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Should we wait and see? The real options approach to watchful waiting.

Tarn Driffield
Centre for Health Economics / Department of Economics and Related Studies
University of York
Heslington
York
YO10 5DD
tmm105@york.ac.uk

Abstract
Real options analysis is being increasingly used to assess the desirability of investment opportunities in the presence of uncertainty, irreversibility and an ability to defer. Such analysis highlights the similarities between exercising financial options and initiating investment opportunities, and suggests the use of financial options pricing techniques to value 'real' opportunities. Despite increasing appeal in other branches of economics such as environmental economics, real options methodologies have yet to be applied to opportunities within the field of health economics. With the handling of uncertainty dominating much economic evaluation literature, real options analysis that explicitly values uncertainty, whilst simultaneously considering assumptions governing irreversibility and deferability, seems an attractive way to take economic evaluation forward. To demonstrate the applicability of financial techniques to valuing health care opportunities, this paper focuses on the analogy between an American call option and an option to defer surgery. The issue of deferring opportunities has previously received some attention in the health literature under the guise of 'watchful waiting'. Using treatment of abdominal aneurysms as a case study, this paper examines whether such health care decision problems can justifiably be considered as 'options'. In so doing this paper aims to illustrate that it is appropriate to use option pricing techniques to determine the cost-effectiveness of immediate surgery in comparison to a strategy of deferred action. The implications of using real options analysis in preference to standard decision making criterion, are also considered.

Section1. Introduction

Within clinical areas where disease progression is slow, and conventional therapies do not dramatically extend life expectancy or quality, a patient management strategy of watchful waiting may be a relevant treatment alternative.

Watchful waiting is a strategy in which immediate curative treatment is not given. During watchful waiting, a patient under goes a period of close observation, returning periodically to their clinician for check ups which permit illness progression to be monitored. These assessments provide valuable information that will inform the final treatment decision. Watchful waiting implies a conditional treatment decision, not a policy in which an ailment is left to deteriorate unchecked, or where a placebo therapy is given, and should be distinguished from any period of time spent on a waiting list. Deferring treatment whilst waiting and observing is an active treatment strategy that has also been referred to as 'intelligent watchful waiting'[1] and 'expectant management'[2]. The growing quantity of watchful waiting studies, including economic evaluations, testifies to the increasing recognition that deferring aggressive therapy can be an appropriate and in some cases, cost-effective, treatment alternative[3,4].

To assess the desirability of deferring treatment Johansson[5] followed 233 patients with early stage prostate cancer between March 1977 and February 1984 who fulfilled the criteria for deferred management[i]. Patients younger than 75 were randomised to deferred treatment or radiation therapy. After 12 years and 6 months follow up 148 (66%) patients died, only 23 (10%) of whom died from prostate cancer. Risk of progression and death was found to be high in grade III compared to grades II and I tumours, suggesting that watchful waiting may be most appropriate for patients in the latter groups. Although now an outdated study, this paper demonstrates the need for systematic clinical evaluation of deferred treatment.

More recently Warner and Whitmore[2] analysed 75 of 4000 prostatic cancer registrations who received no therapy for at least one year following diagnosis and who were

[i] Any patient with stage T0 tumour, those of stage T1-2 tumours of grade I, and those older than 75 with Stage T1-2 and grades II-III.

managed expectantly. Since in the majority of patients with progression, local progression preceded distant metastasis, the authors concluded that "short periods of observation may be permissible if such prove useful in estimating tumour growth rates".

Decision making for patients with prostatic cancer is not alone in drawing attention to the deferral alternative. Early surgery versus watchful waiting for glue ear[6,7] has been examined in a randomised trial. The cost-effectiveness of treatment for small abdominal aortic aneurysms[8,9], the efficacy of deferred treatment for mild chronic hepatitis C[10], the management of solitary pulmonary nodules[11], and treatment for acute bacterial rhinosinusitus[12] have also been considered. Conclusions have varied according to the illness, severity, patient age, methods of observation used in the waiting period, and compliance.

Generally if conventional therapies do not significantly extend life expectancy or improve health related quality of life then watchful waiting may be relevant. Watchful waiting may also be considered when a given illness is over-diagnosed in the sense that screening increases the prevalence of positively diagnosed cases that would not otherwise have been identified, and do not require urgent treatment. It is the interactions between uncertainty over outcome, the risks associated (complications, infections, side effects), and the high financial costs, of immediate treatment that combine to provide motivation for deferral. Deferring the decision to implement may allow more data on population, sub-group, and individual cost-effectiveness to be collected from on-going trials, or monitoring of disease progression. Both sources of information may help in the final decision of whether or not to approve treatment for a defined (group of) patient(s). When deferral shows that treatment is unnecessary, the potential adverse effects of immediate action are avoided.

When assessing cost-effectiveness of watchful waiting, current decision technologies do not take in to account the possibility that deferring preserves the option to commence treatment at some point in the future. Should the disease in question begin to deteriorate significantly the patient can still, ceteris paribus, undergo immediate therapy. In failing to account for this source of value, existing decision criterion may arrive at mistaken conclusions with regards to the attractiveness of watchful waiting. This paper proposes that real options analysis, a methodology that explicitly values an option to act in the future, be used to assess the cost-effectiveness of a watchful waiting program.

