |
| 5. Treatment of cystic fibrosis with ceftazidime | 12434 | 13110-14499 |
| 6. Haemodialysis | | |
| 7. Continuous Ambulatory Peritoneal Dialysis (CAPD) | | |

Source: Petrou et al (1993).[9]

The potential problems the decision makers face in interpreting the results of sensitivity analysis can be clearly illustrated. In Table 2 seven procedures (Petrou *et al* 1993) have been initially ranked in terms of their incremental cost per QALY estimates. According to the

efficiency criterion, scoliosis surgery, with the lowest cost per QALY gained, represents the most efficient intervention. However, these point estimates do not provide an indication of the likely impact that any uncertainties may have on the point estimate of the CER. Table 3 provides a graphical illustration of the potential differences in cost-per-QALY estimates for 7 different medical procedures following sensitivity analysis of outcome and survival data.

If the critical cut-off point had been set at £8,000 per QALY, using the point estimates of the cost-per-QALY estimates would lead the decision maker to adopt procedures 1-4. Since the cost-per-QALY estimates for procedures 5-7 exceed the critical threshold the decision maker would not choose to adopt these from an efficiency perspective. However, when the impact of uncertainty is explored using sensitivity analysis, the decision becomes less clear. While scoliosis surgery for neuromuscular illness has the lowest point cost per QALY estimate, it also has the largest range in cost-per-QALY estimates following sensitivity analysis. The implication is that scoliosis surgery could be either the most efficient or least efficient intervention presented. Similarly the ranges in cost per QALY estimates could mean that the true CER for procedures 1,2 and 4 lies outside the critical threshold value, while only kidney transplantation can be deemed robust according to the efficiency criterion since the range of the CER lies within the constraint imposed. Furthermore, treatment of cystic fibrosis with ceftazidime could potentially be deemed efficient since the lower end of the CER range lies within the cost-per-QALY constraint.

**Table 3: Graphical representation of the impact of sensitivity analysis on the CERs**

**Procedure**

| Procedure | £0 | £5000 | £10000 | £15000 | £20000 | £25000 |
|---|---|---|---|---|---|---|
| 1. Scoliosis surgery for neuromuscular illness | ← | | | | | → |
| 2. Shoulder joint replacement | ← | | | | → | |
| 3. Kidney transplant | | ↔ | | | | |
| 4. Surgery for idiopathic scoliosis in adolescents | ← | | → | | | |
| 5. Treatment of cystic fibrosis with ceftazidime | | ← | → | | | |
| 6. Haemodialysis | | | ↔ | | | |
| 7. Continuous ambulatory preoneal dialysis (CAPD) | | | | ↔ | | |

**Statistical analysis**

The trend towards conducting prospective economic evaluations alongside clinical trials increases the opportunity for measuring the whole distribution of costs rather than simply producing a point estimate ('wholly stochastic' analysis), allowing statistical tests of economic hypotheses to be performed (Coyle 1996, Office of Health Economics 1995) and uncertainty in stochastic data to be quantified using confidence intervals (O'Brien and Drummond 1994).

The confidence interval (CI) provides a statistical measure of precision for estimates with sample variation. The conventional 95% CI defines a range of values for the CER within which one can be 95% confident that the true value lies. The calculation of confidence intervals around cost-effectiveness ratios is considered particularly important because the economic importance of a change in costs can only be considered in combination with the clinical importance of changes in effect (Drummond and O'Brien 1993).

Statistical analysis has a considerable advantage over simple sensitivity analysis in being able to consider multiple sources of uncertainty and, over multiway sensitivity analysis, by providing decision makers with an easily interpretable result (i.e. a p-value relating to the differences in the CER allowing for uncertainty). However, particular problems in statistical analysis arise in the calculation of confidence intervals around cost-effectiveness ratios. The distribution of the ratio may be unknown, and there is no known unbiased and efficient estimator of the ratio's standard error. Although at present there is no general consensus on the most appropriate method of conducting such statistical analysis, this area is currently an active field of research and it is likely that this will be an extremely promising approach.

In the presence of uncertainty, the reporting of the confidence intervals around CERs in statistical analysis clearly enables decision makers to make more informed judgements about the value for money of an intervention than using sensitivity analysis (Polsky *et al* 1997). However, similar problems to those described for sensitivity analysis will occur when decision makers are faced with interpreting the results of CER whose confidence intervals exceed the critical threshold value. In the end, in such circumstances, the decision becomes a matter of judgement for which quantitative data can give only limited guidance.

