# Incorporating affordability concerns within cost-effectiveness analysis for health technology assessment

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## Abstract

Recent policy developments and journal articles have emphasised a divergence: when interventions are found to be cost-effective but unaffordable. From the perspective that being cost-effective implies producing a benefit over and above the opportunity cost we argue that these conflicting results make little sense. Rather, this apparent paradox reflects a conventional practice of cost-effectiveness analysis that does not properly evaluate the opportunity costs of an intervention that imposes non-marginal costs on the health care system. This paper presents a framework by which concerns for affordability can be appropriately incorporated within cost-effectiveness analysis and highlights important methodological and policy implications. In addition, key parameters and relationships are identified within this framework that require further empirical research.

## Background

A number of recent articles have highlighted concerns around affordability of new technologies as a challenge to the role of cost-effectiveness analysis (CEA) in informing health technology assessment (HTA), both in the context of low- and middle-income countries1 and high income countries, such as the UK and USA.2,3

While there is consensus that conventional practice in cost-effectiveness analysis does not explicitly incorporate concerns for affordability, beyond the consideration of incremental cost per patient and the use of a cost-effectiveness ‘threshold’, there is little consensus on how budget impact analysis (BIA) evidence should be used in informing HTA decisions alongside CEA.4,5 A number of papers have called for evidence from CEA and BIA be “integrated”, which is taken to mean that results from both should be presented to decision-makers, implicitly arguing that they independently provide useful information.1,3

Others have argued that budget impact should be incorporated within CEA through the use of a varying cost-effectiveness ‘threshold’ against which incremental cost-effectiveness ratios (ICERs) are compared – reflecting the larger opportunity costs that would follow from larger budget impacts.6–9 While largely accepted as a premise, some have questioned the feasibility of determining the relationship between the ‘threshold’ and budget impact and employing and defending it in practice.3 Whilst these challenges are no doubt significant, there are examples of the logic being applied in practice, with the Australian Pharmaceutical Benefits Advisory Committee (PBAC) recommending a “lower acceptable cost per QALY” for new medications for Hepatitis C given the large budget impact.10 In addition, a recent paper estimated the relationship between health opportunity costs and budget impact empirically using UK administrative data.11 Using the estimated relationship, it then illustrates implications for estimating the health opportunity costs associated with treatments for Hepatitis C in England, which could then be used to inform an appropriate cost-effectiveness ‘threshold’ or be used as an input into the calculation of net health benefit.11

In their paper, Bilinski et al. (2017)1 outline four reasons why conventional CEA suggests that certain treatments are cost-effective but may be unaffordable in practice: cost-effectiveness judged next to an inappropriate cost-effectiveness ‘threshold’, societal perspective that includes costs not falling on the payer’s budget, no explicit consideration of the distribution of costs over time and the use of an inappropriate discount rate that may not accurately reflect the borrowing and investment opportunities facing the payer. In this paper, we outline a framework illustrated from a healthcare sector perspective that could in principle resolve all of these issues conditional on the successful estimation of health opportunity costs that vary with budget impact and the identification of an appropriate discount rate (a matter beyond the scope of this paper, and considered elsewhere12,13).

## Perspective and decision rules

The analysis we present here considers a decision-maker who is interested in improving overall population health with constrained resources to employ across competing potential uses. The resources available to the decision-maker are exogenous, assumed to be determined by some social process. Given these constraints, the decision-maker must consider the health opportunity costs (or shadow price) of committing expenditure to a particular use. Within this literature these are estimated using the parameter $k$, which reflects the rate at which health opportunity costs are incurred with health care expenditure (expressed in terms of cost per QALY). From the perspective of the decision-maker $k$ is therefore exogenously determined in any given time period as a result of the social process by which resource allocation occurs. Our analysis adopts the perspective of the exogenously constrained decision-making agent, rather than the resource allocating principal, and so does not directly answer questions regarding whether the available resources can themselves be considered optimal.