This paper is organised as follows; section 2 examines the current status of incorporating the waiting alternative. Limitations of the current techniques are identified and real options analysis is proposed as a tool to overcome some of these problems. Section 3 considers whether medical decision making can truly be deferred at a patient level and sets up the deferral decision as a real options problem. The analogy between variables used for financial decision making and medical decision making is demonstrated. A hypothetical numerical example is shown in section 4 assessing the desirability of watchful waiting as a treatment alternative for patients with abdominal aortic aneurysms. This gives some idea of the practical ability to implement real options models and the limitations encountered by these methods. Section 5 concludes.

Section 2. Incorporating the deferral alternative in to decision making

Deferring active treatment may mot always be a suitable strategy. If there is not a reasonably slow progression rate the patient may suffer long term effects during deferral that make this course of action in appropriate. The decision problem is to evaluate whether watchful waiting might be a cost-effective treatment alternative. This section approaches the question by evaluating how the deferral alternative has previously been introduced into methods of decision making.

The cost-effectiveness of a deferral strategy can be considered in the same manner as any other treatment. An examination of costs and benefits discounted to present values provides an estimated incremental cost effectiveness ratio (ICER) that is comparable to alternative available treatments. Once dominated and extendedly dominated alternatives are removed from consideration, the remaining therapies can be ranked. Alternatives are selected in order, up to and including, the regime with the largest incremental cost effectiveness ratio that is still compatible with society's willingness to pay for a unit of health benefit. Ratios may equivalently be converted to net benefit estimates via monetary valuation of health benefits, and programmes chosen in order of greatest net benefit. Uncertainties in future values can be handled using expected values or using models that incorporate variability such as Monte Carlo simulation. Although there is much to debate within this methodology, this is not the scope of the current work, and this framework is therefore taken as given.

Wong et al[10] carried out a cost-effectiveness analysis of watchful waiting versus immediate therapy for mild chronic hepatitis C. Using both clinical trial data and data from published sources these authors considered the relative merits over a twenty-year period of biopsy every three years compared to immediate antiviral therapy. Those patients randomised to watchful waiting were subsequently treated with combination therapy (ribavirin and interferon) for 24 weeks if biopsy revealed cirrhosis or moderate hepatitis. Markov simulation was used to estimate prognosis beyond the capacity of the trial. The results of this study claimed that immediate therapy was cost-effective at baseline characteristics. At a 5% discount rate for costs and survival, the incremental cost effectiveness ratio for immediate therapy was $13500, and was shown to have extended dominance over biopsy management. In this instance the high repeated costs ($1033) of observing information from deferral (use of biopsy to detect clinical state of the liver) and the inability of this therapy to prevent future hepatitis C, meant that deferral was not optimal for patients with baseline characteristics.

Attempts have been made to evaluate the waiting alternative in economic terms using decision analytic methods. A standard decision tree incorporates alternative immediate treatments with sequential actions and events. A given combination of decisions and events leads to a health outcome and associated cost that may be used to compare the expected outcomes associated with each of the therapies under consideration. Deferring is itself a decision so introducing this alternative requires inclusion of a branch in addition to those representing immediate treatments. This is shown in figure 1 which assumes a single alternative is available that can be implemented now or deferred for some period of time.

When watchful waiting is chosen, observed disease progression may influence the treatment decision faced after the period of observation. Costs and benefits associated with outcomes following watchful waiting are likely to differ from those associated with immediate therapy, leading the expected values of the two arms to differ and a preference to be made between the alternatives.