## 2. THE "OPTIONS" APPROACH

The central insight of the options approach to investment appraisal is that most investment decisions have three important characteristics:

1.    there exists a degree of *uncertainty* about the future state of the world;
2.    the investment entails an essentially *irreversible* commitment of resources;
3.    there is usually some discretion as to the *timing* of the investment.

Conventional cash flow techniques treat these issues in a rather unimaginative and unrealistic fashion.  In particular, it  is usual to consider the investment as being "now or never", and little attention is paid to the possibility of deferring a decision until some later time, when better information regarding costs and benefits may be available.  Yet in practice deferral is one of the most important (and frequent) decisions taken.  This being the case, it is clear that some flexibility in the timing of an investment decision is often a desirable characteristic with an economic value.  The question therefore arises: how can we value such flexibility?  The answer lies in some form of option pricing theory.

Options are ubiquitous in economic life.  Hitherto, most academic and practitioner emphasis has been on financial options, in the form of various sorts of derivative securities.  However, as Trigeorgis (1996) notes, there is no reason to exclude more concrete situations (what have become known as "real" options) from the analytic framework.  Examples include the valuation of mineral rights or film rights, or decisions to invest in research and development (which may confer an option to enter a market).  Indeed it is probably the case that option considerations are dominant when real investment decisions appear to fly in the face of NPV calculations.  For example, it is well documented that firms are much more cautious about big investments (market entry) than NPV calculations suggest they should be.  This may be because they consider deferral to be a valuable strategy.  In the same way, this would explain the well-documented corporate reluctance to exit markets even when NPV rules would suggest abandonment.  In this respect, apparent conservatism in the investment market is readily explained in terms of reluctance to make irreversible decisions and the associated retention of options.  Note that a decision to proceed with an irreversible decision is equivalent to a loss of a hitherto available option.

### A simple example

In order to explore some of the important issues underlying option pricing theory, we present a very simple stylized model within a cost-benefit framework, equivalent to the traditional NPV evaluation framework, with the concept of "net social benefit" (NSB) replacing the NPV criterion.  Consider an investment of instantaneous cost C(=4500) which yields expected benefits with financial value B in perpetuity.  Depending on the future state of the world, those benefits might be large (L=400) with probability q or small (S=200) with probability (1-q).  The situation is shown below, and we assume numerical values as shown. We assume q=0.4 and a discount rate r of 5% per annum.

If the investment is to be made now, then the expected future stream of benefits is $[qL + (1-q)S] = [0.4*400+0.6*200] = £280$ per annum.  Hence the NSB of the investment is as follows:

$$NSB_1 = -C + \sum_{t=1}^{\infty} \frac{qL+(1-q)S}{(1+r)^t} = -4500+280/0.05 = 1,100$$

If on the other hand investment can be deferred for one year, then the future stream of benefits would be known with certainty.  The current NSB of the project if benefits are favourable will be:

$$NSB_2 = \frac{1}{[1+r]}\left[-C + \sum_{t=1}^{\infty}\frac{L}{(1+r)^t}\right] = \frac{1}{1.05}[-4500+400/0.05] = 3,333$$

while the current NSB of the project if benefits turn out to be unfavourable will be

$$NSB_3 = \frac{1}{[1+r]}\left[-C + \sum_{t=1}^{\infty}\frac{S}{(1+r)^t}\right] = \frac{1}{1.05}[-4500+200/0.05] = -476$$

Thus, the decision maker would only implement in one year's time if the benefits turned out to be favourable.  Otherwise the project would be abandoned (with NSB therefore zero rather than -476).  The NSB of the project with deferral is therefore $0.4*NSB_2 + 0.6*0 = 1,333$. Note that this exceeds the NSB of the project implemented immediately by 233.

That is, although the benefits are deferred for one year, the loss arising from the delay in implementation is more than offset by the improved information which permits the decision-maker to abandon the project in unfavourable circumstances.  Note that in this situation the value of the *option* to abandon the project can be quantified at 233, the difference between the NSBs with and without deferral.  In effect, the value of the option is the difference between the benefits arising from abandonment in unfavourable circumstances and the costs of deferring immediate implementation.

Clearly this example is very artificial.  However, at least conceptually, it can be readily extended to many time periods and many more states of the world.  It highlights a number of issues that are features of most option valuations.  Notably, other things being equal the greater the level of uncertainty implicit in the decision (either in cash flows or discount rates), the greater the value of the option, as it becomes more worthwhile to await new information.  An associated issue is that, as the time for which a decision may be deferred increases, so the value of the option increases.  It is perhaps interesting to note that option pricing theory explains why many decisions are much more sensitive to *uncertainty* in discount rates than to the absolute level of discount rates.

