AUTHOR ACCEPTED VERSION

**Resolving the ‘cost-effective but unaffordable’ ‘paradox’: estimating the health opportunity costs of non-marginal budget impacts**

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## Abstract

Considering whether or not a proposed investment (an intervention, technology or programme of care) is affordable is really asking whether the benefits it offers are greater than its opportunity cost. To say that an investment is cost-effective but not affordable must mean that the (implicit or explicit) ‘threshold’ used to judge cost-effectiveness does not reflect the scale and value of the opportunity costs. Existing empirical estimates of health opportunity costs are based on cross-sectional variation in expenditure and mortality outcomes by programme budget categories (PBCs) and do not reflect the likely effect of non-marginal budget impacts on health opportunity costs.

The UK Department of Health regularly updates the needs-based target allocation of resources to local areas of the NHS, creating two subgroups of local areas (those under and over target allocation). These data provide the opportunity to explore how the effects of changes in health care expenditure differ with available resources. We use 2008/09 data to evaluate two econometric approaches to estimation and explore a range of criteria for accepting subgroup specific effects for differences in expenditure and outcome elasticities across the 23 PBCs.

Our results indicate that health opportunity costs arising from an investment imposing net increases in expenditure are underestimated unless account is taken of likely non-marginal effects. They also indicate the benefits (reduced health opportunity costs or increased value-based price of a technology) of being able to ‘smooth’ these non-marginal budget impacts by health care systems borrowing against future budgets or from manufacturers offering ‘mortgage’ type arrangements.

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## 1. Introduction

### Policy context

In 2015, the National Institute for Health and Care Excellence (NICE) completed appraisals of a number of new drugs for treating hepatitis C (NICE 2015a; NICE 2015b; NICE 2015c). Whilst these drugs were approved as cost-effective by NICE for many patients[[1]](#footnote-1), NHS England (NHSE) raised serious concerns about the affordability of such a commitment, given the projected budget impact based on estimates of hepatitis C prevalence in the UK and the prices charged by the manufacturer for these drugs. As a result the implementation period of NICE guidance was extended beyond the usual timeframe (NICE 2015b). Hence, there was a conflict between NICE, judging these drugs to be cost-effective, but NHSE regarding them unaffordable. Subsequently, NICE and NHSE have changed to the process of technology assessment to explicitly consider budget impact (NICE 2016; NICE 2017). Now, new technologies judged to be ‘cost-effective’ by NICE but with a budget impact of over £20m will not immediately be required to be funded by the NHS, but instead will be subject to additional negotiation between NHSE and the manufacturer. Immediate funding will be reserved for new technologies that are more cost-effective (less than £10,000 per QALY, quality adjusted life year) and with lower budget impact. Different approaches have been taken by other institutions in other health care systems. For example, the USA-based Institute for Clinical and Economic Review evaluates budget impact as a separate attribute in addition to ‘cost-effectiveness’. This is justified on the basis that short-term affordability is the main determinant of coverage decisions by private insurers in the USA (ICER 2017). Another example is Australia’s Pharmaceutical Benefits Advisory Committee (PBAC) where the new hepatitis C drugs have been judged by more stringent criteria (a lower cost per QALY ‘threshold’) due to the scale of their likely budget impact (Harris 2016). In effect PBAC are insisting that the maximum acceptable price for the new hepatitis C drugs should be lower because of the significance of the projected budget impact.

Considering whether or not a proposed investment (an intervention, technology or programme of care) is affordable is really asking whether the benefits it offers are greater than the value of those things that are likely to be given up if the additional costs must be accommodated within existing expenditure and commitments. Alternatively, if the additional costs of the investment are to be covered through increases in health expenditure, some assessment the benefits that could have been gained elsewhere from the alternative use of these additional resources needs to be considered. Therefore, an assessment of health opportunity cost, founded on evidence of the marginal productivity of health care expenditure, is required whether or not heath care is funded through fixed administrative budgets. The question of affordability is precisely the question that cost-effectiveness analysis seeks to inform, when the criteria for judging whether or not an intervention is cost-effective is founded on an empirical assessment of the likely opportunity costs elsewhere in the health care system.[[2]](#footnote-2) To say that an alternative is cost-effective but not affordable must mean that the (implicit or explicit) ‘threshold’ used to judge cost-effectiveness does not reflect the opportunity costs incurred given the scale of the impact on health expenditure.

The problem of assessing the expected health opportunity costs of a proposed investment is the same as estimating the relationship between changes in health care expenditure and health outcome. This is the approach that is taken in research conducted in the United Kingdom (Martin et al. 2008; Claxton, Martin, et al. 2015). The research uses national data on expenditure and outcomes in different disease areas (programme budget categories, PBCs) reported at a local level.[[3]](#footnote-3) By exploiting the variation in expenditure and mortality outcomes, the relationship between changes in spending and mortality is estimated while accounting for sources of endogeneity. With additional information about age and gender of the patient population these mortality effects can be expressed in terms of cost per life-year (£25 241 per life year). By using the effect of expenditure on the mortality and life-year burden of disease as a surrogate for the effects on a more complete measure of health burden (one that also includes morbidity burden), the result can be expressed in terms of cost per QALY, which reflects the likely impact of expenditure at the margin on both mortality and morbidity (£12 936 per QALY)(Claxton, Martin, et al. 2015).[[4]](#footnote-4) This empirical work provides the opportunity to explore how health opportunity costs are likely to change with the scale of non-marginal or ‘large’[[5]](#footnote-5) budget impacts. Non-marginal is a term used in Claxton et al. (2013) and Claxton et al. (2015) and is defined in Paulden et al. (2017) as when the budget impact is large.

### Empirical work on health opportunity costs of non-marginal expenditures

While the conceptual basis for expected health opportunity costs of a proposed investment varying with the level of incremental costs or budget impact is well established, see for instance McCabe et al. (2008); Paulden et al. (2017) and Culyer (2016), there has only so far been limited empirical work that attempts to quantify this relationship. One study, Claxton, Martin, et al. (2015), conduct an exploratory analysis where different types of primary care trust (PCT) are found to have different productivity in terms of cost per life-year based on 2006/07 expenditure in the NHS in the 'big four' PBCs.[[6]](#footnote-6) The two types of PCT being considered are those that are 'over target' in terms of their budget allocation and those that are 'under target', where deviations of actual budget allocations from targets occurred due to periodic adjustments of targets based on changes in the results of a needs-based formula. Over target PCTs received an actual allocation which was greater than their target allocation, while under target PCTs were allocated less than their target allocation. The cost per life-year estimates for the big four PBCs are £10,604 for all PCTs combined; £8441 for those PCTs under their target allocation; and £14,083 for PCTs over their target allocation. The results stem from the larger magnitude of outcome elasticities in the big four PBCs when the regression models are estimated on the under target PCTs only, and smaller magnitude of outcome elasticities when estimated on the over target PCTs only. This is consistent with the concept that there are diminishing marginal returns to health care expenditure where PCTs under greater financial pressure prioritise more cost-effective treatments within PBCs compared to PCTs facing less pressure.

