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Cost-equality analysis of health care programmes – a methodological case study of the UK Bowel Cancer Screening Programme

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Abstract:

Cost equality analysis is a methodological framework for combining the objectives of maximising health and minimising unfair variation in health when evaluating population health interventions. The NHS Bowel Cancer Screening Programme (BCSP) introduced in 2006 has been shown to improve population health on average but also to worsen population health inequalities associated with deprivation and ethnicity – a classic case of "intervention generated inequality". We demonstrate the cost equality analysis framework by examining two redesign options for the BCSP: (1) the introduction of an enhanced targeted reminder aimed at increasing screening uptake in deprived and ethnically diverse neighbourhoods and (2) the introduction of a basic universal reminder aimed at increasing screening uptake across the whole population. We find that the universal reminder is the strategy that maximises population health while the targeted reminder is the strategy that minimises unfair variation in health. We demonstrate how these two objectives can be traded off against each other in our framework, initially making the social value judgement that variations by deprivation, ethnicity and sex are all considered unfair. We then show how alternative social value judgements influence the assessment of which strategy is best, including judgements about which dimensions of health variation are considered fair and which unfair and judgements about societal levels of inequality aversion.

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1. Introduction

Cost-effectiveness analysis is used to support health sector decisions about the allocation of limited resources with the objective of maximising health [1]. When dealing with population health interventions we often have the additional objective of minimising "unfair" health inequality [2] and to this end are also interested in the distribution of both health gains and health opportunity costs due to the intervention. In this paper we propose a methodology for quantifying and combining these two objectives within a unified economic evaluation framework, clearly stating the social value judgements underpinning any particular conclusion. We call this methodology "cost-equality analysis" and demonstrate it through a case study looking at potential redesign options for the NHS Bowel Cancer Screening Programme in England.

2. Background

Colorectal cancer (CRC) is the third most common cancer in the UK with approximately 40,000 new cases diagnosed annually resulting in almost 16,000 CRC related deaths per year.[3] Research has shown that using screening to diagnose and treat CRC earlier can significantly reduce the number of CRC deaths[4]. Screening for CRC is typically carried out by either faecal occult blood testing (FOBT), a self administered test where stool samples are collected by the patient and then sent to a lab to test for the presence of blood, or by flexible sigmoidoscopy (FS), a more invasive procedure carried out by a clinician examining the patient's sigmoid colon searching for abnormal growth using an endoscope. Following a number of pilot studies to evaluate the feasibility and efficacy of guaiac faecal occult blood test (gFOBT) based screening [5] [6] [7] [8] [9] [10] the Department of Health launched the NHS Bowel Cancer Screening Programme in England (BCSP) in 2006 offering biennial screening with gFOBT to persons aged 60-69 years. In 2009 the programme was extended to also include those aged 70-74 and, following a large UK RCT of FS, [11] the BCSP is being further extended to include an additional offer of FS screening to all persons at the age of 55 [12]. Those patients who screen positive for CRC through either FS or gFOBT are sent for a more thorough follow up colonoscopy examination and if found to have CRC are administered appropriate treatment.

Evaluations of both the gFOBT and FS pilot studies suggest that screening uptake is low overall, and that there are significant inequalities in the uptake of both screening methods [13] [14] [15] [16] [17]. The literature suggests that uptake varies by age, gender, ethnicity and level of deprivation [18], and that uptake increases with age, is higher for women than for men, decreases with increasing levels of small area ethnic diversity and decreases with increasing levels of small area deprivation [19]. Similarly low and unequal uptake of screening was also observed in the early results from the BCSP with gFOBT uptake averaging only 54% among the first 2.6 million invitees, ranging from 61% in the least deprived areas to 35% in the most deprived areas, and showing a similar gradient in terms of small area based ethnic diversity measures [20] [21] . Furthermore for those individuals with positive screening results there is also evidence of inequality in the uptake of follow up colonoscopy [22]. It is reasonable to expect that these inequalities in the uptake of the screening programme will exacerbate the already unequal distribution of health, with the screening

programme disproportionately benefiting more advantaged groups (for whom uptake is highest) – a classic case of "intervention generated inequality" [23].

There have been a number of studies looking at how to increase uptake of CRC screening overall and many redesign options for screening programmes have been proposed. Suggestions range from requiring greater GP involvement [24 25 26 27] and the sending of reminders and repeat invitations [28 29 30] to the use of alternative screening technologies [31 32 33 34 35]. However, while these interventions may have been shown to increase overall uptake, there is currently little evidence on their impact in reducing the inequality in uptake of screening – though evidence will emerge in a few years time from the ongoing ASCEND project (2012 - 2016) which specifically looks at strategies to reduce the social gradient in bowel cancer screening [36].

3. Cost-effectiveness analysis

Prior to the introduction of the BCSP a number of possible screening options were evaluated to help national NHS decision makers determine the form that the screening programme should take. As part of that process a model was developed to perform the economic evaluation of the various options [37]. This original economic evaluation model was later refined and updated to reflect data emerging from the BSCP [38]. In this paper we build on the latest version of this economic evaluation model. However, given the methodological objective of our exposition, we simplify the analysis by focusing on a set of decision options that could potentially have been on the table in 2006 regarding gFOBT screening. Taking this step back in time to the original 2006 form of the BSCP allows us to simplify the analysis by setting aside the soon to be introduced FS based element of the screening programme. We compare the following three strategies for the BSCP:

1. Standard screening as implemented in the BCSP from 2006 with no additional intervention
2. Screening plus a targeted enhanced reminder letter (personal GP signed letter and tailored information package) sent only to those living in the most income deprived 40% of small areas (IMD4 and IMD5) as well as to those living in areas with the highest proportion of inhabitants from the Indian subcontinent (IS5). This targeted subgroup comprises of 52% of the total population invited for screening. Costs of this strategy per person targeted are £7 [39] resulting in an increase in average uptake of gFOBT among the targeted population of 12% [24].
3. Screening plus a universal basic reminder letter (sending a GP endorsed reminder letter to all eligible patients). Costs of this strategy per person are £3.50 [39] resulting in an increase in average uptake of gFOBT of 6% [24].