However, most importantly, the example indicates that - providing a small number of important elements of the problem can be modelled - there is no reason why the value of an option should not be quantified just like any other valued asset. Of course, the methodology for such quantification is far from straightforward. In particular, it may in general involve complex dynamic optimization methods with demanding data and computational requirements. However, in most circumstances the valuation problem can be reduced to a relatively manageable format, so that apparently complex situations are not necessarily analytically or computationally intractable.

Central to the option pricing problem is the modelling of uncertainty. Traditionally, uncertainty in option pricing theory has been modelled using the mathematical techniques of stochastic calculus. Uncertainty is modelled as a stochastic process, in which the variable of interest evolves over time in a partially random fashion. In this respect, two particularly important useful tools are the Wiener process and the Poisson process.

Under the Wiener process (also known as Brownian motion), an underlying random variable varies incrementally with known variance in each time period. The simplest form of this form of uncertainty is the random walk, in which the best predictor of tomorrow's value is today's value. The change from today to tomorrow follows a normal statistical distribution. In health care, it might be used to model a continuously varying variable such as (say) the prevalence of a disease. Quite frequently a "drift" is introduced into the Wiener process, which allows a systematic trend to be modelled independently of the random element. This might be incorporated (say) in order to model an expected downward drift in the price of a drug. Figure 1 illustrates a typical Wiener process with upward drift. The mathematical form of this process can be written as:

$$dx = \alpha dt + \sigma dz$$

where x is the variable of interest, dx is its movement in small time dt, $\alpha$ is the drift parameter, dz is the stochastic change in time dt, and $\sigma$ is the standard error of the random change per unit time period. A number of further generalizations of the basic Wiener process can be introduced where necessary.

In the simplest form of a Poisson process, a random variable can take only two values and has a fixed probability in each time period of changing from one to the other. This process is used to model situations in which the variable of interest is subject to rare but critical "jumps". In health care, it might for example be used to model the emergence of a new drug (which constitutes a discrete shock to the associated market). The magnitude of the jump may also be allowed to vary (for example, the improved efficacy offered by the new drug may be allowed to vary stochastically).

**Figure 1: Wiener process with drift**



**Time**
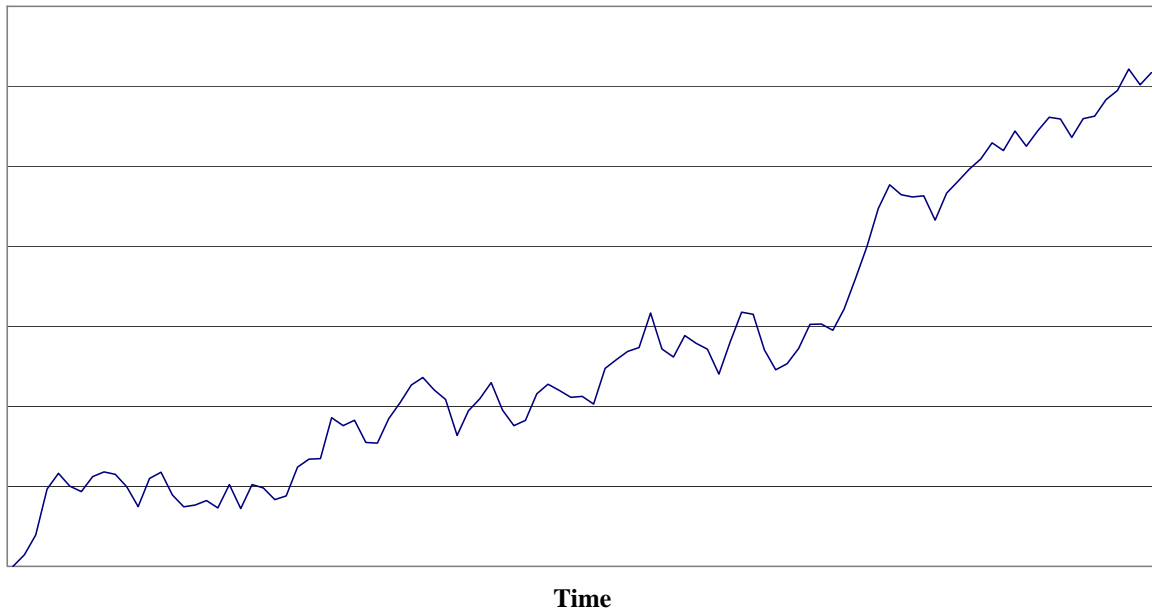
The type of stochastic process used in any modelling work must of course depend on the nature of the problem under investigation. However, having decided how to model uncertainty, the next stage is to estimate the implications for the economic evaluation. Two basic approaches have been applied in the corporate sector: dynamic programming and continuous calculus.