While the results of Claxton, Martin, et al. (2015) for over and under target PCTs are intuitive and consistent with a health production function that exhibits diminishing marginal returns to health care expenditure, there are a number of limitations to the study: i) only differences in outcome elasticities between PCT subgroups are considered when differences in how a change in resources are allocated might also be expected; ii) only the 4 largest PBCs were included in the analysis when differences in productivity and reallocation between all 23 PBCs is possible; iii) only cost per life year were reported rather than using estimated mortality effects as a surrogate for the effects of changes in expenditure on a more complete measure of health outcome (QALYs) and iv) there was no consideration of whether estimated differences between subgroups were likely to reflect systematic differences with adequate power or merely chance variations driven by noise in the data.

This paper contributes to the literature in two main ways. Firstly we are able to overcome the key limitations associated with the exploration undertaken in Claxton, Martin, et al. (2015) by: i) allowing expenditure and outcome elasticities to differ between the over and under target PCTs; ii) including all PBCs in the analysis; iii) reporting the overall cost per QALY using the same methods and assumptions as used in Claxton, Martin, et al. (2015); iv) exploring two alternative approaches to estimation and v) considering a range of alternative cut-off points regarding the statistical significance of differences in estimated elasticities. Secondly, we show how these type of estimates can be used to construct a health production function that can be used to report the health opportunity costs associated with a range of budget impacts that a proposed investment might impose, or, equivalently, the appropriate cost per QALY ’threshold’ that should be applied for different budget impacts.

## Data

### Overview

The core data underlying this has come from two relatively recently created sources. One data set contains mortality rates for various disease categories at the level of geographically defined local health authorities, PCTs. The other data set presents NHS expenditure by PCT on 23 broad programmes of care. This data set comprises most items of publicly funded expenditure, including inpatient, outpatient and community care, and pharmaceutical prescriptions.

The NHS is organised geographically, with devolved responsibility for local administration given to PCTs. PCTs are allocated fixed annual budgets by the Department of Health, within which they are expected to manage the health care in the locality. Funding allocation targets are set for health authorities on the basis of a well-developed allocation formula that takes into account local considerations such as population size and need for healthcare (NHS England 2016). Periodically the formula is updated to better reflect resource allocation needs and a new target is generated for each health authority. The change in target can be significant and so actual allocations of budgets can not be adjusted to match the new target immediately. Instead annual financial allocations are gradually transitioned to the updated target. This means that in any year PCTs receive an actual budget that is greater than their target, in which case they have more financial resources than is required according to the formula. Conversely some PCTs will receive a budget that is less than estimated to be required. We refer to the former group as over target PCTs and the latter as under target PCTs. In the financial year of 2008/09 there were 151 PCTs in total, 84 of which were under target, 65 over target and 2 on target. Those that are under target can be considered to be relatively more constrained in terms of their budget, which makes disinvestment more likely, and those that are over target are relatively less constrained and may be able to invest more into health services.

### Expenditure

Programme budgeting (PB) data collection was initiated by the Department of Health in April 2003 when each PCT was required to prepare expenditure data disaggregated according to 23 programmes of health care. These programmes are defined by reference to ICD-10 codes at the four digit level, and most PBCs reflect ICD-10 chapter headings (e.g. cancer and tumour, circulation problems, renal problems, neonates, problems associated with the skin, problems associated with vision, problems associated with hearing, etc.). In addition, two specific non-clinical groups – ‘healthy individuals’ and ‘social care needs’ – have been created. These are intended to capture the costs of disease-prevention programmes and the costs of services that support individuals with social rather than health-care needs. In addition, in some cases it is not possible to assign activity by medical condition, preventative activity, or social care need and, in these cases, expenditure is assigned to a residual category (PBC 23) entitled ‘other’. The most important element of this residual programme is expenditure on general practitioner (GP) services (PBC 23a).

### Mortality

We follow Claxton, Martin, et al. (2015) in employing mortality as an outcome measure for two key practical reasons. First, it is a relevant (albeit not comprehensive) measure of the outcome of health-care expenditure; and second, it is available for more disease areas than any other outcome measure at PCT level. Although mortality is available (by PCT) for several disease areas, it is not available for just over a half of all programmes not least because it is not relevant for these programmes (e.g. for learning disabilities, vision problems, hearing problems, dental problems and skin problems). The specific mortality outcome considered is (age) standardised years of life lost rate.

### Other variables

In addition to outcome and expenditure, variables are required to control for the heterogeneity of different PCTs and also to instrument endogenous variables. In terms of observable heterogeneity, measures of need are used as covariates within the regression models. The primary measure of need was the Department of Health’s ‘need for health care’ index. There is substantial variation in PCT values of this index, averaging around 1, but with some PCTs having a needs index more than 25% below the national average and others facing a need for health care more than 30% above the national average. Endogeneity arises due to either (i) own programme expenditure is likely to be endogenous in the outcome equation or (ii) other programme need is likely to be endogenous in the own programme expenditure equation. The instrumental variables (IVs) used reflect factors, such as socioeconomic deprivation and the availability of informal care in the community, which might indirectly impact on mortality rates and/or health-care expenditure levels. Most of these are taken from the 2001 Population Census and include the proportion of the population providing unpaid care; the proportion of households that are one pensioner households; index of multiple deprivation; and proportion of the population in the white ethnic group.

### Descriptive statistics

Table - Descriptive statistics for over and under target PCTs (2008/09)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **N** | **Mean amount over (under) target [range]** | **Mean % over (under) target [range]** |
| **Over target PCT** | 65 | £12,800,040  [£4,591 - £66,105,570] | 3.024544% [0.001311% - 12.95502%] |
| **Under target PCT** | 84 | (£9,904,789)  [(£119,850) - (£33,232,770)] | (2.064847%) [(0.0351803%) - (3.712661%)] |
| **On target PCT** | 2 | £0  [£0 - £0] | 0%  [0% - 0%] |
| **All PCT** | 151 | £0 [(£33,232,770) - £66,105,570] | 0% [(3.712661%) - 12.95502%] |

## Estimating health effects of non-marginal changes in expenditure

For all PBCs an expenditure elasticity is estimated as well as an outcome elasticity for those PBCs with associated mortality data.[[7]](#footnote-7) The estimated expenditure elasticity reflects the percentage change in PBC expenditure following a one percent increase in total NHS PCT expenditure, while the outcome elasticity reflects the percentage change in PBC mortality resulting from a one percent increase in PBC expenditure. The task is to identify the causal effects of changes in expenditure accounting for endogeneity by using an IV approach where this is appropriate. Throughout this paper we take the approach to estimation, model specifications, the covariates and instrumental variables used for each PBC, from those used in Claxton, Martin, et al. (2015), chapter 3 and appendix 2 (in particular tables 85, p.316-317, and 86, pp.318-323), as a starting point. We also adopt the same approach and assumptions when using estimated mortality effects of changes in expenditure as a surrogate for the likely effects on a more complete measure of health outcome (QALY). Therefore, for more details on model selection, see chapter 3 and appendix 2 of Claxton, Martin, et al. (2015), and for data and assumptions required to link estimated elasticities to results expressed in terms of cost per QALY, see chapter 4 of Claxton, Martin, et al. (2015).