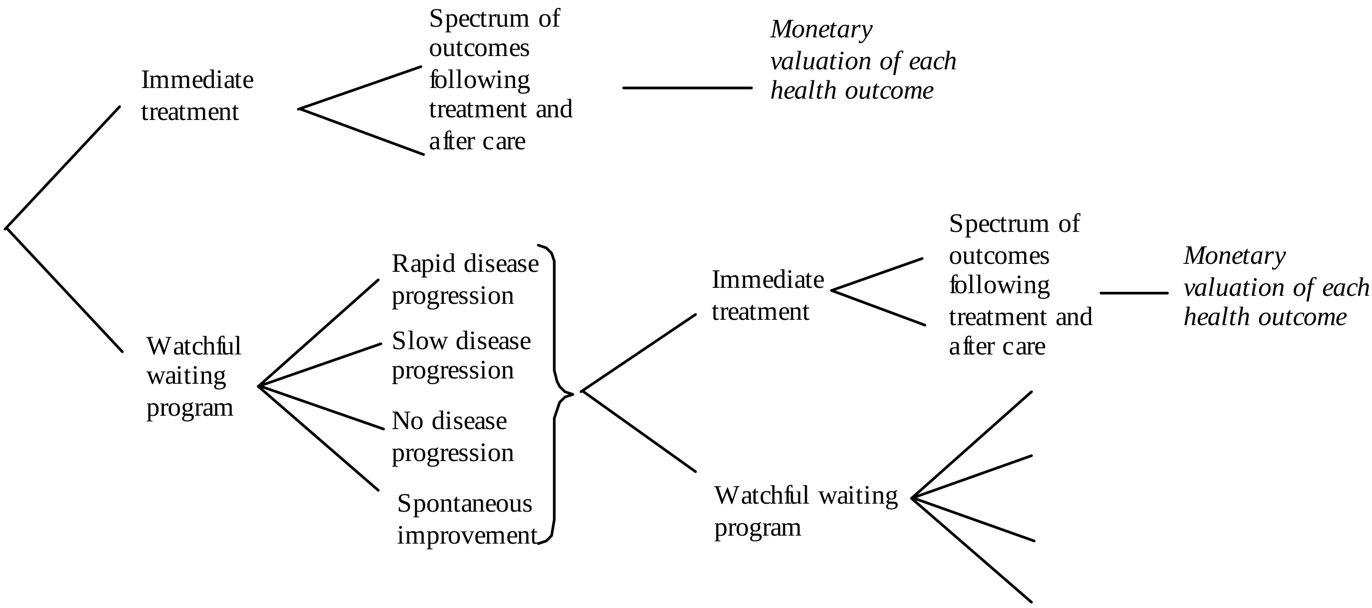

Figure 1: Decision tree with a single immediate action and a possibility for deferral.

Dietlein et al[11]used this style of analysis in assessing the cost-effectiveness of varying treatments for the management of solitary pulmonary nodules. Watchful waiting was compared to transthoracic needle biopsy (TNB), exploratory surgery, and positron emission tomography. When a 100% nodule growth was observed by computer tomography during the observation period, the patient was referred for immediate exploratory surgery. Observation continued for two years with regular computer tomography checks. Mean values for variables used in the analysis were obtained from medical literature. At baseline values the alternatives involving immediate action lead to improved health outcomes at a higher cost. When the probability of malignancy was small (0.1-0.7) the immediate therapy with the lowest ICER still exceeded the stated willingness to pay for a life year saved (50 000 EUR). For this range of probabilities watchful waiting was declared the preferred strategy.

Despite the apparent attractiveness of this logical approach there exist significant drawbacks. Some of these are illustrated succinctly through examination of an early attempt to incorporate the waiting alternative. Williams[13] demonstrates both the beauty and limitations of the decision tree by describing a reasonably complex technology adoption problem. Although not a watchful waiting study Williams' work illustrates some of the generic problems associated with modelling deferral.

When there are multiple treatments available, each of which might be deferred, the complexity far exceeds that of the relatively simple stylised example in figure 1. For each outcome following deferral, the basic structure of the decision tree stemming from 'no deferral', is repeated. Each opportunity to defer causes a geometric increase in the number of branches, whether occurring from different treatments that might be deferred or multiple opportunities to defer the same treatment. This complexity is immediately apparent in William's work. Williams 'buy now' tree contains 55 possible outcomes. Introducing the defer purchase branch in each of the four periods generates an *additional* 90 possible outcomes – nearly tripling the size of the tree. When a decision problem encompasses several uncertain variables, perhaps input and output prices, demand, and technological development, deferral may improve information on each of these. Added complexity not only hinders understanding but also complicates both analysis and interpretation of results. Such 'bushyness' of decision models has been reduced by the use of state transition models, such as Markov modelling that uses transition probabilities to determine movement between disease states over consecutive time cycles. Although useful in considering events that recur over time, Markov modelling does not explicitly consider the issue of deferral.

In Williams's hypothetical example the initial problem description is not overly complex, with no debate over demand for the technology once installed, no uncertainty over the benefit of the technology to patients, and few time periods. Yet despite the simplifying assumptions there is sufficient complexity to prompt questions concerning what may be learnt over time and why deferral is considered to be a relevant alternative. Answers to such questions are not immediately apparent from Williams work yet these are essential questions that must be understood and answered if a deferral analysis is to provide useful conclusions. It is the evolution of information concerning disease progression that renders watchful waiting a potentially viable treatment alternative.

Conventional methods do not explicitly realise that valuing deferral is a method of valuing the less tangible benefit of possessing choice. Deferring is an important way to hold on to existing choices, and since choices are valuable, deferral too is a valuable alternative. If an option is defined as a choice that may be deferred, then the option to defer treatment becomes analogous to a financial option. This enables financial option pricing techniques to be used to ascertain the value of the option; a process known as real options analysis.

Existing methodology most frequently considers our current perception of uncertainty as defined by a probability distribution. Real options analysis supplements this through consideration of how this perception changes over time examining how the mean of a distribution of interest, such as the growth rate of an aneurysm or the demand for a new technology, alters through time[ii]. In terms of the decision tree, for each event node there is some current perception of uncertainty given by a single distribution, which is supplemented by a family of distributions representing time periods and illustrating the evolving perception of uncertainty for each period in which deferral is appropriate. Information available over time is incorporated explicitly into today's decision making through the current decision being conditional upon anticipated future information.