The structure of the simple example given above is similar to the familiar decision tree of conventional decision analysis, and one solution method could be the familiar method of "folding back" the decision tree using backward induction. Dynamic programming is a more general and efficient method of solving such problems. With modern computing capability, calculation of multiperiod, multiple state examples may often be feasible, the most problematic issue often being the availability of relevant data rather than the solution method. Dynamic programming can also be extended to continuous rather than discrete time.

The continuous calculus approach has been widely applied in financial economics, where it is used to value financial options and has therefore become known as "contingent claims analysis". It yields very similar results to dynamic programming, the key difference being that dynamic programming requires an exogenously specified discount rate. Contingent claims analysis depends on the existence of a complete market in tradeable assets, and can then treat the interest rate as endogenous. Given the nature of health care, it is probably more appropriate to use the dynamic programming formulation, with exogenously fixed discount rate.

**A more general example**

We now consider a more general treatment of an investment decision, which is analogous to a typical decision as to whether or not to implement a new health technology. We consider the benefits of the technology to be valued as V, and there is an investment cost of I. Let the discount rate be ρ. Then suppose the value of the project evolves over time according to the geometric Brownian motion

$$dV = \alpha V dt + \sigma V dz$$

which unfolds over an infinite time horizon. Here V is the variable of interest (the value of the technology), dV is its movement in small time dt, α is the drift parameter, dz is the stochastic change in time dt, and σ is the standard error of the random change per unit time period. Note that, compared with the pure Wiener process, the formulation of this process introduces a term in V on the right hand side, which effectively allows us to model percentage changes rather than absolute changes in the variable V.

Using dynamic programming, Dixit and Pindyck show how this formulation gives rise to a differential equation

$$\frac{1}{2}\sigma^2 V^2 F''(V) + \alpha V F'(V) - \rho F = 0$$

with a set of associated boundary conditions. The function F(V) is the current value of the investment if its current estimated benefits are V (that is, before implementation, F(V) comprises the sum of the "intrinsic" value V and the option value of having the potential to implement V). This set of equations has a solution of the form

$$F(V) = AV^{\beta}$$

where

$$A = \frac{(\beta-1)^{(\beta-1)}}{\beta^{\beta} I^{(\beta-1)}}$$

and

$$\beta = \frac{1}{2} - \alpha/\sigma^2 + \sqrt{\left[\alpha/\sigma^2 - \frac{1}{2}\right]^2 + 2\rho/\sigma^2}$$

More importantly, the solution yields an optimal value of V, denoted $V^*$, which is such that once V exceeds $V^*$, the technology should be implemented. $V^*$ is given by:

$$V^* = \frac{\beta}{\beta-1} I$$

From the point of view of this paper the key observation is that $V^*/I$, the required benefit cost ratio, is not a constant. With no uncertainty (σ = 0), $V^*/I = 1$. That is, the critical benefit:cost

ratio is 1. This reflects the traditional cash flow rule that in order to invest, benefits must simply exceed costs. However, if uncertainty exists ($\sigma > 0$) then the critical ratio $V^*/I$ depends on the value of $\beta$, which is itself determined by the discount rate $\rho$, the drift parameter $\alpha$ and the stochastic standard variability $\sigma$.

In order to illustrate the importance of this result, consider the perfectly reasonable situation in which the annual discount rate is 5% ($r = 0.05$), there is no drift ($\alpha = 0$) and the estimated value of V has an annual standard deviation of 10%. This implies that $\sigma = 0.1$. Then it can be readily shown that $\beta = 3.7$, and the critical ratio $V^*/I$ becomes 1.37. That is, estimated benefits must be 37% higher than costs before implementation is optimal. More generally, Figure 2 illustrates the relationship between the amount of uncertainty $\sigma$ and the critical ratio, given r=0.05 and $\alpha$=0. Note the rapid increase in the ratio associated with quite modest increases in uncertainty.