Given the limited number of observations, with only 84 PCTs in the under target PCT sub-group and 65 in the over target PCT sub-group in 2008/09, there are concerns around the extent to which the data can adequately reflect true signal in the presence of noisy variables. This concern is intensified given the need to control for heterogeneity as well as concerns around endogeneity, with well-known potential losses in precision when using an IV estimator (see e.g. Martens et al., 2006). For this reason, we only wish to use sub-group specific elasticities when they are found to be statistically different from the other sub-group. If this is not the case, then we use the elasticity estimated using the whole sample of PCTs. In order to establish in which PBCs there is demonstrated statistical difference between PCT sub-groups we use a rule based on a p-value threshold, where a range of cut-off points are considered. At one extreme a cut-off of p=1 represents an assumption that all variation in elasticities represents signal, and not noise. At the other end of the spectrum a cut-off of p=0 implies that we believe that all variation is noise and that the sub-group specific elasticities do not systematically differ.

The combined effect of significant differences in outcome and expenditure elasticities (productivity within a PBC and allocation between PBCs) are expected to provide results that are consistent with diminishing marginal returns to health expenditure. For example, our expectation is that the significantly different outcome elasticities will tend to have a higher magnitude for those PCTs that are under their target allocation (are under more financial pressure), possibly reflecting the prioritisation of more cost-effective treatments within each PBC. We would also expect higher expenditure elasticities for those PBCs that are more productive (offer lower cost per QALY) and lower elasticities for those that are less productive (offer higher cost per QALY). Although productivity by PBC can be inferred from this type of analysis (see table 178 of Claxton, Martin, et al. (2015), differences should not be over-interpreted because expenditure in one PBC may contribute to improvement health outcomes in others. In addition,the assumption of proportionality between the effect of changes in expenditure on the QALY burden disease and the estimated proportionate effect on mortality burden may be more appropriate for some PBCs than others.

## Two approaches to estimating sub-group specific elasticities: using an interaction term and estimating separately on each sub-sample

### Econometric specifications

#### Interaction term approach

Our primary interest in looking into the different sub-groups is the different expenditure and outcome elasticities that they might have. As such, the most intuitive approach would be to use the all-PCT model specification, but to include an additional sub-group interaction term applied to the variable of interest. This method restricts the covariates and IVs used to be the same between different PCT sub-groups, and also the coefficients estimated on these, but allows the treatment effect of interest (the expenditure/outcome elasticity) to vary between the sub-groups.

In terms of expenditure equations, this is straightforward to implement owing to the variable of interest, NHS expenditure, being considered as an exogenous variable (with other programme need as endogenous). When estimating outcome equations the variable of interest, PBC expenditure, is itself endogenous, which means that any interaction term involving this variable will also be endogenous. As a result it is necessary to instrument both the PBC expenditure and the interaction term with PCT sub-group. We implement an approach that was discovered suggested by Angrist (Angrist & Pischke 2010), which has been applied elsewhere (Moreno-Serra & Smith (2015)), where both the treatment variable and the interaction term are instrumented using treatment variable IVs and these IVs interacted with the sub-group variable. This approach should be valid when the sub-group variable can itself be assumed to be exogenous. In our context this implies instrumenting both PBC expenditure and interaction term with PCT sub-group[[8]](#footnote-8) using the IVs employed in the all-PCT model for PBC expenditure and each of these interacted the PCT sub-group variable.

To determine whether the sub-group specific elasticities are statistically different from each other, in both cases of outcome and expenditure equations we use the p-value on the interaction term with the variable of interest.

#### Sub-sample estimation approach

A key assumption in the interaction term approach is that the financial allocation being over or under target for a PCT is randomly assigned, or is at least unrelated to health outcomes. This is unlikely to hold since changes in allocation between PCTs are likely to be based on past and expected health outcomes. In addition, the interaction term method restricts estimated effects of all covariates beside the elasticity under consideration to be the same for both sub-groups of PCT. An alternative approach is to divide the sample and estimate the same equations on each sub-group of PCTs separately.[[9]](#footnote-9) Clearly, the drawback of this approach is that there are relatively few observations within each sub-sample on which the regression models are estimated.

To determine whether the sub-group specific elasticities are statistically different from each other, in both cases of outcome and expenditure equations we use the p-value of the difference of the estimated coefficients for each PCT sub-group using Welch’s t-test assuming unequal variances.

### Differences in estimated elasticities using the two approaches

#### Outcome elasticities

First we consider the differences in outcome elasticities between the under and over target PCTs with the two implemented model specifications. In Table 2 we report the sign of the difference in the magnitude, which would be expected to be higher for under target PCTs given the diminishing marginal returns argument, and whether or not the difference is statistically significant (p<0.1).

Table - Summary of outcome elasticities results for over and under target PCTs by PBCs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | Interaction term approach | | Sub-sample estimation approach | |
| PBC | PBC label | Magnitude of outcome elasticity for under target PCTs relative to over target PCTs | Is difference statistically significant using cut-off p=0.1? | Magnitude of outcome elasticity for under target PCTs relative to over target PCTs | Is difference statistically significant using cut-off p=0.1? |
| 2 | Cancer | Lower | No | **Higher** | No |
| 10 | Circulatory | **Higher** | No | **Higher** | **Yes** |
| 11 | Respiratory | **Higher** | **Yes** | **Higher** | No |
| 13 | Gastrointestinal | **Higher** | **Yes** | **Higher** | No |
| 1 | Infectious diseases | Lower | No | **Higher** | No |
| 4 | Endocrine | Lower | **Yes** | Lower | No |
| 7 | Neurological | Lower | **Yes** | **Higher** | No |
| 17 | Genitourinary | Lower | No | Lower | No |
| 16 | Trauma and injuries | N/A | N/A | N/A | N/A |
| 18+19 | Maternity and neonates | **Higher** | No | **Higher** | **Yes** |

Looking first at the results from the interaction term approach, of the 9 PBCs with an outcome indicator, and estimated outcome elasticity, 4 PBCs exhibit the expected direction of difference between under and over target PCTs. Only in 2 of these 4 PBCs is the difference found to be statistically significant, respiratory (PBC 11) and gastrointestinal (PBC 13), which are both in the big four PBCs group. This contrasts with results from the sub-sample estimation approach where 7 of the 9 PBCs exhibit the expected direction of difference between under and over target PCTs, but with only 2 of these 7 PBCs where the difference found to be statistically significant, circulatory (PBC 10), one of the big four PBCs, and maternity and neonates (PBC 18+19).