Real options methodology specialises in valuing choices through sequential decision making in the presence of uncertainty, irreversibility, and the ability to defer. The analogy between financial and real option has developed since the 1980's when McDonald and Seigel[14] and Paddock, Seigel and Smith[15] considered deferral of investments in resource extraction industries. Dixit and Pindyck[16], and Trigeorgis[17] provide summaries of real options techniques along with several applications. The number and variety of applications has grown particularly within environmental economics focussing on climate policy[18], forestation[19], and the development of agricultural land[20]. Despite these and other applications to broader subject areas such as migration[21] and control of infectious diseases[22], real options analysis has yet to receive significant attention in the health economics arena. Palmer and Smith[23] have introduced the notion focussing on option valuation as an alternative way to handle uncertainty.

[ii] Basic real options models assume a constant variance, although changing variance can be incorporated through numerical methods.

The aim of the current paper is to develop this grounding and explore the methodological and conceptual justification for application of real options theories to watchful waiting.

Section3. Watchful waiting as an option on treatment; The real options problem

The purchase of a financial options contract confers the right to perform a specific future stock transaction. For instance a call option permits the holder to buy a fixed number of units of a given commodity (the underlying asset) at a prespecified price (exercise price), on or before a stated date (the exercise date). Having initially bought such an option, the owner has the right but not the obligation, to go ahead with the transaction. Whilst call options entitle the owner to buy, put options confer similar rights to sell assets. Options also differ in their condition of exercise. Options that may be exercised only on the exercise date are referred to as European while those that may additionally be exercised prior to this date are referred to as American options. Option value arises from the asymmetry created by having the right but not obligation to exercise.

Deferring the decision to actively treat a patient is akin to an American call option; the act of exercise can be deferred for some period of time and on exercise some 'cost' is incurred in return for an expected benefit. To demonstrate the analogy between financial and real options requires consideration of characteristics defining the decision problem, and parameters necessary for valuation.

In order to receive the benefits of deferred stock purchase decision making bodies such as individuals or firms, must first purchase an option. Real options, such as the option to defer treatment are rarely purchase on a market but are usually conferred to patients and clinicians through previous actions. In the case of watchful waiting the treatment option may be conferred via early screening which identifies potential problems before they become self-evident. Although the methods of obtaining options differ substantially, once owned the similarities between the situations facing financial and real decision-makers become apparent. The characteristics of similarity are summarised in table 1, which focuses on the option to defer treatment for abdominal aortic aneurysms (AAA's), and discussed below.

A financial investor must decide on what date, prior to the option expiring, it is optimal to exercise. Waiting allows information gathering on stock price uncertainty but also defers the benefits of owning stock, such as capital appreciation and dividends. The clinician must decide when it is optimal to commence therapy, prior to contraindications arising, such as patients becoming unfit for surgery.

Three defining characteristics of financial options are the ability to defer, uncertainty, and irreversibility of the exercise decision. These are also present in the real option to defer treatment. The ability to defer is inherent to the problem and does not warrant extended discussion except to say that in both instances deferral is limited although unlike financial options, real options may have an uncertain exercise date.

Characteristics	**Financial option**	**Real option to defer immediate treatment**	**Option to defer treatment of abdominal aortic aneurysms**
Decision maker	Owner of option, individual or unit	Clinician in conjunction with patient and family	Clinician and patient
Source of option	Bought, conferred through previous activities.	Conferred endogenously through previous investment in technology and exogenously via gradual progression of disease	Screening technology, surgical development, early presentation by individual
Source of uncertainty	Stock price	Underlying disease progression and individual's response coping mechanisms	Rate of increase of aneurysm
Information gained through deferral	Changes in stock price allows updated probability calculations of up and down stock movements	More extensive historical data both at the group and individual level. Other variables impacting on the decision may still remain uncertain at the time of exercise. Eg. Variables whose uncertainty must be actively resolved	Occurrence growth / shrinkage, rates of change
Source of irreversibility	Final exercise price paid	Ultimate treatment and associated costs	Surgical reparation of aneurysm, associated risks and costs
Ability to defer	Limited by exercise date	Will vary between diseases and from patient to patient depending on treatments available, rates of progression and patient responses	Limited by growth aneurysm and factors rendering the patient unfit for surgery

Table 1: Summary of the characteristics defining financial options and how these relate to real options, specifically the option to defer treatment for abdominal aortic aneurysms.

Both decision agents face sources of uncertainty that influence their decision-making strategies. On deferring exercise of a financial option, the price of an asset underlying a contract is observed. Each new observation may alter the exercise decision. Clinicians face a similar situation with respect to the well being of their patient. The nature of illnesses and the physical body's ability to respond, fight back, and cope, combine to create a state of well being that evolves over time. Numerous scales, including disease specific measures such as growth rate of a tumour or aneurysm, and PSA (Prostate specific antigen) levels or generic scales such as blood pressure, self rated quality of life or expected remaining QALY's may be used to measure well being.

Despite knowledge of historical price variation, the random walk element of stock prices means that financiers are no more informed about what will *actually* happen in the future. Although this is true also of real options, more emphasis may be placed on historical observations when current and historic well being are shown to be predictors of future changes. With real options therefore, the passing of time increases available information upon which a decision to exercise is conditioned. A clinician may observe a relatively large aneurysm that would normally undergo immediate repair. Following a single period of deferral, the absence of diameter growth may alter the clinician's recommendation. Observed rapid growth of a small aneurysm may likewise alter prior opinions to reflect the wider information set.