**Figure 2: V* as a function of sigma**
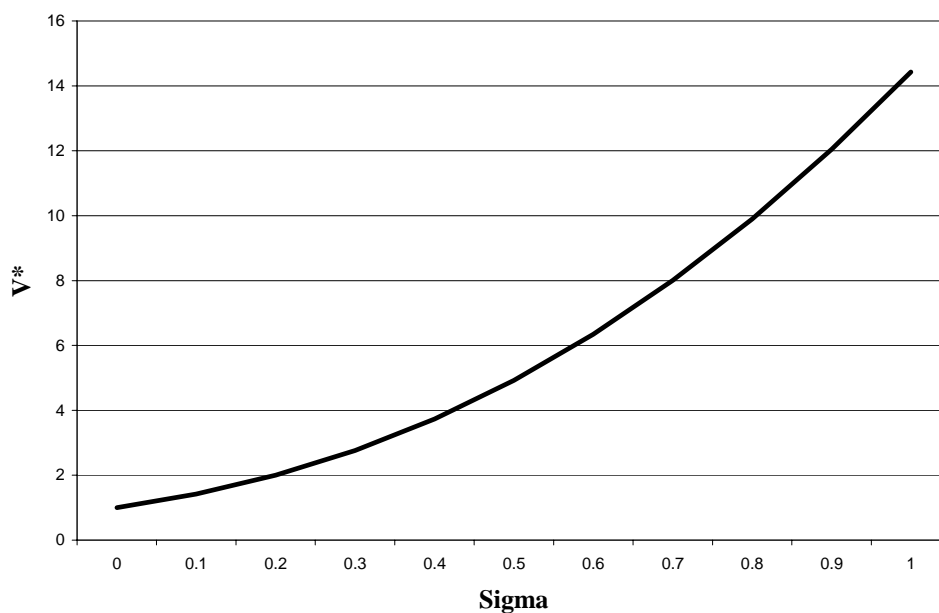


Finally, Figure 3 demonstrates the value of the option to invest. If the investment is a now or never proposition, then the value of the option is shown by the solid line. If the benefit-to-cost ratio exceeds 1 (NSB positive), the option value is the estimated value of the net benefits. If the ratio is less than 1 (NSB negative) then the value of the option is zero, because in that case the decision maker will choose not to make the investment. However, if the investment can be postponed, then the option is valuable even if the computed benefit-to-cost ratio is less than 1 (represented by the dashed line). Even though the investment may have a zero or negative NSB were it to be undertaken today, the option still has a value because the delay gives room for the hope that additional information will reduce the uncertainty associated with the investment.

**Figure 3: The Value of the Technology**
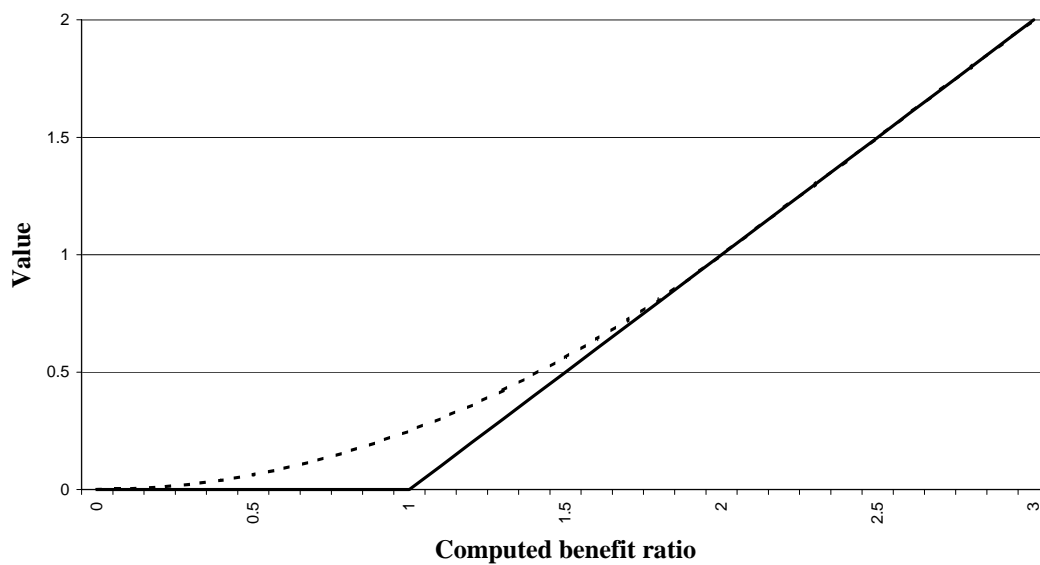
## 3. IMPLICATIONS FOR HEALTH TECHNOLOGY ASSESSMENT

Crucial to the options approach is the notion that the passage of time will tend to reveal new estimates for key sources of uncertainty. In practice this will often be the case. For example:

- the equilibrium price of new drugs or capital equipment will become clearer once the initial stage of the product life cycle has ended;
- estimates of the long term benefits of a therapy and the generalisability of the results will become clearer as more trials become available, and longer term outcomes are reported;
- the external validity and generalisability of the results of pharmacoeconomic evaluations will become evident when the results of late phase III, post-marketing and phase IV studies are reported;
- estimates of population costs and benefits will become clearer as more epidemiological evidence is assembled.