The interaction term approach gives 5 PBCs where the differences in the outcome elasticity are in the unexpected direction, 2 are statistically significant: endocrine (PBC 4) and neurological (PBC 7). With the sub-sample estimation approach there are only 2 PBCs where the differences in the outcome elasticity are in the unexpected direction, endocrine (PBC 4) and genitourinary (PBC 17), neither of which are statistically significant.

The results from the sub-sample estimation approach appear more intuitive than those generated using the interaction term specification. This makes sense given the concerns regarding the endogeneity of the PCT sub-group variable. Also intuitively, however, the sub-sample estimation approach seems to lack statistical power, with a smaller number of statistically significant estimated differences.

#### Expenditure elasticities

Second, we consider the differences between different PCT groups in terms of the estimated expenditure elasticities. As discussed earlier we cannot state the expected direction here, *a priori*, since it is not possible to know exactly the productivity of each PBC. Table 3 presents a summary of the results with the direction of the difference in the magnitudes of the estimated expenditure elasticities and if these differences are found to be statistically significant (p<0.1).

As expected, under both specifications, there is a mix of direction of differences in the relative magnitude of PBC expenditure elasticities, since under target PCTs must reallocate to prioritise certain PBCs by allocating away from other PBCs. It is hard to assess how intuitive these results are, for a number of reasons. The first is the caution with which it is necessary to interpret the results of Table 178 in Claxton, Martin, et al. (2015) with potential ‘spillovers’ between PBCs and the assumption of proportionality between the effect of changes in expenditure on the QALY burden disease and the estimated proportionate effect on the mortality burden may be more appropriate for some PBCs than others even if regarded as reasonable overall.

Using the interaction term approach there are 13 PBCs that are prioritised and 9 that are reallocated away from when the budget is squeezed. The expenditure elasticities between over and under target PCTs are found to be significantly different in 5 of the 22 PBCs. Focusing on these 5 PBCs, the results suggest that there is reallocation by under target PCTs toward cancer (PBC 2), healthy individuals (PBC 21) and other (PBC 23), and reallocation away from disorders of blood (PBC 3) and social care needs (PBC 22). However, if taken at face value, our results imply that there is reallocation away from PBC 3 (disorders of blood) with cost per QALY of £9,419 by under target PCTs and towards PBCs 2 (cancer) and 21 (healthy individuals) with higher cost per QALY productivities of £16,997 and £526,771[[10]](#footnote-10), respectively.

Results for expenditure elasticities with the sub-sample estimation approach are similarly mixed, but again are perhaps more intuitive than the interaction term approach results. There are 13 PBCs that are prioritised and 9 that are reallocated away from. Only 3 PBCs have a significant difference in estimated elasticity, all of which indicate prioritisation of these PBCs by under target PCTs: PBC 16 (trauma and injuries), PBC 5 (mental health) and PBC 9 (problems of hearing). While the cost per QALY associated with trauma (PBC 16), one can envisage a situation where expenditure on trauma is relatively more influential in PCTs under financial pressure, since they have little choice but to provide care for these. And PBCs 5 (mental health) and 9 (problems of hearing) are associated with middling and relatively high productivity, respectively, according to Claxton, Martin, et al. (2015) with estimated cost per QALY productivities of £18,744 and £6,239[[11]](#footnote-11), respectively.

Table - Summary of expenditure elasticities results for over and under target PCTs by PBCs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | Interaction term approach | | Sub-sample estimation approach | |
| PBC | PBC label | Magnitude of expenditure elasticity for under target PCTs relative to over target PCTs | Is difference statistically significant using cut-off p=0.1? | Magnitude of expenditure elasticity for under target PCTs relative to over target PCTs | Is difference statistically significant using cut-off p=0.1? |
| 2 | Cancer | Higher | **Yes** | Higher | No |
| 10 | Circulatory | Higher | No | Lower | No |
| 11 | Respiratory | Lower | No | Lower | No |
| 13 | Gastrointestinal | Lower | No | Lower | No |
| 1 | Infectious diseases | Lower | No | Lower | No |
| 4 | Endocrine | Higher | No | Higher | No |
| 7 | Neurological | Higher | No | Higher | No |
| 17 | Genitourinary | Lower | No | Lower | No |
| 16 | Trauma and injuries | Lower | No | Higher | **Yes** |
| 18+19 | Maternity and neonates | Higher | No | Higher | No |
| 3 | Disorders of blood | Lower | **Yes** | Higher | No |
| 5 | Mental health | Lower | No | Higher | **Yes** |
| 6 | Learning disability | Higher | No | Higher | No |
| 8 | Problems of vision | Higher | No | Higher | No |
| 9 | Problems of hearing | Higher | No | Higher | **Yes** |
| 12 | Dental problems | Lower | **Yes** | Lower | No |
| 14 | Skin | Higher | No | Higher | No |
| 15 | Musculoskeletal | Higher | No | Higher | No |
| 20 | Poisoning and adverse events | Higher | No | Lower | No |
| 21 | Healthy individuals | Higher | **Yes** | Higher | No |
| 22 | Social care needs | Lower | **Yes** | Lower | No |
| 23 | Other | Higher | **Yes** | Lower | No |

## Discussion

### Overview

The results above are used to inform health opportunity costs of non-marginal budget impacts, where non-marginal means that the scale of the budget impact is large. It is expected that health opportunity costs will occur at a greater rate for a large budget impact as more health care is displaced and there are diminishing returns (McCabe et al. 2008; Paulden et al. 2017). However, whether this occurs and to what extent is an empirical question.

Due to theoretical reasons to favour the sub-sample estimation approach, and practical issues of difficulties in interpreting the implausible results from the interaction term approach, the sub-sample estimation approach forms the preferred econometric analysis. The results from this approach imply estimates of cost per QALY of £12,047 for under target PCTs and £13,464 for over target PCTs, when sub-group specific elasticities are inputted according to being significantly different from the all-PCT elasticity estimates. These cost per QALY estimates are consistent with diminishing marginal returns to health expenditure and allow a portion of the heath production function to be derived; from which estimates of the health opportunity costs of a range of budget impacts can be inferred. These results indicate that health opportunity costs are likely to underestimate unless account is taken of the scale of budget impact. In an illustrative example, it is found that the health opportunity costs of a recent hepatitis C treatment would be underestimated by 3.9% when calculated using the Claxton et al. (2015) cost per QALY estimate rather than using this analysis.