Unlike financial options, real options may have multiple sources of uncertainty. Consequently the direct positive relationship between the value of the call option and changes in the value of the uncertainty variable may not exist for real options.

Financial options are irreversible in the sense that exercise requires a sunk cost. On exercise the investor gives up an 'exercise price', or asset cost as given in the options contract. Real options tend to have sources of irreversibility additional to sunk costs. Watchful waiting defers some treatment, usually surgery, which involves extensive sunk costs in the form of bed costs, surgeon and anaesthetist costs, and the cost of disposables. There are also elements of physical irreversibility such as side effects of surgery that may occur which are specific to the option under consideration. Deferral of treatment for localised prostate cancers defers the possible irreversible effects of impotence and incontinence, not to mention risk of infection, or worse; death. Deferring amputation likewise provides an example of irreversibility. Where the deferred treatment is medical rather than surgical commencing some drug regimes may create irreversibility due to withdrawal effects.

As can be seen from these parallels, characteristics defining financial options have analogies within the real sector. But if the use of financial option pricing techniques to value real options is to be defended, there must be some analogy between parameters used in financial formulae and the workings of real options. Parameters commonly used in financial option pricing formulae are given in table 2, along with details of how these relate to the option to defer treatment. The parameters actually used in an application will depend on the pricing method chosen but are always closely related to those specified here.

Parameter	**Financial option**	**Real option to defer immediate treatment**	**Option to defer treatment of abdominal aortic aneurysms**
Current value of source of uncertainty	Current spot price of the asset (S)	Current estimated monetary benefit of immediate action	Current estimated present benefit from surgical repair
Estimate of uncertainty	Variance in stock value (σ^2) (as a % of stock value)	Uncertainty surrounding magnitude of benefit	Estimated uncertainty surround benefit from repair over time
Cost of exercising option	Exercise price (X) of stock agreed in contract	Cost of resources used such as disposables, surgeon. (Remains fairly constant over life of option)	Cost of carrying out surgical repair including anaesthetics, antiseptics, bed costs
Date before which option must be exercised	Exercise date stated in contract. (Time until expiration given by T)	Date when option becomes un-available influenced by life expectancy or a threshold of disease after which treatment becomes futile	Date when aneurysm ruptures or patient becomes unfit for surgical repair

Table 2: Parameters commonly used in financial option pricing techniques and their relation to the real option to defer treatment for abdominal aortic aneurysms.

The parameters required for valuation are closely related to the defining characteristics. The current value of the uncertain variable and degree of uncertainty governing the evolution of this parameter are given in finance by stock price and associated volatility. A real options problem proxies these with estimates of the present benefit from treatment and associated volatility through time. The cost of exercising a real option, equivalent to the exercise price and measuring irreversibility, is simply the investment cost. The date before which the option must be exercised, or exercise date is found by estimating the point in time when the option will no longer be available, although this may not exist for many real options and may be stochastic for many others. The apparent ability to approximate financial variables suggests health care decision problems are naturally amenable to real options analysis.

Section 4. Watchful waiting as option on treatment; a numerical example

With the parallels between financial options and real options to defer treatment reasonably apparent, it seems appropriate to attempt to apply the financial theories to a specific decision problem. To this end, this section uses the deferred treatment of abdominal aneurysms as a case study, in which to help to identify the merits of specific applications, problems encountered, and how these might be overcome in future applications.

Optimal treatment for patients presenting with abdominal aortic aneurysm (AAA's) involves surgical repair of those AAA's that are likely to rupture and shorten life expectancy, whilst avoiding unnecessary surgery in patients who would otherwise die of unrelated causes. Currently, for aneurysms smaller than 5cm the risk of rupture is relatively low causing some debate about whether immediate elective repair is necessary, and fuelling arguments in favour of watchful waiting.

