Working Paper Series
Department of Economics
University of Verona

Dynamic, economic approaches to HTA under uncertainty

Martin Forster, Paolo Pertile

WP Number: 3 March 2011

ISSN: 2036-2919 (paper), 2036-4679 (online)

Dynamic, economic approaches to HTA under uncertainty

Martin Forster,* Paolo Pertile†,

Abstract

A simple, two period framework is used to interpret existing contributions to the literature on decision rules for HTA under uncertainty and to contrast them with a dynamic, economic model solved using backward induction.

JEL codes: I10, C61
Keywords: economic evaluation, dynamic programming

1 Introduction

The consistency of decision rules delivered by statistical approaches to Health Technology Assessment (HTA) with those based on dynamic, economic, approaches has been questioned in recent years. Claxton (1999) proposes that, if an adoption decision cannot be deferred, it should be based on the maximization of net expected value, with uncertainty surrounding the point estimate being used to inform a decision about whether to carry out further research. Palmer and Smith (2000) propose a 'real option' approach to HTA. Eckermann and Willan (2007, 2008) show that, if the decision to adopt is irreversible, it cannot be separated from the decision to research. Further, they link the decision-theoretic concept of the Expected Value of Sample Information to the concept of the option.

This note uses a simple, two-period, framework to argue that successful development of a truly dynamic, economic, stochastic model for HTA should

*Department of Economics and Related Studies, University of York, York YO10 5DD, U.K..

†Corresponding author. Department of Economics, University of Verona, 37129 Verona, Italy. e-mail: paolo.pertile@univr.it, tel.: +39 045 8028438.

be based on established methodology - namely dynamic programming (Bellman, 1957) - which models research and adoption decisions together as one project, whose expected discounted value is to be maximised (Roberts and Weitzman, 1981; Eckermann and Willan, 2008). Optimal rules for adoption and research should be obtained recursively, using backward induction. The framework shows how the option value and the Expected Value of Perfect Information may be calculated, under various combinations of irreversibility and flexibility regarding the timing of an adoption decision.

2 A two-period model

An expected utility maximising decision-maker (DM) is considering whether or not to treat P_t patients in period t and P_{t+1} patients in period $t+1$ with a new or existing health technology. In period t there exists uncertainty over the incremental net monetary benefit (INMB) of the new technology versus the existing one which can be completely eliminated by carrying out research in t at cost $c > 0$, the results of which will be available in $t+1$, prior to the point at which the DM must make the adoption decision. A number of simplifying assumptions are made: there exists no sunk cost associated with adoption of the new technology; once a patient has been treated with either one of the two technologies, it is not possible to treat that patient again (with either technology); research and treatment populations are separated, implying that value accrues for the treatment population only and that this population is not used for research. These are straightforward to relax.

Viewing the decision in $t+1$ from the perspective of t, and conditional upon the DM's information set in t, the DM believes that, should research be carried out, it will indicate that the new technology is superior, with INMB equal to $x > 0$, with probability p, and the existing technology is superior (with INMB equal to $y < 0$) with probability $(1-p)$. Define the expected incremental net monetary benefit of treating one patient with the new technology as $z = px + (1-p)y$ and assume that costs and benefits accruing in $t+1$ are discounted by the rate δ. We consider the case in which $z > 0$, that is, the new technology is expected to be superior to the existing

one (the analysis is simple to repeat for the case of $z < 0$).

The optimal actions for the DM may be established recursively. In period $t+1$, the DM's information concerning INMB is the same as that in t if no research is carried out in t and is 'perfect' if research is carried out in t. If no research is carried out in t, the DM chooses the new technology since $z > 0$. If research is carried out in t, the DM's optimal action is to adopt the new technology if INMB $= x$ (for an incremental reward of x at the individual level) and stick with the existing technology if INMB $= y$ (for an incremental reward of zero).

The actions available to the DM in period t are as follows: adopt/do not adopt the new technology, treat/do not treat the P_t patients and research/do not research.