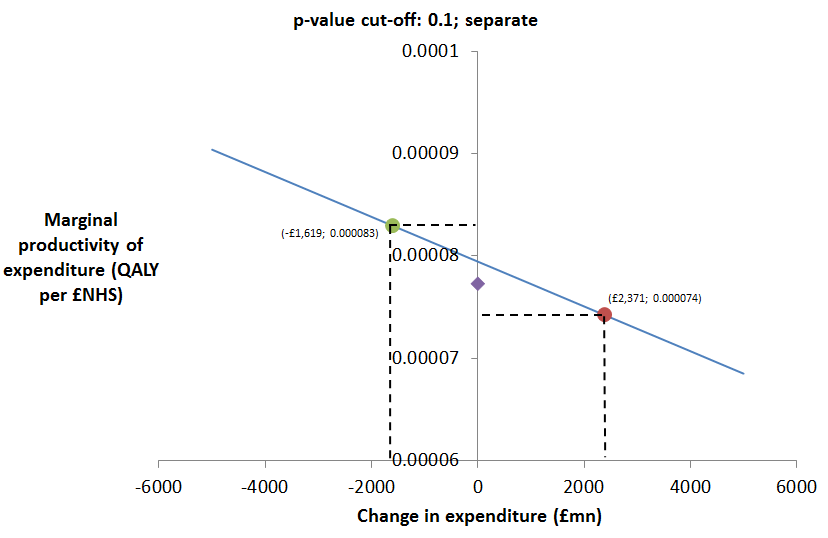
### Preferred analysis

Our preferred analysis is where we use estimates based on models estimated on separate sub-samples of observations, with a p-value threshold of p=0.1. First, we have argued that the interaction term approach is valid only if we can be sure that financial allocation relative to health care need is randomly assigned, which seems unlikely. Second, we feel that somewhere in between believing that all variation in estimated coefficients between sub-groups is signal and believing that all is due to noise lies the truth and so we illustrate our findings for such a point: cut-off p=0.1. This means that we use the sub-group specific estimated elasticities when the difference between elasticities is found to be significantly different, but use the all PCT elasticities where no such significant difference is observed. The results are a cost per QALY of £12,047 for under target PCTs and £13,464 for over target PCTs. These estimates are associated with a mean 2.06% reduction and a 3.02% increase in available resources (see Table 1).

We can investigate the implications of our estimates for PCT sub-groups in terms of the relationship between the expected health opportunity costs and scale of total additional expenditure (budget impact) of a proposed investment. Consider a new intervention that will lead to a significant net expenditure on the NHS. The health that will be generated by funding such an intervention should be compared to the health that could have been generated with the heath care resources required. Our interest is the total health that is foregone by displaced activity, which therefore can be expressed as the integral of the marginal productivity function over the increased expenditure (£EXP) (where marginal productivity is measured in terms of QALY per £NHS):

In the equation above, represents expenditure and represents marginal productivity (QALY-per-cost), which may be a function of . When is regarded as a constant with respect to expenditure (as is typically the case) the above equation reduces to the health opportunity cost being equal to the product of expenditure and marginal productivity.

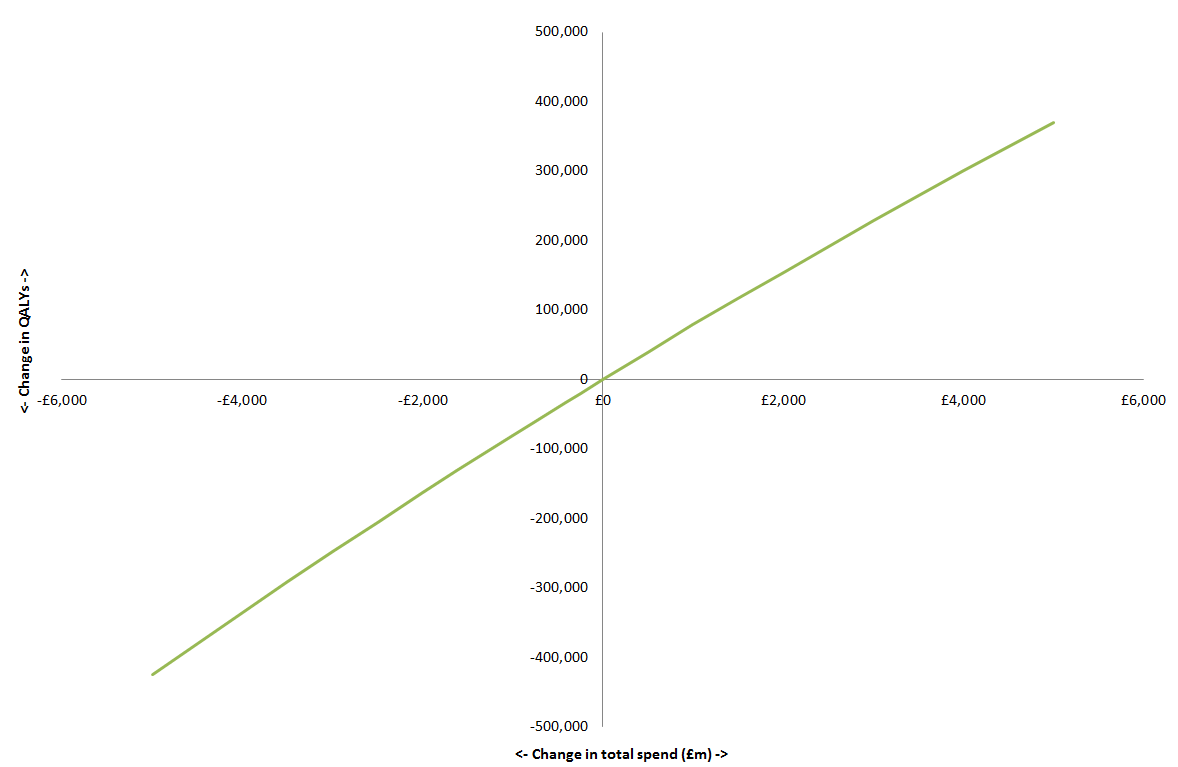
Using the results from the earlier section we can approximate the relationship between marginal productivity and expenditure. Because of the limited results (an over target PCT estimate of marginal productivity and an under target PCT estimate of marginal productivity) and for ease of calculation and exposition, we represent the relationship between marginal productivity and expenditure by using a linear approximation. In the figure below, we plot the estimated marginal productivity against expenditure, where expenditure is calculated by assuming that the whole NHS budget is over (under) target by the same percentage that over (under) target PCTs exceed (fall short of) their target allocation.

Figure - Linear approximation of relationship between marginal productivity and expenditure

The all-PCT estimate of marginal productivity of 0.000077 QALYs per £NHS (= 1/£12,936, indicated by the diamond) does not exactly fit on the linear approximation (marginal productivity at zero change in expenditure is estimated to be 0.000079 QALYS per £NHS). This is expected, since linearity is inconsistent with the conceptualisation of the econometric modelling, which is based on a Cobb-Douglas health production function (HPF) where the first derivative of marginal productivity with respect to expenditure is not constant, but decreasing at an decreasing rate (second derivative is positive).[[12]](#footnote-12)

The linear approximation to the relationship between marginal productivity and changes in expenditure in Figure 1 is consistent with diminishing marginal returns, albeit diminishing at a constant rate. Although it is clearly an approximation, in the absence of more than two points it is useful for demonstrating how health opportunity costs for different sizes of budget impact can be derived from understanding this relationship. The health opportunity cost of a budget impact can be calculated by integrating the marginal productivity function over the net expenditure, which visually can be thought of as the area under the line in Figure 1 between the two points of interest (for a budget impact with net expenditure of £EXP it will be the area between the line and the -axis from to ), given by the equation (following the visual analogy it is clear that the integral will be equal to the area of a trapezium):

Using this information the health production function (HPF) can be represented graphically, as in Figure 2, where health effects resulting from changes in expenditure can be reported.