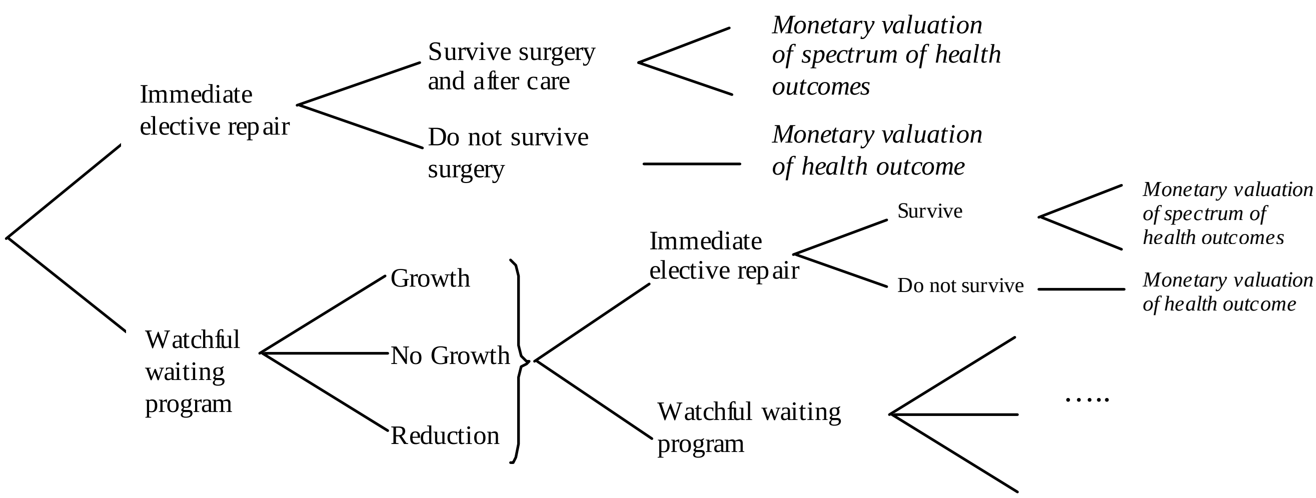

Figure 2: Decision tree illustrating the management of a patient presenting with an abdominal aortic aneurysm.

Figure 2 shows a decision tree in which a clinician must decide on a treatment management strategy for a presenting patient. The patient may be treated immediately via surgical repair or undertake watchful waiting.

Immediate action brings risk of operative mortality (primarily cardiac risk) and is considered more costly than deferred treatment. If the final treatment decision is deferred, the patient is monitored at regular intervals, with ultrasound or computed tomography scanning being used to supply information required by the real options model on key sources of uncertainty, such as size and growth rate of the aneurysm. Repair is carried out when the diameter of the aneurysm reaches some threshold size[iii]. Deferral, although cheaper, is associated with risk of rupture and thus death, both of which are positively related to size and growth rate. It is not uncommon for patients to become medically unfit for surgery during a deferral period. The treatment decision of when to beginning immediate treatment is conditional upon the clinicians current information set which is dictated by the results of scans. Following deferral the decision-maker faces the same decision situation as when the patient initially presented, as in figure 2. Real options analysis is used here to value watchful waiting with immediate elective repair when deemed necessary.

An aneurysm is assumed to be able to grow, remain constant size, or reduce in size during a deferral period. The current present benefit of immediate surgery is given as £10000. A model based on real world data would estimated this figure given knowledge of the current size and growth of the aneurysm, which serves as a partial determinant of well being from surgery. Monte Carlo simulation would be used to combine the various sources of uncertainty, as shown in figure 2, such as risk of rupture and surgical risk. The well being estimate, defined as the difference between projected quality adjusted life years with and without surgery, can be converted into a financial benefit to surgery via society's willingness to pay, and discounted to a present value. So long as at least one underlying variable can be projected through time, the final outcome, current benefit to surgery, becomes an evolving variable.

[iii] Katz 1994 uses 6 monthly observations and a treatment triggering threshold of 5cm.

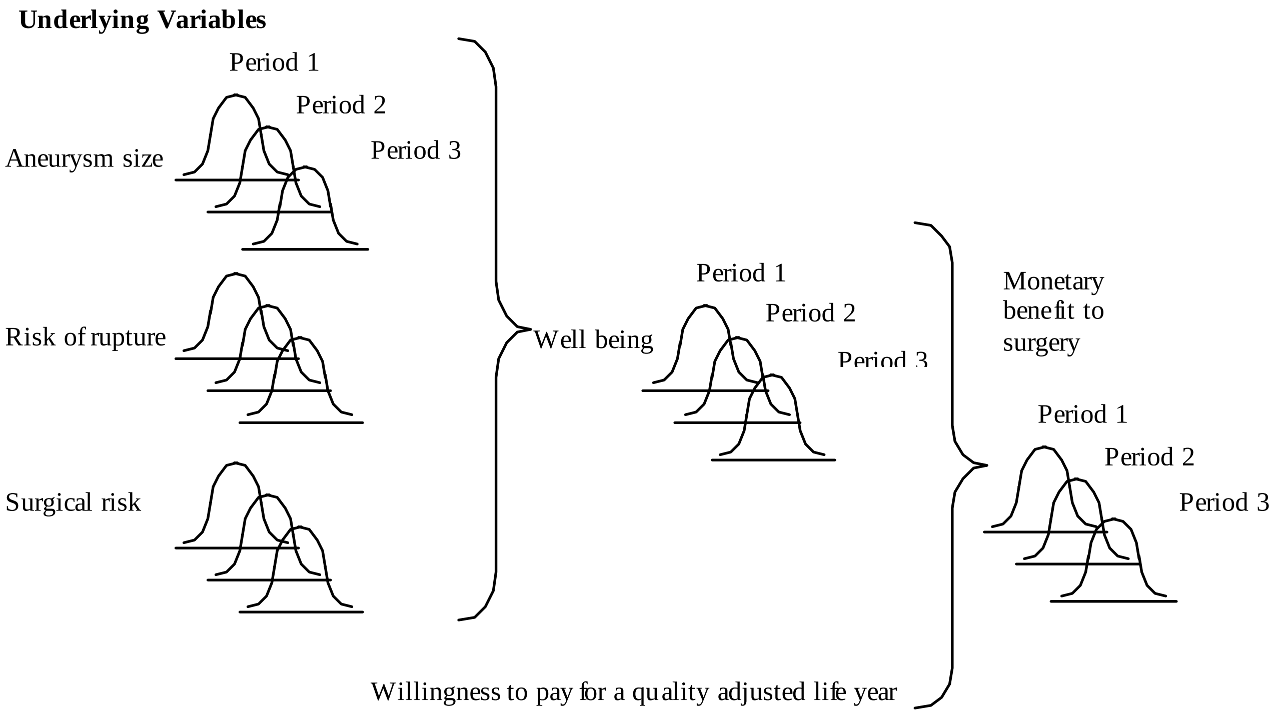

Figure 3: Combining sources of uncertainty to derive a financial benefit form surgery that evolves through time and can be used in a model of option valuation.