We identify the optimal actions and rewards in four scenarios which differ according to whether or not adoption of the new technology in t is irreversible and treatment of patients in t can be deferred (research can only take place in t). These are summarised in Table 1. We show how to calculate the value of the option, bearing in mind that, in order for a non-zero option value to exist, at least one action (the relevant actions being adopt/do not adopt and treat/do not treat the P_t patients) must be both irreversible and flexible (Dixit and Pindyck, 1994). Note that all scenarios assume that the treatment of patients is irreversible and the DM has the flexibility to choose the timing of adoption.

Consider first scenario 1(a). In period t, the DM does not have the flexibility to delay treatment of P_t patients until $t+1$ and is unable, in period $t+1$, to reverse a decision to adopt the new technology if it is made in period t. Figure 1 shows a decision tree for the problem and the associated expected, discounted, period t rewards for the DM are shown in the first 2×2 table of Table 2. For each scenario in Table 2, the values reported in the cells of the tables refer to expected values in t assuming optimal behaviour according to following appropriate policy rules in $t+1$ and then t, calculated recursively. Shaded cells represent a combination of actions whose rewards are strictly less than the rewards in one of the other cells.

For scenario 1(a), irreversibility of a decision to adopt the new technology

made in period t means the DM has no choice but to use the new technology in $t+1$. Hence the decision tree in Figure 1 has no branches for adopt/do not adopt choices in $t+1$, conditional upon having adopted the new technology in t. Conditional upon adoption in t, it is never beneficial to carry out research, since cell YY (the first Y/N always references "Adopt in t?", the second "Research in t?") in Table 2 is always of lower value than cell YN by the amount c (hence the grey shading of cell YY). If the DM does not adopt in t and carries out research, perfect information will be available in $t+1$, allowing the DM to invest in the new technology for total reward $P_{t+1}x$ if the research favours the new technology and continue with the existing technology, with payoff 0 (and probability $1-p$) if research favours the existing technology. Hence, using backward induction, from the perspective of period t, the expected discounted value associated with not adopting and carrying out research is $-c+p(P_{t+1}x)(1+\delta)^{-1}$. Finally, cell NN is strictly less than cell YN. Only two feasible cells are available in scenario 1(a). Non-adoption and carrying out research will be optimal if the value in cell NY strictly exceeds that in cell YN, in other words, if:

$$\frac{1}{1+\delta}\left(\underbrace{pP_{t+1}x}_{\text{EV|PI}}-\underbrace{P_{t+1}z}_{\text{EV}}\right) > P_tz+c, \tag{1}$$

where EV|PI is the expected value conditional upon being in possession of perfect information in $t+1$ and EV is the expected value in $t+1$, the difference between the two being the expected value of perfect information (EVPI). On the right hand side is the total cost of deciding to postpone adoption to acquire more information: the expected loss of INMB associated with not treating patients in t with the new technology, together with the cost of research. Eq. (1) can also be interpreted in terms of option values: the left hand side is simply the value of the option to postpone investment, whereas the right hand side is the exercise cost of the option.

It is straightforward to continue this analysis for the other three scenarios

in Table 1. For scenario 1(b), NY is preferred to YN if:

$$\frac{1}{1+\delta}\left[p(P_t + P_{t+1})x - P_{t+1}z\right] > P_t z + c, \tag{2}$$

the difference between this scenario and that of scenario 1(a) lying in the P_t patients whose treatment may be deferred until $t+1$ owing to the flexibility to delay treatment, thereby increasing the value of the option (they show up as the P_{t+1} patients in the EV|PI term of Eq. (2)). For scenario 2(a), there exists full and costless reversal of the adoption decision (that is, no irreversibility) and no flexibility to defer treatment of period t's patients. The conditions for the existence of a non-zero option value no longer hold and adoption in t is optimal because $z > 0$, with the question of whether to carry out research dependent upon a comparison of Scenario 2(a)'s EVPI with c. This is the 'irrelevance of inference' result (Claxton, 1999), a special case of our general framework. Finally, in scenario 2(b), the optimal decision involves choosing the maximum value of three feasible action combinations. Conditional upon adoption in t being optimal, the criterion concerning whether or not to carry out research is the same as that for scenario 2(a). Conditional upon YY not being optimal, the criterion is the same as that for scenario 1(b).