Figure - Health production function for 2008/09 assuming linear approximation

The HPF is not linear, because the marginal productivity is non-constant over different levels of expenditure. It is now possible to pick points from the graph in order to estimate the expected health opportunity cost of different budget impacts associated with proposed investments. In order to make this clearer to the reader, and to pick out a specific result relating to our case study, we present a range of results in Table 4.

Table – Health opportunity costs for different scales of budget impact

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ***(1)*** | ***(2)*** | ***(3)*** | ***(4)*** | ***(5)*** | ***(6)*** | ***(7)*** |
| **Budget impact (£m of NHS expenditure)** | **Health opportunity costs accounting for non-marginal impact (QALYs)** | **Health opportunity costs of a marginal impact, Claxton et al., (2015) estimates (QALYs)** | **Health benefit of smoothing so marginal (QALYs)** | **Monetary benefit of smoothing budget impacts (£m of NHS expenditure)** | **Marginal k = 1/MP(£NHS)** | **Average k = 1/(0.5\*MP(0) + 0.5\*MP(£NHS))** |
| -£250 | -19,934 | -19,325 | 608 | £7.87 | £12,498.65 | £12,541.56 |
| -£500 | -40,004 | -38,651 | 1,354 | £17.51 | £12,413.73 | £12,498.65 |
| -£772 | -61,997 | -59,677 | 2,320 | £30.01 | £12,322.63 | £12,452.31 |
| -£1,000 | -80,556 | -77,301 | 3,255 | £42.10 | £12,247.29 | £12,413.73 |
| -£1,500 | -121,655 | -115,952 | 5,703 | £73.78 | £12,085.25 | £12,329.95 |
| -£1,619 | -131,517 | -125,151 | 6,366 | £82.36 | £12,047.32 | £12,310.17 |
| -£2,000 | -163,301 | -154,603 | 8,699 | £112.53 | £11,927.45 | £12,247.29 |
| -£2,500 | -205,495 | -193,253 | 12,242 | £158.37 | £11,773.72 | £12,165.73 |

The results in Table 4 are presented for a range of budget impacts following the linear approximation depicted in Figure 1. Column (2) reports health opportunity costs when accounting for the results of estimation in section 3 and the linear approximation in Figure 1. Column (3) indicates what the health opportunity costs would be thought to be if the scale of budget impact was ignored or if the budget impact was actually a marginal one, i.e., evaluated the full sample £12,936 per QALY estimate. The differences between the these values ((2)-(3)) is reported in column (4) and indicates either the potential to underestimate health opportunity costs if the scale of budget impact is not accounted for, or the benefit of avoiding non-marginal changes in expenditure through smoothing of expenditure over time. The cost to the NHS of not being able to perfectly smooth expenditures over time is reported in column (5). These values represent the maximum amount of NHS resources (£NHS) that could be given up to smooth non-marginal effects.

Finally, in columns (6) and (7) we present two values of the NHS cost (£NHS) per QALY. Column (6), ‘marginal k’, is the rate at which the NHS spends to produce QALYs after the change in spending has occurred (this is the inverse of the marginal productivity at the change in spending, ). Column (7), ‘average k’, presents the rate at which the NHS spends to produce QALYs on average for the change in spending itself. Column (7) can be obtained by dividing column (1) by column (2). It is the values in Column (7) that represent the cost per QALY ‘threshold’ that would represent health opportunity costs for a particular scale of budget impact. For example, the ‘threshold’ for an investment with a budget impact of £1,000m would be £12,414 per QALY, i.e., lower than a threshold that represents the health opportunity costs of a marginal change (i.e, £12,936 per QALY).

The results in Table 4 can be used to address the motivating example of the health opportunity costs of new hepatitis C treatments. In order to estimate the health opportunity costs of these treatments fully, we would need to know the time profile of expenditures, the time profile of marginal productivity and how the relationship between expected health opportunity cost of a proposed investment and level of expenditure will change over time, and the appropriate discount rate. However, for illustration, assuming that the estimated discounted additional costs fall in a single expenditure year the opportunity costs of estimated £772mn (NICE 2015b) of potential net budget impact would be expected to result in health opportunity costs of 61,997 QALYs rather than 59,677 QALYs if the non-marginal impact was not accounted. So, a cost per QALY ‘threshold’ that reflects health opportunity cost should be lower for this scale of budget impact at £12,452 rather than £12,936 per QALY.

The health benefits of avoiding this scale of non-marginal impact by having an opportunity to smooth the additional expenditure over time are 2,320 QALYs. Rather than accepting the single year impact of £772mn, the NHS could in principle smooth this budget impact by borrowing from future expected budget allocations at a rate relevant to public expenditure. Alternatively manufacturers could smooth this budget impact by offering a ‘mortgage like’ repayment at a real rate of return that reflects their real return to capital (analogous to private finance initiative financing of upfront costs in the NHS).[[13]](#footnote-13) The maximum amount of NHS resources (£NHS) that could be given up to smooth the budget impact of the hepatitis C treatments is £30m. A potential benefit of £30m to the NHS on a total upfront expenditure of £772m (3.9%) may be worthwhile given the value of smoothing is greater than the real rate used by HM Treasury (3.5%) and the real rates on current government borrowing, however may not be worthwhile if compared to opportunity cost of capital for manufacturers as this is likely to require a real rate of return greater than 3.9%.[[14]](#footnote-14)

## Conclusions

The 'cost-effective but unaffordable' paradox is more apparent than real and turns on whether the criteria for judging whether or not an intervention is cost-effective is founded on an empirical assessment of the likely opportunity costs elsewhere in the health care system. To say that an alternative is cost-effective but not affordable must mean that the (implicit or explicit) ‘threshold’ used to judge cost-effectiveness does not reflect the scale and value of the opportunity costs. Therefore, some assessment of how the expected health opportunity cost of a proposed investment is likely to vary with the scale of the total additional costs (budget impact) is required.

This paper provides an account of a methodology for analysing existing data in order to look at how the expected health opportunity cost of a proposed investment varies by sub-groups of PCT, in particular over and under target PCTs where the results can be used to investigate the relationship between expected health opportunity cost of a proposed investment and budget impact. We specify a preferred analysis, where sub-group specific elasticity estimates are used when differences are likely to be signal rather than noise, and find that the appropriate health opportunity cost for a given change in expenditure when there is a large budget impact is – as expected – higher than the marginal estimate as reported by Claxton, Martin, et al. (2015). Despite the limited number of observations available across the two sub groups the analysis demonstrates that an empirical examination of this relationship is possible. Future work could extend this approach to look at different waves of data or to analyse this relationship with multiple waves of data in a panel setting. The results are consistent with diminishing marginal returns to health expenditure and allow a portion of the heath production function to be derived; from which estimates of the health opportunity costs of a range of budget impacts can be inferred. These results indicate that health opportunity costs are likely to underestimate unless account is taken of the scale of budget impact. It should be noted that there may be many other factors besides the relationship between opportunity costs and budget impact that might prohibit the immediate implementation of a new technology (Hauck et al. 2016).