In principle, mathematical programming could be employed to design the optimal portfolio of health care given scarce resources, however implementing this in practice would make infeasible informational demands on behalf of the decision maker and require impractical constant funding and de-funding of services.14 The use of ICER-based decision rules is widespread and is held to reflect a pragmatic approximate solution of the mathematical programming solution to this optimisation problem. The degree to which the approximation is reasonable is affected by key assumptions around divisibility (relative to total spend), returns to scale (conditional on observed heterogeneity) and consequences of budget over-spends.15

Practically, the use of ICER-based decision rules is limited in other ways. First, several versions of the decision rule are required depending on whether the new intervention has a positive or negative incremental cost and whether or not the new intervention has a positive or negative incremental QALY in the patient population under consideration. Second, using ICERs is challenging when trying to characterise the associated uncertainty given its alternative interpretations depending on direction of incremental cost and effect and its statistical properties as a ratio of two random variables. Third, ICER-based decision rules can only be used within the context where decisions are made only to approve in full or reject in full. This simplification means that we do not consider decisions to approve with research recommendations16 or to only partially approve a technology.17 Fourth, ICERs will take the same value regardless of whether the $∆C$ and $∆QALY$ are calculated at the population or the per-patient level. Finally, it is worth bearing in mind that the distribution of costs over time are not at all visible from the ICER, which collapses all information on the time series of costs down to one summary statistic.

An alternative decision rule using net benefit is proposed18–21, which is mathematically equivalent and results in the same decision as a rule based on ICERs when $k$ is assumed constant (implicitly assuming constant returns to the scale of total expenditure). The net health benefit ($NHB$) formulation allows results to reflect the overall gain to population health, which is comprised of the $∆QALY$ in the patient population receiving the intervention, the $∆C$ imposed upon the health care system and the health opportunity costs that result from $∆C$ (here given by the function $HOC(∆C)$ and then related back to $k$ in the manner in which CEA is conventionally practised, equation 1).

$NHB=∆QALY-HOC(∆C)=∆QALY-\frac{∆C}{k}$ (1)

The key advantage of using this formulation for the purpose of this paper is that net health benefit has a natural measure (QALYs) and, unlike the ICER, can be aggregated and averaged in a meaningful way. This provides additional flexibility that is required to fully reflect health opportunity costs in a decision rule when $k$ is no longer assumed constant (thereby relaxing the constant returns to scale assumption), but specified as a function of budget impact ($k(∆C)$). This is illustrated in equation 2.

$NHB=∆QALY-HOC(∆C)=∆QALY-\frac{∆C}{k(∆C)}$ (2)

## Motivating example

In recent years, a number of medications for the treatment of Hepatitis C have been made available to the English NHS. These pharmacological treatments have often been found to be cost-effective for many patients owing to their greater effectiveness, despite the large estimated incremental cost per patient because of the prices charged by the manufacturers.22–24 These high acquisition costs, coupled with the prevalence of Hepatitis C in England, led to projected budget impacts that resulted in serious concerns about the affordability of these new drugs from NHS England. Depending upon assumptions about the likely patient population, the budget impact on the NHS was estimated to be between £60mn and £772mn.23 As a result NHS England decided that the implementation period of NICE guidance was to be extended beyond the usual timeframe for these drugs.23

In this example there are three key components leading to concerns about affordability: i) the scale of the budget impact, with the largest estimated budget impact representing around 0.7% of the total NHS budget; ii) while some cost savings in future years might result from the new Hepatitis C treatments’ increased effectiveness, these savings are insignificant next to the up-front budget impact from approving the use of the new medications for all patients with Hepatitis C; and iii) the budget impact is uncertain and the estimates under different assumptions led to vastly different results. These three factors make this an interesting and policy-relevant example for discussing a framework that can incorporate concerns for affordability within CEA.

This context was also analysed in Lomas et al. (2018) where two scenarios were compared. One where the budget impact of £772mn was incurred in the first year of approval, and another scenario where this budget impact was spread over an infinite number of years in small instalments such that the net present value was £772mn. In conventional CEA the health opportunity costs of these two cost schedules would be equal since $k$ is assumed to be constant (equation 1). Using their estimated relationship between budget impact and $k$, they find that for the first of these cost schedules, where all budget impact occurs in year one, the appropriate value of $k$ would be £12,452 per QALY rather than the Claxton et al. (2015)25 estimate of £12,936 per QALY for marginal investments. Estimating health opportunity costs using this value of $k$ resulted in a value roughly 4% greater than when estimated using Claxton et al. (2015).