The scenarios show the following:

1. the existence of irreversibility and flexiblity of actions (scenarios 1(a),(b) and 2(b), with at least one column with entries 'YY', in Table 1) means that research and adoption decisions are made simultaneously;

2. in this simple two-period model, where uncertainty is completely eliminated in the second period, the concepts of EVPI and the value of the option are equivalent.

A natural question that arises is what would happen if one were to extend the analysis to a multi-period framework; in real life applications, new information will typically not lead to perfect information and so the DM will once again face the alternatives of carrying out more research, adopting the technology and stopping research (without adopting). In this case, the optimal policies may be established by solving the Bellman equation, which works

recursively to give optimal rules today conditional on the state and information set of the DM and assuming optimal behaviour in the future (Bellman, 1957; Bertsekas, 1976; Puterman, 1994; Dixit and Pindyck, 1994). The value of waiting will not equal the Expected Value of Sample Information. Pertile et al. (2010) show that it is possible to derive optimal sequential sampling rules for technology adoption and research abandonment decisions, referring to the methods developed by Chernoff (1961, 1972) and Chernoff and Ray (1965).

References

Bellman, R. E. (1957). *Dynamic Programming*. Princeton University Press, Princeton, New Jersey, First edition.

Bertsekas, D. (1976). *Dynamic Programming and Stochastic Control*. Academic Press, New York, First edition.

Chernoff, H. (1961). Sequential tests for the mean of a normal distribution. Proceedings of the fourth Berkeley Symposium on Mathematical Statistics and Probability,. pages 79–91.

Chernoff, H. (1972). *Sequetial analysis and optimal design*, volume 8. Siam, Philadelphia, first edition.

Chernoff, H. and Ray, S. N. (1965). A Bayes sequential sampling inspection plan. *Ann. Math. Statist.*, 36(5):1387–1407.

Claxton, K. (1999). The irrelevance of inference: a decision-making approach to the stochastic evaluation of health care technologies. *Journal of Health Economics*, 18(3):341–364.

Dixit, A. K. and Pindyck, R. S. (1994). *Investment under Uncertainty*. Princeton University Press, Princeton, New Jersey, First edition.

Eckermann, S. and Willan, A. R. (2007). Expected value of information and decision-making in hta. *Health Economics*, 16:195–209.

Eckermann, S. and Willan, A. R. (2008). The option value of delay in health technology assessment. *Medical Decision Making*, 28(3):300–305.

Palmer, S. and Smith, P. C. (2000). Incorporating option values into the economic evaluation of health care technologies. *Journal of Health Economics*, 19:755–766.

Pertile, P., Forster, M., and La Torre, D. (2010). Optimal sequential sampling rules for the economic evaluation of health technologies, Department of Economics and Related Studies Discussion Paper 2010/24.

Puterman, M. L. (1994). *Markov Decision Processes*. Wiley, New York, First edition.

Roberts, K. and Weitzman, M. L. (1981). Funding criteria for research, development and exploration projects. *Econometrica*, 49(5):1261–1288.

Table 1: The four scenarios defined according to presence, in period t, of irreversible adoption of the new technology and flexibility of treatment of patients

	Scenario 1(a)		Scenario 1(b)	
	Adoption of new technology	Treatment of patients	Adoption of new technology	Treatment of patients
Irreversible	Y	Y	Y	Y
Flexible	Y	N	Y	Y
	Scenario 2(a)		Scenario 2(b)	
	Adoption of new technology	Treatment of patients	Adoption of new technology	Treatment of patients
Irreversible	N	Y	N	Y
Flexible	Y	N	Y	Y

Figure 1: Decision tree for scenario 1(a)