If an "all or nothing" decision is taken now, the data available may preclude secure judgement, leading to the potential for an incorrect decision. If a decision on implementation is delayed, then some short term losses may be incurred (if the therapy subsequently turns out to be cost-effective) but this must be weighed against the potential for making a more informed decision at a later date, when better data may be available.

The results outlined above may therefore have crucial implications for the economic evaluation of health care technology. They imply that the presence of even modest degrees of uncertainty may give rise to substantial increases in the cost-effectiveness ratio in order for implementation to be recommended. In this section we first outline the main strands of economic evaluation methodology, and summarize the principal issues they give rise to. We then discuss their shortcomings from an options perspective.

### Cost-benefit analysis

Most of the theory of option pricing has been developed in the context of the net present value model, as applied to the commercial sector. Within health care, this is analogous to the principle of *cost-benefit analysis* (CBA), which represents the most comprehensive and theoretically sound form of economic evaluation (Robinson 1993) being explicitly grounded in welfare-economic principles. Practical measurement difficulties and objections to valuing health benefits in monetary terms, however, have tended to limit the use of CBA in the health care field. Instead, cost-effectiveness and cost-utility analyses, which value health outcomes in non-monetary units, have become more prevalent form of analyses in this area (Elixhauser *et al* 1998). Whilst these approaches avoid the objections raised regarding the monetary valuation of health benefits, the efficiency of alternative interventions cannot be assessed using the net-benefit criterion. Instead, the ratio of cost to effect is calculated.

## Cost-effectiveness analysis

In cost-effectiveness analysis (CEA) the health benefits of alternative interventions are measured in non-monetary units such as life years 'saved' or quality-adjusted life years (QALYs).  Since costs and benefits are measured in non-comparable units, the central measure of relative efficiency becomes the ratio of costs to benefits (e.g. cost per life-year saved or quality-adjusted life years).  The cost-effectiveness ratio (CER) for comparing the alternatives is the difference in their costs ($\Delta C$) divided by the difference in their effectiveness ($\Delta E$), or CER = C/E ($\Delta C/\Delta E$). The CER ratio represents the incremental cost of obtaining a unit health effect (e.g. cost per year of life saved, cost per quality-adjusted life year gained) from a given health intervention when compared with the next best alternative.

Within CEA, an intervention is considered dominant (more efficient) if it results in higher (or equivalent) benefits and lower costs than the existing intervention (Drummond *et al* 1997). Similarly, when the new intervention results in lower (or the same) benefits at a higher cost, this intervention is inefficient relative to the existing intervention.  Accordingly, interventions in each of these categories are considered to provide compelling evidence for adoption and rejection respectively from an efficiency perspective (Laupacis *et al* 1992, Drummond *et al* 1997).  However, such a decision rule does not enable the relative efficiency of those interventions which are either: more effective and more costly or, less effective and less costly, or indeed whether a dominant intervention is worth pursuing at all when compared to other independent health care programmes (Birch and Gafni 1992). In these instances the relative efficiency of an intervention cannot be assessed without reference to a critical ratio (or threshold value of the incremental CER) which is used to determine whether a particular value of the cost-effectiveness ratio is considered acceptable.

### Determining the critical ratio for cost-effectiveness analysis

The most appropriate method for determining the critical ratio has been the subject of considerable debate in recent years (Birch and Gafni 1992; Johannesson and Weinstein 1993; Johannesson 1995).  While a number of alternative approaches have been identified (e.g. reference to published QALY league tables, rule of thumb), two alternative approaches have been established as the most theoretically correct methods for establishing the critical ratio for the CER (Karlsson and Johannesson 1996).

The first approach is based on the maximisation of health gain subject to an explicit  budget criterion. For programs competing for a limited budget, the choice of treatments will depend on the size of the budget.  Interventions are ranked according to their incremental cost-utility ratios from lowest to highest. For a specified budget, the optimal decision rule is choose the intervention with the lowest incremental CUR and then add independent treatments or replace mutually exclusive treatments from the list until the resources are depleted (Weinstein and Zeckhauser 1973, Weinstein and Stason 1977).  Hence, the lower the value of the incremental ratio, the higher the priority in terms of maximising health benefits derived from a given level of expenditure.  The point at which resources are exhausted defines a

maximum price for a unit of effectiveness (e.g. £20,000 per QALY) that is affordable within an explicit budget constraint, based on the incremental cost-effectiveness ratio of the marginal intervention. The relative efficiency of any new intervention can then be assessed in relation to the marginal intervention(s) which would be replaced if the new intervention were funded.