## Implications when the time profile of budget impacts is significant

Conventional practice in CEA is to collapse information on the time profile of costs and effects into a single summary measure: the net present value. Budget impacts in the short term are given greater weight, when a positive discount rate is employed, which means that quantities in the future are more heavily discounted. However, this doesn’t explicitly deal with the affordability of budget impacts in any given time period and the greater opportunity costs faced when the budget impact is larger. To illustrate, let us consider an example based upon the Hepatitis C context and the published estimates of $k$ and $k(∆C)$.11,25 Note that the implications here are not limited to these specific estimates. First, consider the general form in which results might be obtained from a decision model, and the conventional way in which these would be analysed in terms of informing a decision rule.

Table 1 - General form of time profile of costs and effects

|  |  |  |
| --- | --- | --- |
| Time (t, years) | $$∆QALY\_{t}$$ | $$∆C\_{t}$$ |
| 1 | $$∆QALY\_{1}$$ | $$∆C\_{1}$$ |
| 2 | $$∆QALY\_{2}$$ | $$∆C\_{2}$$ |
| 3 | $$∆QALY\_{3}$$ | $$∆C\_{3}$$ |
| … | … | … |
| T | $$∆QALY\_{T}$$ | $$∆C\_{T}$$ |
| Net present value | $$\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}$$ | $$\sum\_{t=1}^{T}\frac{∆C\_{t}}{(1+d\_{c})^{t}}$$ |

Where $d\_{c}$ is the discount rate used for costs and $d\_{h}$ is the discount rate used for health.

Focusing for now on the costs column and how these might look under different schedules for the Hepatitis C example, assuming $d\_{c}=0$ for simplicity without loss of generality, we consider three different scenarios. In all three scenarios the net present value of the incremental cost is £772mn, but each scenario represents quite a different time profile of budget impacts. Scenarios 1 and 2 correspond exactly to the examples in Lomas et al. (2018). Scenario 1 is where the entire budget impact is faced in year 1, while scenario 2 is where the budget impact in any given year is small to the extent that they are marginal, but that the net present value of these spread over a sufficiently long time horizon to result in a net present value of £772mn. Finally, scenario 3 corresponds to somewhere in between scenarios 1 and 2 where the budget impact is spread over 3 years with half the impact in year 1 and the remaining impact split evenly over years 2 and 3.

### Conventional practice in CEA

For all of these scenarios the health opportunity costs would be calculated to be the same using the conventional approach where $k$ is constant despite the very different time profile of costs. Adapting equation 1, the decision rule associated with these results would calculate NHB in the following manner for all three scenarios using a constant value for $k$ based on Claxton et al. (2015), where a value greater than zero would indicate that the intervention should be approved:

$NHB=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}-\frac{\sum\_{t=1}^{T}\frac{∆C\_{t}}{\left(1+d\_{c}\right)^{t}}}{k}=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{\left(1+d\_{h}\right)^{t}}-\frac{£772mn}{£12,936 per QALY}=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{\left(1+d\_{h}\right)^{t}}-59,677>0$ (3)

For all three scenarios, irrespective of the large scale of the budget impacts and how they are distributed over time, the intervention would be found to be cost-effective if the net present value of population health gains exceeded 59,677 QALYs. It is possible to re-formulate equation (3) as an equivalent ICER-based decision rule, assuming both the net present value of incremental costs and incremental QALYs are positive, which indicates that the intervention should be approved if the estimated ICER is less than the value of $k$ adopted:

$ICER=\frac{\sum\_{t=1}^{T}\frac{∆C\_{t}}{\left(1+d\_{c}\right)^{t}}}{\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}}=\frac{£772mn}{\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}}<£12,936 per QALY$ (4)

The decision rules illustrated in (3) and (4) clearly show that all three scenarios are estimated to have equal health opportunity costs, despite there likely being much greater concerns for affordability in scenarios 1 and 3 than in scenario 2 due to the differing time profiles of budget impact. Such concerns reflect the greater health opportunity costs associated with scenarios 1 and 3.