Current benefit is assumed to follow the trinomial distribution of the growth rate of the aneurysm, but since true biomedical state follows a continuous time diffusion process, parameters are chosen to approximate continuous time. This is achieved by subdividing the total deferral period (T) into N equal discrete sub intervals of length dt such that T = N * dt. As dt tends to zero the trinomial converges to a continuous distribution. This conforms to standards set by Trigeorgis[24] who uses a log transformed binomial to show how to estimate binomial state and time variables to guarantee stability of the discrete time approximation to the continuous process.

The current cost of surgery including disposables, clinician time, and bed costs is assumed to be £13000. For consistency with financial models the cost of monitoring the patient is assumed negligible. Although currently not cost-effective (Net benefit = -£3000) net benefit fails to account for the option to treat at some point in the future, when the treatment may have become cost-effective due to changing parameter values.

Setting up the problem as an option to defer treatment, £10,000 becomes the current estimate of the uncertain variable, while £13,000 becomes the exercise price. Base case deferral of up to one year, with monthly observations, is used. A riskless discount rate of 6%, and a volatility parameter of 25% applied to the current benefit from surgery, is used in the first instance. Fortran code based on algorithms suggested by Haug[25] is used to project current benefit of surgery through time until the exercise date, calculate final period option values and perform backward induction to derive option values for each period. The ability to exercise the option during any time period is specifically incorporated, to account for the American nature of the option.

Given these base case parameter estimates the value of the option to defer immediate treatment is £1656 despite the negative net benefit estimate. If these estimates were true in practice deferral would be the recommended patient strategy. Table 3 provides the option value and net benefit for a range of current benefits from surgery. Examining the range of option values and net benefit estimates that result, permits a comparison of the decision rules resulting from the two methods. Net Benefits presents a dichotomous decision, accept or reject, identified by the level of benefits where net benefit equals zero. Real options presents a trichotomous decision structure; reject, defer, and accept. The combination of these two sets means there are four regions of possible conflict or agreement between real options and net benefit decisions; agree to reject, agree to accept immediately, agree to accept but real options recommending deferral, disagree totally.

Benefit to treatment	Option Value	Net Benefit
5000	0	-8000
6000	1	-7000
7000	8	-6000
8000	42	-5000
9000	137	-4000
10000	328	-3000
11000	644	-2000
12000	1090	-1000
13000	1656	0
14000	2372	1000
15000	2978	2000
16000	4002	3000
17000	4920	4000
18000	5853	5000
19000	6817	6000
20000	7792	7000

Table 3: Sensitivity analysis about the benefit of treatment.

These regions are more clearly illustrated in figure 4, a graphically representation of the same information. Below £6000 both techniques agree to reject immediate treatment (Region 1), although in practical terms a patient would still be monitored. In region 2 between £6000 and £13000, option value exceeds zero recommending deferral, whilst net benefit still supports rejection. After £13000 net benefit becomes positive recommending accept but option value conservatively continues to support deferral (region3). Finally in region 4, above £16000 when the marginal benefit from the two outcome measures becomes equal, both methodologies agree to accept immediate treatment. The region of most interest to current decision making is region 3 where real options would alter the preferred treatment strategy from immediate surgical repair to watchful waiting.