Recognising the importance of non-marginal effects , how they might change over time and the profile of the total additional cost imposed (accounting for future cost saving) opens the possibility of considering whether other policy options might reduce health opportunity costs of simply accepting the current profile of budget impact, e.g., by: ‘smoothing’ the profile using public resources (at a discount rate that represents opportunity cost to the public purse); or inviting manufacturers to ‘smooth’ these impacts using their resources at a discount rate that reflects their opportunity cost of capital (Epstein et al. 2007).

The current methods of NICE appraisal do not properly account for the scale of budget impacts or their time profile so they are likely to underestimate health opportunity costs even if they adopted a cost per QALY ‘threshold’ that reflected the balance of evidence of the health opportunity costs of marginal changes in health expenditure. Once proper account is taken of the scale of budget impacts other policy options become available which may offer net gains that can be shared between the NHS (through lower health opportunity costs) and manufacturers (higher prices can be charged if larger budget impacts are smoothed). Whether or not there are net gains to be shared depends on the real discount rated faced, as well as the estimated relationship between the marginal productivity of NHS expenditure and the scale of total expenditure.

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## Appendix A

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Interaction specification estimation |  |  | Expenditure equation |  | Outcome equation |  |
| PBC |  |  | Coefficient of interest | p-value of difference | Coefficient of interest | p-value of difference |
| 2 | Cancer | All | 0.525 |  | 0.307 |  |
|  |  | Under | 0.728 |  | 0.285 |  |
|  |  | Over | 0.721 | 0.088 | 0.285 | 0.865 |
| 10 | Circulatory | All | 0.648 |  | 1.319 |  |
|  |  | Under | 0.716 |  | 1.34 |  |
|  |  | Over | 0.714 | 0.657 | 1.335 | 0.506 |
| 11 | Respiratory | All | 0.652 |  | 1.808 |  |
|  |  | Under | 0.586 |  | 1.597 |  |
|  |  | Over | 0.588 | 0.659 | 1.573 | 0.043 |
| 13 | Gastrointestinal | All | 0.456 |  | 1.364 |  |
|  |  | Under | 0.346 |  | 0.933 |  |
|  |  | Over | 0.351 | 0.2 | 0.894 | 0.001 |
| 1 | Infectious diseases | All | 1.546 |  | 0.504 |  |
|  |  | Under | 1.518 |  | 0.315 |  |
|  |  | Over | 1.522 | 0.473 | 0.332 | 0.347 |
| 4 | Endocrine | All | 0.484 |  | 1.17 |  |
|  |  | Under | 0.58 |  | 0.928 |  |
|  |  | Over | 0.575 | 0.174 | 0.968 | 0.03 |
| 7 | Neurological | All | 0.98 |  | 0.417 |  |
|  |  | Under | 1.038 |  | 0.424 |  |
|  |  | Over | 1.035 | 0.476 | 0.454 | 0.073 |
| 17 | Genitourinary | All | 0.697 |  | 1.615 |  |
|  |  | Under | 0.683 |  | 1.171 |  |
|  |  | Over | 0.683 | 0.905 | 1.193 | 0.554 |
| 16 | Trauma and injuries | All | 1.344 |  | 0 |  |
|  |  | Under | 1.314 |  | 0 |  |
|  |  | Over | 1.322 | 0.155 | 0 | 0 |
| 18+19 | Maternity and neonates | All | 0.975 |  | 0.125 |  |
|  |  | Under | 1.158 |  | 0.141 |  |
|  |  | Over | 1.151 | 0.138 | 0.138 | 0.737 |
| 3 | Disorders of blood | All | 1.171 |  |  |  |
|  |  | Under | 0.66 |  |  |  |
|  |  | Over | 0.681 | 0.006 |  |  |
| 5 | Mental health | All | 1.036 |  |  |  |
|  |  | Under | 1.008 |  |  |  |
|  |  | Over | 1.01 | 0.504 |  |  |
| 6 | Learning disability | All | 0.205 |  |  |  |
|  |  | Under | 0.263 |  |  |  |
|  |  | Over | 0.259 | 0.579 |  |  |
| 8 | Problems of vision | All | 0.654 |  |  |  |
|  |  | Under | 0.758 |  |  |  |
|  |  | Over | 0.752 | 0.206 |  |  |
| 9 | Problems of hearing | All | 1.191 |  |  |  |
|  |  | Under | 1.237 |  |  |  |
|  |  | Over | 1.236 | 0.897 |  |  |
| 12 | Dental problems | All | 0.513 |  |  |  |
|  |  | Under | 0.483 |  |  |  |
|  |  | Over | 0.492 | 0.038 |  |  |
| 14 | Skin | All | 0.674 |  |  |  |
|  |  | Under | 0.7 |  |  |  |
|  |  | Over | 0.698 | 0.614 |  |  |
| 15 | Musculoskeletal | All | 0.505 |  |  |  |
|  |  | Under | 0.728 |  |  |  |
|  |  | Over | 0.719 | 0.112 |  |  |
| 20 | Poisoning and adverse events | All | 0.562 |  |  |  |
|  |  | Under | 0.772 |  |  |  |
|  |  | Over | 0.766 | 0.253 |  |  |
| 21 | Healthy individuals | All | 1.097 |  |  |  |
|  |  | Under | 2.049 |  |  |  |
|  |  | Over | 2.012 | 0 |  |  |
| 22 | Social care needs | All | 0.911 |  |  |  |
|  |  | Under | 0.084 |  |  |  |
|  |  | Over | 0.109 | 0.085 |  |  |
| 23 | Other | All | 0.494 |  |  |  |
|  |  | Under | 0.568 |  |  |  |
|  |  | Over | 0.564 | 0.09 |  |  |