With the large overall scale of the investment required for this intervention, one approach to reflecting the expected health opportunity costs would be to use a lower value of $k$. The simplest way to do this would be to employ the relationship estimated by Lomas et al. (2018), inputting the net present value of the incremental costs. The resultant value of $k$ would be £12,452 per QALY. Using this approach, the decision rule would again be the same for all three scenarios given that they all share the same estimate of net present value of the incremental cost. This approach seems appropriate for scenario 1 where the health opportunity costs of the non-marginal impact in year 1 can be estimated in this way, but not appropriate for scenarios 2 and 3 where individual year budget impacts vary in size and non-marginality. As with the earlier example, under conventional CEA, it is possible to write out this as a decision rule based on either net benefit or ICER (again assuming both the net present value of incremental costs and incremental QALYs are positive):

$NHB=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}-\frac{\sum\_{t=1}^{T}\frac{∆C\_{t}}{\left(1+d\_{c}\right)^{t}}}{k}=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{\left(1+d\_{h}\right)^{t}}-\frac{£772mn}{£12,452 per QALY}=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{\left(1+d\_{h}\right)^{t}}-61,997>0$ (5)

$ICER=\frac{\sum\_{t=1}^{T}\frac{∆C\_{t}}{\left(1+d\_{c}\right)^{t}}}{\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}}=\frac{£772mn}{\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}}<£12,452 per QALY$ (6)

Using this single value of $k$, the intervention would be found to be cost-effective if the net present value of population health gains exceeded 61,997 QALYs. The ICER decision rule indicates that the estimated ICER would need to be lower than £12,452 per QALY. In summary, using this rule sets a higher bar for the intervention to be found cost-effective and explicitly incorporates the scale of the overall budget impact into the CEA decision rule. However, this approach does not differentiate between the different time profiles of the budget impacts from the 3 scenarios. In particular, it is assumed that health opportunity costs will be greater for scenario 2 than for an intervention with a marginal budget impact, even though the budget impacts in each individual year are themselves are marginal. The decision rules in (3) – (6) might therefore be found to be unsatisfactory in that they do not reflect both the scale of the budget impacts and their distribution over time.

### Explicitly accounting for the time profile of costs

By construction the net present values of the overall incremental costs of the intervention are the same across all three scenarios, but the distribution over time is different. To fully account for this, it is not sufficient to calculate the net present value of health opportunity costs based on the net present value of incremental costs. Instead, it is necessary to calculate the health opportunity cost in each time period and then to discount these to obtain the net present value. To visualise this, in Table 4, we add an additional column to the general form of the time profile of costs and effects from Table 3. This additional column contains the time profile of health opportunity cost that are calculated by dividing the incremental cost in each time period by the relevant value of $k$.

Table 2 - General form of time profile of costs, effects and health opportunity costs

|  |  |  |  |
| --- | --- | --- | --- |
| Time (t, years) | $$∆QALY\_{t}$$ | $$∆C\_{t}$$ | $$HOC(∆C\_{t})$$ |
| 1 | $$∆QALY\_{1}$$ | $$∆C\_{1}$$ | $${∆C\_{1}}/{k(∆C\_{1})}$$ |
| 2 | $$∆QALY\_{2}$$ | $$∆C\_{2}$$ | $${∆C\_{2}}/{k(∆C\_{2})}$$ |
| 3 | $$∆QALY\_{3}$$ | $$∆C\_{3}$$ | $${∆C\_{3}}/{k(∆C\_{3})}$$ |
| … | … | … | … |
| T | $$∆QALY\_{T}$$ | $$∆C\_{T}$$ | $${∆C\_{T}}/{k(∆C\_{T})}$$ |
| Net present value | $$\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}$$ | $$\sum\_{t=1}^{T}\frac{∆C\_{t}}{(1+d\_{c})^{t}}$$ | $$\sum\_{t=1}^{T}\frac{{∆C\_{t}}/{k(∆C\_{t})}}{(1+d\_{hoc})^{t}}$$ |