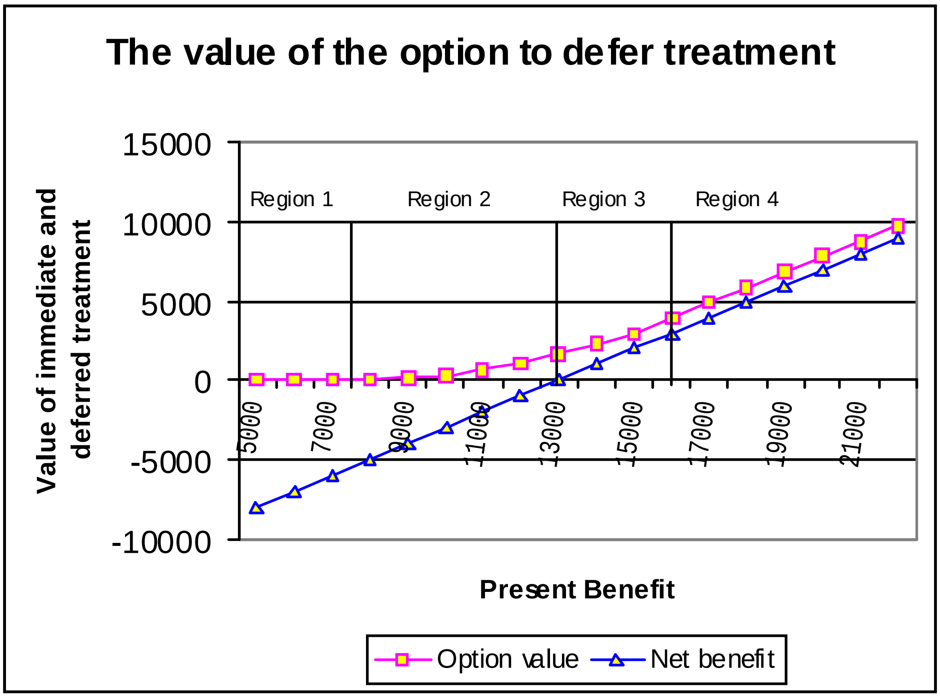

Figure 4: Graphical representation of sensitivity analysis about the benefits of treatment

The effect of changes in the parameters on option value is explored in table 4. This univariate analysis demonstrates a positive relationship between the deferral period, discount rate and volatility, and option value. The number of observation periods in a given deferral time has an indeterminate effect on option value.

Time to expiration (years)	Option value	Number of time periods	Option value	Discount rate	Option value	Volatility	Option value
0.5	87.4	365	325.4	0.02	252	0.1	7.1
1	**328.8**	52	325.9	0.04	288.5	0.15	64.6
1.5	584.1	**12**	**328.8**	**0.06**	**328.8**	0.2	175.8
2	861.3	6	320.6	0.08	373.1	**0.25**	**328.8**
2.5	1137.9	2	257.3	0.1	421.5	0.3	486.4

Table 4: Univariate sensitivity analysis of parameter values on option value. Baseline values are displayed in **bold**

Section5. Conclusions

Wong et al's study of watchful waiting versus immediate therapy for mild chronic hepatitis C uses standard techniques to calculate cost per QALY and concludes that deferral is not optimal. Incorporating option value into the analysis may lead to deferral being cost-effective in some cases where it is not currently. Failing to account for option value may therefore result in inaccurate conclusions. This paper has attempted to correct this methodological deficiency through the use of real options analysis applied to the decision to defer treatment for abdominal aortic aneurysms.

The similarities between financial options and real options are apparent at an intuitive level with uncertainty, irreversibility and the ability to defer characterising both forms of option. Watchful waiting is likely to be viable when disease progression is slow, when the costs (both monetary and physical) of aggressive therapy, are high, and when observation costs incurred during the waiting period are low. The first two of these issues are well represented in the real options model and impact on the value of the option to defer. Observation costs pose some problems for financial based valuation techniques. Information gained through deferring financial options is collected passively, through observation of stock prices, with the owner of the option going to little effort or expense. As a result, such transaction costs are assumed negligible in financial models. This creates problems for real options models where observation costs may be large. Wong et al's conclusion that deferral is dominated rests predominantly on the high costs of repeated biopsy. Failure to incorporate monitoring costs is currently a drawback of many valuation techniques including the trinomial algorithm used here. An important way to improve this model is therefore to adapt the financial techniques to include such costs.

Aspects such as the source of uncertainty also strain the analogy between the financial and real options. Simple financial options have a single source of uncertainty that impacts directly on the payoff from exercise. Real options tend to be influence by numerous sources of uncertainty that create a significantly less direct link between each source and the final outcome. This problem is, however, more apparent than real. Closer examination of financial markets reveals complex options on more than one asset. In addition techniques such as Monte Carlo simulation allows sources of uncertainty to be combined into a single output.

Problems with the application of real options methods can arise in the choice of valuation techniques. Significant advances have arisen in the pricing of financial options in recent years such as the valuation of options on the maximum or minimum of two assets. But there is some delay in making these financial techniques suitable for real options analysis. As a result there is severe limitation in the number of financial techniques available to the applied real options analyst. Few real options problems have closed-form solutions making the use of numerical techniques and programming inevitable. The analyst therefore faces a trade off between simplifying the real option to fit a basic valuation technique or accepting a realistic financial valuation that stains the analogy. Do we concentrate on intuitive yet overly simple techniques or adopt more accurate black box type valuations?

A final problem with the application of real options methodology is data collection. Currently data is collected with a static perspective. Cost-effectiveness estimates represent the desirability of a technology at a single point in time given current estimates of uncertainty. Real options requires a projection of uncertainty into the future which requires regular, periodic measurements of uncertain variables today. Clinical trials monitor data at intervals but these intervals tend to be uneven, extending as the trial progresses (ie 1 month, 3 month, 6 month observation points). Adoption of real options methodology therefore requires that existing habits be altered in order to meet the data requirements.

The aim of this exploratory study was to attempt to establish a methodological and conceptual justification for the use of real options analysis within health care. This paper has used standard techniques to demonstrate that real options analysis may and can be applied to health care decision making and to fail to do so may introduce bias into evaluations where deferral is a potentially viable alternative. Further work in this area includes assessing the desirability of application of these methods to a wider range of decision problems, as well as considering the implications of real options analysis for value of information studies.

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