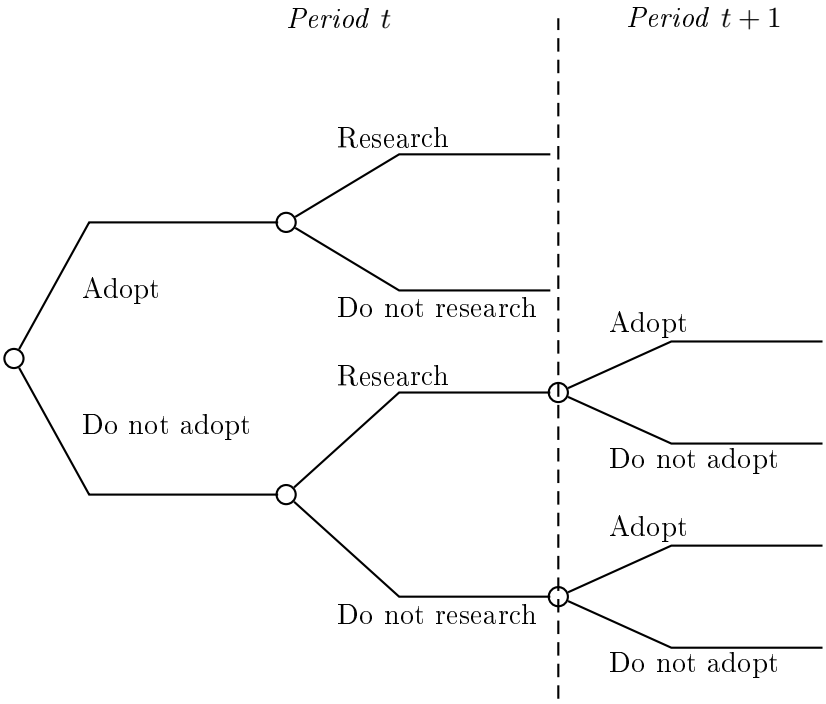

Table 2: Actions and expected discounted rewards for the project in period t under the four scenarios of Table 1. Cells shaded in grey are strictly less than other cells in the table under the assumptions of the model

1. Adoption decision is irreversible

(a) Deferral of treatment for patients in t not permitted ('no flexibility')

		Research in t? Y	Research in t? N
Adopt in t?	Y	$P_t z - c + \left(\frac{P_{t+1} z}{1+\delta}\right)$	$P_t z + \left(\frac{P_{t+1} z}{1+\delta}\right)$
	N	$-c + p\left(\frac{P_{t+1} x}{1+\delta}\right)$	$\frac{P_{t+1} z}{1+\delta}$

(b) Deferral of treatment for patients in t permitted ('flexibility')

		Research in t? Y	Research in t? N
Adopt in t?	Y	$P_t z - c + \left(\frac{P_{t+1} z}{1+\delta}\right)$	$P_t z + \left(\frac{P_{t+1} z}{1+\delta}\right)$
	N	$-c + p\left(\frac{(P_t + P_{t+1}) x}{1+\delta}\right)$	$\frac{(P_t + P_{t+1}) z}{1+\delta}$

2. Adoption decision is fully and costlessly reversible

(a) Deferral of treatment for patients in t not permitted ('no flexibility')

		Research in t? Y	Research in t? N
Adopt in t?	Y	$P_t z - c + p\left(\frac{P_{t+1} x}{1+\delta}\right)$	$P_t z + \left(\frac{P_{t+1} z}{1+\delta}\right)$
	N	$-c + p\left(\frac{P_{t+1} x}{1+\delta}\right)$	$\frac{P_{t+1} z}{1+\delta}$

(b) Deferral of treatment for patients in t permitted ('flexibility')

		Research in t? Y	Research in t? N
Adopt in t?	Y	$P_t z - c + p\left(\frac{P_{t+1} x}{1+\delta}\right)$	$P_t z + \left(\frac{P_{t+1} z}{1+\delta}\right)$
	N	$-c + p\left(\frac{(P_t + P_{t+1}) x}{1+\delta}\right)$	$\frac{(P_t + P_{t+1}) z}{1+\delta}$