Using this framework we can estimate the health opportunity costs with a variable value of $k$ for each of the three different scenarios (depicted in Figure 1). Health opportunity costs for scenario 2 are evaluated using the Claxton et al. (2015) estimate of $k=£12,936$ per QALY as these expenditures would be considered marginal. For all other budget impacts the results from Lomas et al. (2018)are used to inform appropriate values of $k(∆C)$. As before, we simplify by assuming $d\_{c}=d\_{hoc}=0$.

Table 3 - Evaluating health opportunity costs for the three scenarios

|  |  |  |  |
| --- | --- | --- | --- |
|  | Scenario 1 | Scenario 2 | Scenario 3 |
| Time (t, years) | $$∆C\_{t}$$ | $$HOC(∆C\_{t})$$ | $$∆C\_{t}$$ | $$HOC(∆C\_{t})$$ | $$∆C\_{t}$$ | $$HOC(∆C\_{t})$$ |
| 1 | $$£772mn$$ | $$£772mn/£12,452$$ | $$\rightarrow 0$$ | $${\rightarrow 0}/{£12,936}$$ | $$£386mn$$ | $${£386mn}/{£12,}518$$ |
| 2 | $$0$$ | $$0$$ | $$\rightarrow 0$$ | $${\rightarrow 0}/{£12,936}$$ | $$£193mn$$ | $${£193mn}/{£12,}551$$ |
| 3 | $$0$$ | $$0$$ | $$\rightarrow 0$$ | $${\rightarrow 0}/{£12,936}$$ | $$£193mn$$ | $${£193mn}/{£12,}551$$ |
| … | $$0$$ | $$0$$ | $$\rightarrow 0$$ | $${\rightarrow 0}/{£12,936}$$ | $$0$$ | $$0$$ |
| T | $$0$$ | $$0$$ | $$\rightarrow 0$$ | $${\rightarrow 0}/{£12,936}$$ | $$0$$ | $$0$$ |
| Net present value | $$£772mn$$ | $$\frac{£772mn}{£12,452}=61,997$$ | $$£772mn$$ | $$\frac{£772mn}{£12,936}=59,677$$ | $$£772mn$$ | $$\frac{£386mn}{£12,518}+2\*\frac{£193mn}{£12,551}=61,589$$ |



Figure 1 - Evaluating the time profile of health opportunity costs

The estimate of the net present value of health opportunity costs for scenario 2 is the same as calculated in equation 3, because it is mathematically equivalent (assuming $d\_{c}=d\_{hoc}$).[[1]](#footnote-1) Evaluating the health opportunity costs in this way for scenario 1 yields the same result as equation 5. This is straightforward as a result of all budget impact being concentrated in the present time period. The comparison between scenarios 1 and 2 here is the same as the comparison in Lomas et al. (2018) showing that if the whole £772mn budget impact is faced in year 1 then accounting for that through $k(∆C)$ results in health opportunity costs that are 3.9% higher than if its non-marginality in the first year was ignored (using a value of $k$ that is appropriate for marginal interventions, see equation 3). Unlike scenarios 1 and 2, it is not possible to evaluate the time profile of health opportunity costs of scenario 3 with a single value of $k$ or $k(∆C)$. Instead, because there is a non-uniform time profile of incremental costs, $k(∆C)$ will take different values in the different time periods as shown in Table 5. The resulting health opportunity costs for scenario 3 are 3.2% greater compared to when a value of $k$ that is appropriate for marginal interventions is used. This means that there are three different decision rules for each of the scenarios because of the differences in the time profiles of costs:

Scenario 1: $NHB=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}-\sum\_{t=1}^{T}\frac{{∆C\_{t}}/{k(∆C\_{t})}}{(1+d\_{hoc})^{t}}=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{\left(1+d\_{h}\right)^{t}}-61,997>0$ (7)