## Appendix B

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Separate sample estimation |  |  | Expenditure equation |  | Outcome equation |  |
| PBC |  |  | Coefficient of interest | p-value of difference | Coefficient of interest | p-value of difference |
| 2 | Cancer | All | 0.525 |  | 0.307 |  |
|  |  | Under | 0.754 |  | 0.381 |  |
|  |  | Over | 0.677 | 0.903 | 0.247 | 0.442 |
| 10 | Circulatory | All | 0.648 |  | 1.319 |  |
|  |  | Under | 0.115 |  | 1.813 |  |
|  |  | Over | 0.725 | 0.573 | 0.895 | 0.019 |
| 11 | Respiratory | All | 0.652 |  | 1.808 |  |
|  |  | Under | 0.176 |  | 2.142 |  |
|  |  | Over | 0.697 | 0.418 | 1.058 | 0.258 |
| 13 | Gastrointestinal | All | 0.456 |  | 1.364 |  |
|  |  | Under | 0.171 |  | 1.511 |  |
|  |  | Over | 0.487 | 0.592 | 0.35 | 0.196 |
| 1 | Infectious diseases | All | 1.546 |  | 0.504 |  |
|  |  | Under | 1.118 |  | 0.991 |  |
|  |  | Over | 1.967 | 0.134 | 0.172 | 0.261 |
| 4 | Endocrine | All | 0.484 |  | 1.17 |  |
|  |  | Under | 0.781 |  | 0.441 |  |
|  |  | Over | 0.372 | 0.359 | 0.992 | 0.506 |
| 7 | Neurological | All | 0.98 |  | 0.417 |  |
|  |  | Under | 1.131 |  | 0.823 |  |
|  |  | Over | 0.793 | 0.473 | 0.298 | 0.604 |
| 17 | Genitourinary | All | 0.697 |  | 1.615 |  |
|  |  | Under | 0.625 |  | -0.658 |  |
|  |  | Over | 0.744 | 0.784 | 6.495 | 0.126 |
| 16 | Trauma and injuries | All | 1.344 |  | 0 |  |
|  |  | Under | 1.747 |  | 0 |  |
|  |  | Over | 0.641 | 0.02 | 0 | 0 |
| 18+19 | Maternity and neonates | All | 0.975 |  | 0.125 |  |
|  |  | Under | 1.316 |  | 0.49 |  |
|  |  | Over | 0.687 | 0.374 | -0.2 | 0.075 |
| 3 | Disorders of blood | All | 1.171 |  |  |  |
|  |  | Under | 0.934 |  |  |  |
|  |  | Over | 0.58 | 0.718 |  |  |
| 5 | Mental health | All | 1.036 |  |  |  |
|  |  | Under | 1.506 |  |  |  |
|  |  | Over | 0.653 | 0.048 |  |  |
| 6 | Learning disability | All | 0.205 |  |  |  |
|  |  | Under | 0.534 |  |  |  |
|  |  | Over | 0.281 | 0.858 |  |  |
| 8 | Problems of vision | All | 0.654 |  |  |  |
|  |  | Under | 1 |  |  |  |
|  |  | Over | 0.546 | 0.562 |  |  |
| 9 | Problems of hearing | All | 1.191 |  |  |  |
|  |  | Under | 2.83 |  |  |  |
|  |  | Over | -0.15 | 0.035 |  |  |
| 12 | Dental problems | All | 0.513 |  |  |  |
|  |  | Under | 0.175 |  |  |  |
|  |  | Over | 0.7 | 0.271 |  |  |
| 14 | Skin | All | 0.674 |  |  |  |
|  |  | Under | 0.771 |  |  |  |
|  |  | Over | 0.645 | 0.839 |  |  |
| 15 | Musculoskeletal | All | 0.505 |  |  |  |
|  |  | Under | 0.894 |  |  |  |
|  |  | Over | 0.505 | 0.618 |  |  |
| 20 | Poisoning and adverse events | All | 0.562 |  |  |  |
|  |  | Under | 0.651 |  |  |  |
|  |  | Over | 0.821 | 0.797 |  |  |
| 21 | Healthy individuals | All | 1.097 |  |  |  |
|  |  | Under | 2.203 |  |  |  |
|  |  | Over | 1.968 | 0.862 |  |  |
| 22 | Social care needs | All | 0.911 |  |  |  |
|  |  | Under | -0.009 |  |  |  |
|  |  | Over | 0.281 | 0.896 |  |  |
| 23 | Other | All | 0.494 |  |  |  |
|  |  | Under | 0.385 |  |  |  |
|  |  | Over | 0.675 | 0.306 |  |  |

1. Cost-effectiveness was judged according to the standard ‘cost-effectiveness threshold’ applied by NICE of £20,000 to £30,000 per QALY. It is worth noting that PBAC made judgements requiring lower cost per QALY than usual given the large budget impact (Harris 2016). [↑](#footnote-ref-1)
2. Such an empirical assessment is described in Vallejo-Torres et al. (2016) as a ‘supply side’ assessment of opportunity costs, which is relevant (Schaffer et al. (2016)) when the additional costs of an investment must be accommodated within existing expenditure or when health expenditure is increased to accommodate it. When non health impacts on private consumption are considered important, some assessment of the equivalent consumption value of health is required, i.e., ‘demand side empirical research’ (Vallejo-Torres et al. 2016). However, some assessment of the opportunity costs of health expenditure on private consumption or ‘net production’ is also necessary and possible (Claxton, Sculpher, et al. 2015). Both are important but are beyond the scope of this paper (for a discussion of decision rules when there are multiple sectoral effects see Claxton et al., 2010; Claxton et al., 2011 and Drummond et al. 2015. [↑](#footnote-ref-2)
3. A key limitation of this work is that data is collected at the level of the health authority, rather than at the level of the individual. Such data can not be obtained at individual-level, but may be available in other national settings. [↑](#footnote-ref-3)
4. Since the publication of Claxton et al. (2013) and Claxton et al. (2015), a number of other articles have been published that discuss the assumptions made in the paper: critical discussion (Barnsley et al., 2013 and Raftery 2014), response to critique (Claxton & Sculpher) and additional sensitivity analysis (Soares & Claxton 2016). [↑](#footnote-ref-4)
5. Large in this context should be judged relative to total expenditure and the significance of the scale of the budget impact depends upon the resulting health opportunity cost. [↑](#footnote-ref-5)
6. Cancer, circulatory disease, respiratory problems and gastrointestinal problems. [↑](#footnote-ref-6)
7. Elasticities are directly estimated since variables are log-transformed prior to estimation of regression models. This specification is consistent with a conceptual model where the health production function follows the Cobb-Douglas form. [↑](#footnote-ref-7)
8. The PCT sub-group variable takes a value of 0 assigned if under-target PCT and 1 if over-target PCT, while on-target PCTs are dropped from analysis. [↑](#footnote-ref-8)
9. This approach follows what is done in the exploratory work on this issue within Claxton, Martin, et al. (2015). [↑](#footnote-ref-9)
10. Of 19 estimated PBC productivities, PBC 2 is the 9th most productive and PBC 21 is the 18th most productive. [↑](#footnote-ref-10)
11. Of 19 estimated PBC productivities, PBC 5 is the 10th most productive and PBC 9 is the 4th most productive. [↑](#footnote-ref-11)
12. That marginal productivity is linear in expenditure would imply a quadratic health production function, note that in the econometric analysis the log of mortality is modelled as a linear function of the log of expenditure based on a Cobb-Douglas health production function. [↑](#footnote-ref-12)
13. A related idea is discussed in Montazerhodjat et al. (2016) where the decision-making unit of interest is the individual and not the social decision maker, which is the focus here. [↑](#footnote-ref-13)
14. It is worth acknowledging that the most appropriate discount rate for this kind of appraisal is disputed, see for instance Paulden & Claxton (2012). [↑](#footnote-ref-14)