The second approach is based on willingness to pay, where the maximum price society is prepared to pay to gain one unit of additional health outcome is derived. Rather than using the existing budget for health care as a decision rule, this method implicitly yields a budget for health care based on the aggregate costs for all programmes that meet the criteria. In a similar manner to the ranking of interventions based on an explicit budget, mutually exclusive and independent programmes are ranked and selected according to the maximum willingness to pay. Hence, any new intervention must have a lower incremental cost per QALY ratio than the WTP criterion.

**Applications of option pricing theory to the evaluation of health care technologies**

The basic premise of the critical ratio for cost-effectiveness analysis is to allow a definitive decision to be made regarding whether an intervention should or should not be implemented on efficiency grounds. However, as previously demonstrated with reference to the NPV calculations, the derivation of a single, definitive critical CER should only be deemed appropriate in conditions of perfect information. Hence, when uncertainty exists in an evaluation, the use of a single criterion for an immediate accept/reject decision may not be appropriate. In the area of health technology assessment, there may be instances where delaying an investment decision is possible in anticipation that improved estimates of key sources of uncertainty will be revealed in the future. Accordingly, it is evident that option pricing theory could be used to value the option to defer a decision until more definitive information is available. In these instances, incorporating the value of this option will have significant implications for the critical CER.

The identification of the critical CER enables the impact of uncertainty to be quantified in cost-effectiveness analysis with minor modifications to the NSB calculations reported previously. Under these revised calculations, the optimal value of V, denoted by V*, represents the maximum acceptable value for the incremental CER. For example, suppose that the critical cut-off value for the ratio had been set at £20,000 per QALY (representing the value of the marginal intervention which would be displaced by a new intervention). Theoretically, any new intervention which has a CER less than £20,000 per QALY should thus be implemented in favour of the marginal intervention. However, this criterion only applies in a situation of perfect information and no uncertainty ($\sigma = 0$). When uncertainty exists ($\sigma > 0$), then the critical ratio should be altered using option price techniques to take account of the type and level of uncertainty.

We previously illustrated the situation in which the annual discount rate is 5% ($r = 0.05$), there is no drift ($\alpha = 0$) and the estimated value of V has an annual standard deviation of

10%. Under these condition it was shown that $\beta = 1.37$, so that the critical ratio, $V^*/I$, for the NPV calculations became 1.37. Hence, according to the revised net-benefit criterion, the benefits of a project would have to exceed the costs by 37% before immediate investment was considered the optimal strategy. In a similar manner,  uncertainty in CEA can be incorporated into the CER.  Using the same example,  the revised decision rule results by dividing the critical cut-off QALY value by 1.37 (i.e. £14,600 per QALY).  In this example, the incremental cost-effectiveness ratio of the new intervention must be less than or equal to £14,600 per QALY before immediate implementation is considered optimal to the decision to defer until further information is available relating to the source(s) of uncertainty.

In the area of economic evaluation, the role of option pricing may have several important applications.  In particular, the approach seems suited to the evaluation of medical technologies that have high initial set-up and operating costs (commonly referred to as the 'Big Ticket Technologies'), such as computed tomographic scanning (CT), magnetic resonance imaging (MRI) and extracorporeal emission tomography (ESWL).  The significant sunk costs associated with these technologies will reduce the irreversibility of an investment decision leading to an extremely high cost of abandonment if the technology is subsequently shown not to be cost-effective.  Furthermore, since high-technology markets are often characterised by a high level of future innovation, existing technologies may be superseded by second generation technologies relatively rapidly. In these cases, the cost of abandonment, upgrading an existing technology, or purchasing the next generation should be considered as part of the investment decision.

Although most attention regarding the  'Big Ticket Technologies' has focused on areas of high technology with large sunk costs, it has also been argued that a second category should include technologies with lower initial set-up and operating costs, but which may be used extensively in patient care (Johansen and Racoceanu 1991).  The widespread diffusion of low cost, high utilisation technologies seems particularly relevant in health care. For example, implementation of  a new screening programme involving little setup costs may at first glance appear readily reversible.  Yet in practice the implementation of the programme may have changed perceptions and expectations, rendering infeasible a reversal of the policy. Depending on the degree of diffusion, the sunk costs associated with implementing an inefficient intervention could be considerable.