Scenario 2: $NHB=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}-\sum\_{t=1}^{T}\frac{{∆C\_{t}}/{k}}{(1+d\_{hoc})^{t}}=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{\left(1+d\_{h}\right)^{t}}-59,677>0$ (8)

Scenario 3: $NHB=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{(1+d\_{h})^{t}}-\sum\_{t=1}^{T}\frac{{∆C\_{t}}/{k(∆C\_{t})}}{(1+d\_{hoc})^{t}}=\sum\_{t=1}^{T}\frac{∆QALY\_{t}}{\left(1+d\_{h}\right)^{t}}-61,589>0$ (9)

For the reasons stated above, namely that there is no need to account for non-marginality of budget impact, equations 8 and 3 are identical, which in turn means that the use of an ICER-based decision rule is suitable and given in equation 4. Given the simplicity of scenario 1, where all budget impact is faced in the first year, it is also possible to design an ICER-based decision rule for this case (equation 6). For more complicated scenarios like scenario 3, it is not clear how an ICER-based decision rule could be created without having gone through the steps to generate a time profile of health opportunity costs. In line with expectations, the net present value of health benefits will need to be greatest for the scenario 1 where the greatest concerns for affordability arise, and least for scenario 2 where the individual instalments are marginal, in order for the intervention to be found cost-effective.

## Implications when uncertainty in budget impact is significant

Another aspect of the motivating example that has been discussed less in the health economics literature on affordability is the financial uncertainty facing the NHS following the approval of the new drugs for Hepatitis C where budget impacts for the NHS were estimated to fall between £60mn and £772mn depending on assumptions about uptake in the patient population.23 To illustrate the importance of this, let us again consider an example based upon the Hepatitis C example and the published estimates of $k$ and $k(∆C)$.11,25 Once again the implications here are not limited to these specific estimates. To explore this issue, we consider the kind of output that is generated when using a probabilistic decision model, a number of simulation results each corresponding to iterations of running the model with randomly-drawn parameter values from pre-specified probability distributions.

Table 4 - General form of probabilistic output of costs, effects and health opportunity costs

|  |  |  |  |
| --- | --- | --- | --- |
| Iteration no. (i) | $$∆QALY\_{i}$$ | $$∆C\_{i}$$ | $$HOC(∆C\_{i})$$ |
| 1 | $$∆QALY\_{1}$$ | $$∆C\_{1}$$ | $${∆C\_{1}}/{k(∆C\_{1})}$$ |
| 2 | $$∆QALY\_{2}$$ | $$∆C\_{2}$$ | $${∆C\_{2}}/{k(∆C\_{2})}$$ |
| 3 | $$∆QALY\_{3}$$ | $$∆C\_{3}$$ | $${∆C\_{3}}/{k(∆C\_{3})}$$ |
| … | … | … | … |
| N | $$∆QALY\_{N}$$ | $$∆C\_{T}$$ | $${∆C\_{T}}/{k(∆C\_{T})}$$ |
| Expected value | $$\sum\_{i=1}^{N}\frac{∆QALY\_{i}}{N}$$ | $$\sum\_{i=1}^{N}\frac{∆C\_{i}}{N}$$ | $$\sum\_{i=1}^{N}\frac{{∆C\_{i}}/{k(∆C\_{i})}}{N}$$ |

To consider the impact of uncertainty on decisions within this framework, we consider two scenarios based on the Hepatitis C example. Scenario 4 is where the budget impact (the mean incremental cost) of £772mn is known with certainty. In scenario 5 the budget impact follows a gamma distribution with a mean of £772mn and a beta parameter of 200 reflecting that there is uncertainty around how big the expected budget impact is likely to be.