A further application could be in the area of pharmaceuticals as an aid to formulary and reimbursement decisions. In applying this model to the pharmaceutical industry, a distinction could be made between areas of therapeutic activity in which the new therapy is significantly different from existing medical therapy (i.e. new chemical entities) and therapeutic areas with products that may have only slight advantages over, or even duplicate, existing therapy (me-too drugs and generics).  In each of these areas the life-cycle of each product and the relative costs will, in part, be determined by the prevailing market conditions including the degree of product innovation, the number of similar products  and the length of patent life for new chemical entities.  Option pricing could be used to incorporate the likely downward drift in pharmaceutical prices resulting from the competition between generic products, while

extreme 'one-off' shifts in prices caused by the expiration of a patent and the onset of generic competitors could be explored using a poisson 'jump' model, where the passage of time to the jump will be determined by the remaining patent life of a product.

Clearly if option considerations are important then they may lead to considerable variations in the critical cut-off value for the incremental CER, if the chosen interventions are to maximise the health benefit achievable in relation to the resources used. The notion that the relative efficiency of a new intervention can be assessed with reference to a single critical ratio is clearly incorrect. The key determinants of any option value, and hence of variation in the value of the critical CER in health care are:

- The magnitude of uncertainty in parameter estimates;
- The extent to which deferral is possible for some significant (possibly indefinite) period;
- The extent to which the decision to implement is irreversible.

We have already noted the importance of uncertainty in most evaluations, and of course most decisions can be deferred indefinitely.  However, the third criterion of irreversibilty may need a little more consideration when applied to health technology assessment.  An irreversible decision is one that entails an unrecoverable sunk cost.  Clearly the extent to which the introduction of a health care technology is irreversible will vary depending on circumstances. The most obvious example of an irreversible decision is one in which a major piece of capital equipment is purchased.  Yet if this equipment is readily resold on the open market, the implementation may not be as irreversible as it appears.  On the other hand, programmes involving little setup costs may not be readily reversible if perceptions and expectations have changed the degree that reversal of the policy is no longer feasible.  In general, we would expect technologies to exhibit variable degrees of irreversibility, leading to associated variations in the critical cut-off level.

**DISCUSSION**

The aim of this paper is to illustrate the implications of incorporating uncertainty into the decision rules of economic evaluation. We have used a cost-benefit framework in order to illustrate the principles. However, we see no intrinsic difficulty in applying the principles of option pricing theory within the context of cost-effectiveness or cost-utility analysis. The principle that deferral may confer benefits is not altered by the evaluative framework used. However, the discrete treatment of costs and benefits may give rise to special methodological issues. In particular, it may be useful to consider separately the nature of the uncertainty associated with costs and that associated with benefits.

We have shown that – if option considerations are important – they may lead to considerable variations in the critical cut-off value for the incremental CER if the chosen interventions are to maximise the health benefit achievable for a given level of resources.

The paper has concentrated on the macro implications of option pricing for particular technologies. There is however no reason why it should not also be applicable at the micro level of the individual patient. For example, treatments exhibit different degrees of uncertainty and different degrees of reversibility. Furthermore, there are conditions where there may be the ability to defer a decision until more definitive information is available, which could be considered a relevant strategy at this level (e.g. watchful waiting in the management of small abdominal aortic aneurysms and benign prostatic hyperplasia). An option pricing approach may offer the possibility of more systematic advice on the preference ordering for particular treatments for the individual.

We hope that this paper has demonstrated that there is strong *prima facie* evidence that the existence of options in health care gives rise to potentially very large variations in the decision rules conventionally used to evaluate health care technologies. We have shown that – taking a very general model and some reasonable assumptions – large variations in critical cut-off values are likely between technologies exhibiting variations in uncertainty or reversibility. If our arguments are accepted, the key issue that remains to be addressed is how the option pricing issue can be incorporated operationally into health care evaluation. We suggest that in order to do so the following questions need to be addressed:

- How can the uncertainty implicit in a health care evaluation be quantified?
- To what extent is the intervention irreversible?
- To what extent can decisions be deferred?
- How can the associated option considerations be incorporated into the evaluation?
- What are the implications for the cost-effectiveness cut-off values?

One final consideration is that all of the analysis described here assumes an essentially passive approach towards the emergence of new information. It may well be fruitful, however, to seek to integrate the options approach with decision analytic approaches toward acquisition of effectiveness information (Claxton, forthcoming). The intention would be that,

rather than acting as a passive recipient of new information, the regulator should be able to make judgements about where research effort should be directed towards accumulating more information.  This line of enquiry offers a potentially fertile agenda for future research.

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