### Conventional practice in CEA

For both of these scenarios the health opportunity costs would be calculated to be the same using the conventional approach where $k$ is constant despite the very different uncertainty distribution of budget impacts. As with the time profile of costs, the uncertainty surrounding the budget impact is not explicitly incorporated into decision rules through impacts on opportunity costs. Adapting equation 3, the decision rule associated with these results would calculate NHB in the following manner for both scenarios using the Claxton et al. (2015) estimate of $k$, where a value greater than zero would indicates that the intervention should be approved:

$NHB=\sum\_{i=1}^{N}\frac{∆QALY\_{i}}{N}-\frac{\sum\_{i=1}^{N}\frac{∆C\_{i}}{N}}{k}=\sum\_{i=1}^{N}\frac{∆QALY\_{i}}{N}-\frac{£772mn}{£12,936 per QALY}=\sum\_{i=1}^{N}\frac{∆QALY\_{i}}{N}-59,677>0$ (10)

An equivalent ICER-based decision rule can be derived analogous to equation 4. The formulation in equation 10 reflects that with a constant value used for $k$ it is sufficient to use the expectation of incremental cost to estimate expected health opportunity costs. This follows from the equality of ${E(∆C)}/{k}=E({∆C}/{k})$ when $k$ is constant.

### Explicitly accounting for the uncertainty in projected budget impact

In using equation 10, no account has been taken of the scale of the expected budget impact through the use of $k(∆C)$. This could be done by using the appropriate estimate of $k(∆C)$ from Lomas et al. (2018), £12,452 per QALY for $∆C=£772mn$, as opposed to the Claxton et al. (2015) estimate of £12,936 per QALY. This gives the correct evaluation of health opportunity costs for scenario 4 where $∆C$ is known with certainty: 61,997 QALYs. However, it is important to note that health opportunity costs will usually not be linear in $∆C$, which means that ${E(∆C)}/{k(E\left(∆C\right))}\ne E({∆C}/{k(∆C)})$. This is the case when using the Lomas et al. (2018) estimates, for which health opportunity costs are quadratic in $∆C$, meaning that it is necessary to calculate health opportunity costs for each iteration from the probabilistic simulation before calculating the expected health opportunity costs.

$NHB=\sum\_{i=1}^{N}\frac{∆QALY\_{i}}{N}-\sum\_{i=1}^{N}\frac{{∆C\_{i}}/{k(∆C\_{i})}}{N}=\sum\_{i=1}^{N}\frac{∆QALY\_{i}}{N}-62,200>0$ (11)

10,000 draws were taken from the distribution specified in scenario 5 giving the decision rule in equation 11 and health opportunity costs were calculated on the basis of the Lomas et al. (2018) estimates. The result is that the expected health opportunity costs of an uncertain distribution of incremental costs, as specified in scenario 5, are greater than the health opportunity costs when the budget impact is known with certainty in scenario 4.

## Discussion

This paper explores some of the criticisms of conventional CEA, in particular findings that interventions are ‘cost-effective’ but unaffordable. While some papers have argued that CEA and BIA provide different kinds of information and should be “integrated” – i.e. both presented to decision makers,1,3 other papers have called for information on budget impact to be incorporated within CEA.6,7,9,11 In particular, it has been argued that CEA could in principle incorporate information on budget impacts into the appropriate decision rules used to inform decision makers of the cost-effectiveness of an intervention.3 This is consistent with CEA being used to inform whether or not an intervention will produce a net gain or loss in population health, given the opportunity costs that will arise from resources not being available for other purposes. This paper adopts a health care perspective with a constrained decision maker for whom $k$ is exogenous, but its relevance extends to analysis that adopts a broader societal perspective.26,27 In particular, future work should consider the implications for health opportunity costs that arise from non-marginal costs falling outside of the health sector, such as effects on private consumption, which will necessitate the estimation of additional parameters including the consumption value of health, $v$.13 Further, having estimates of both $v$ and $k$ can help to address other higher-level questions such as whether or not the level of resources allocated to health care could be considered optimal.13

In this paper we have investigated the implications for conducting CEA when health opportunity costs are non-linear with respect to budget impact (implying non-constant returns to scale). We find that it is conceptually difficult to incorporate this additional flexibility into a decision rule based on the calculation of an ICER and prefer the net health benefit framework, where net benefit is a variable that can be aggregated, averaged and interpreted on a natural level scale. Once $k$ is thought of as $k(∆C)$ there are a number of implications for CEA:

1. The scale of budget impact matters
2. The time profile of budget impacts matters (the net present value of the incremental cost is not enough)
3. The uncertainty of budget impacts matter (the expected value of the incremental cost is not enough)

All three of these implications mean that CEA that uses $k(∆C)$ rather than $k$ should be better able to reflect concerns around affordability that tend to centre on these three issues, compared to the practice of conventional CEA that does not explicitly take any of these factors into account.

In addition to better estimation of health opportunity costs for use in CEA, this paper demonstrates how a number of key quantities can be estimated that can have important policy implications for payment arrangements.

The first of these quantities is obtained by comparing the health opportunity costs estimated when $k(∆C)$ is used as opposed to a single constant value $k$. This informs the potential gain in health available to the decision maker by smoothing the budget impact faced by the NHS over time. That is, while the decision maker is unable to set their own budget in each time period, they may be able to come to an agreement with the manufacturer about how the payment for the intervention is to be made over time. In the motivating example analysed, using estimates of $k(∆C)$ from Lomas et al. (2018) and $k$ from Claxton et al. (2015), it was found that the health opportunity costs from a budget impact of £772mn in year 1 were roughly 4% higher than a comparator with the same net present value budget impact but spread over time such that the budget impacts in each year were marginal. This difference in health provides a valuable input into considering financing arrangements where borrowing to smooth the budget impact would be costly.[[2]](#footnote-2) If the costs of smoothing impacts over a range of different time horizons were known then these could be used, in conjunction with the value of different smoothing arrangements derived using the framework in this paper, to ascertain the optimal time horizon over which costs are spread. While 4% may seem a somewhat modest difference between the two most extreme time horizons presented here, it is important to note that the effects could be greater in magnitude for different contexts, profiles of budget impacts and estimates of $k$ and $k\left(∆C\right).$

The second quantity that can be calculated in a similar manner is calculated by comparing the health opportunity costs of a certain budget impact with the health opportunity costs of an uncertain budget impact. In the motivating example illustrated in this paper, again the difference is quite modest at 0.3% but this may vary depending upon the context, uncertainty distribution of budget impact and estimates of $k$ and $k\left(∆C\right).$ This quantity could also be used to inform financial arrangements in negotiating sharing of financial risk between the health care payer and the manufacturer of the new intervention. This paper has shown that, even in the context of a risk-neutral health-maximising decision maker, the distribution of the mean incremental cost ($∆C$) and not just its expected value are relevant. Previous work in health economics that discussed the relevance of the distribution of $∆C$ considered risk-averse social decision makers.28–31 In any case, more thought may need to be given to the distribution assigned to mean costs, which may require statistical techniques focused on understanding the distribution of the underlying data previously unused in economic evaluation such as those discussed and compared elsewhere32 and other approaches used within actuarial sciences.

## Conclusion

We have shown in this paper that some of the concerns outlined in the literature about the conduct of conventional CEA are valid. CEA does not typically explicitly account for the distribution of costs, nor is an appropriate ‘threshold’ used that reflects opportunity costs and how they vary for different sized budget impacts. Rather than suggesting that CEA should not reflect these matters, we here present a framework for CEA that means that the scale, time profile and uncertainty of budget impacts do matter and are explicitly incorporated through the effects that they each have on health opportunity costs.

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1. Algebraically this can be written as $\frac{\sum\_{t=1}^{T}\frac{∆C\_{t}}{(1+d\_{c})^{t}}}{k}=\sum\_{t=1}^{T}\frac{{∆C\_{t}}/{k}}{(1+d\_{hoc})^{t}}$. When the discount rates for costs and health opportunity costs are the same ($d\_{c}=d\_{hoc}$) and there is a constant value of $k$ regardless of budget impact, calculating the net present value of health opportunity costs can be done, equivalently, either from the time profile of health opportunity costs or by dividing the net present value of costs by $k$. [↑](#footnote-ref-1)
2. This analysis assumes that the borrowing can only be used for one purpose, offsetting the budget impact of the intervention, and does not consider how inter-temporal financing might be used more generally by the decision maker. [↑](#footnote-ref-2)