The additional costs of the various screening options as compared to no screening are assumed to come from the existing fixed health budget incurring an opportunity cost of 1 QALY per £20,000 spent on screening. Targeted and universal reminder interventions in conjunction with standard screening both have approximately equal total additional direct intervention costs of £2.75 million per screening round over the

costs of the current screening programme, with the targeted intervention being approximately double the cost per person of the universal intervention but targeted to only approximately half the population. The model follows a cohort of one million 30 year olds through their lifetimes, with screening invitations being sent out biennially between the ages of 60 and 74.

Table 1 below shows the per person and population level cost-effectiveness results for the three different options. The results are presented incremental to the lifetime bowel cancer related health care costs and QALYs gained accruing to a population with no screening programme. There are a number of conclusions we can draw from these results. Firstly we note that at the individual level the screening programme in any of its forms has a very small expected per-person incremental benefit over no screening – approximately 0.05 QALYs over a lifetime. However, at a population level this represents a substantial health gain – approximately 50,000 QALYs over the lifetime of the cohort of one million 30 year olds. When interpreting these numbers it is important to keep in mind that this is a population health intervention rather than a clinical intervention targeted only at cancer patients. Most people invited for screening will not have bowel cancer and some people with bowel cancer will not attend screening, and for these reasons we expect the per person health benefit to be small in comparison to the benefits we would expect when evaluating a clinical intervention. Secondly we note that both of the reminder interventions are worthwhile compared to the standard screening programme in terms of net health benefit (NHB) at a cost-effectiveness threshold of £20,000 per QALY. Finally we note that on the basis of these cost-effectiveness results, if our objective was solely to maximise population health, we should choose screening with the addition of the universal basic reminder as the preferred screening strategy among the three compared.

Table 1: Standard cost-effectiveness results

Results based on a lifetime model for a cohort comprising of one million 30 year olds [a]	Incremental Bowel Cancer Related Cost (£) compared to no screening [b] *population* **per person**	Incremental Life Years compared to no screening *population* **per person**	Incremental QALYs compared to no screening *population* **per person**	Cost per QALY gained (£/QALY) compared to no screening	Incremental NHB @£20k per QALY (QALYs) compared to no screening *population* **per person**
1. Standard screening	*44,013,836* **44**	*58,219* **0.0582**	*50,324* **0.0503**	*875*	*48,123* **0.0481**
2. Screening + targeted reminder	*75,604,844* **76**	*63,281* **0.0633**	*54,566* **0.0546**	*1,386*	*50,785* **0.0508**
3. Screening + universal reminder	*75,886,777* **76**	*63,561* **0.0636**	*54,919* **0.0549**	*1,382*	*51,124* **0.0511**

a) These are compared to baseline no screening results which per one million of population invited to screening are : **Costs** £277,766,467**; Life years** 50,721,691; **QALYs** 41,042,480; **Cost per QALY** £7; **NHB @ £20k per QALY** 41,028,592

b) Costs are overall lifetime health care costs from an health system perspective including both direct screening costs and costs of CRC treatment and care – the cost of sending reminders constitutes approximately two thirds of the difference in cost between the standard screening programme and the screening programmes with reminders

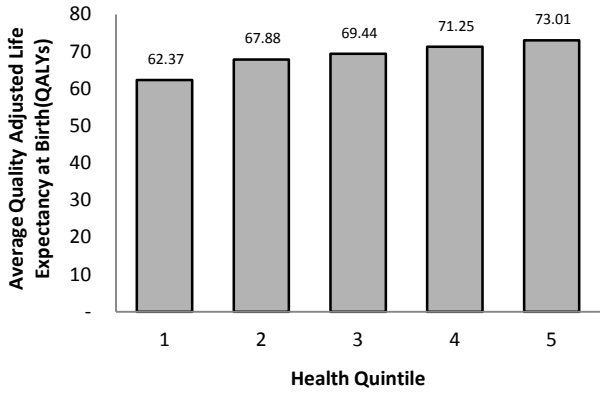
4. Cost-equality analysis - assuming all variation in health unfair

Cost-effectiveness analysis allows us to identify which one of the strategies maximises total health. In order to extend this analysis to allow us to evaluate our other key objective, that of minimising health

inequality, we require descriptions of the distributions of health in the general population produced by the interventions being compared. To assess changes in the distribution of health levels under each strategy, we first require information on the general population distribution of total health levels without the intervention. We then add to this the general population distribution of changes in health attributed to each intervention. This is informed not only by the distribution of the health gains among recipients of the intervention, but also by the distribution of health opportunity costs among those who would have received the displaced activities. The opportunity costs are unlikely to fall in proportion to the intervention costs or benefits for particular recipients, and those who would otherwise have benefited from the displaced activities may also include non-recipients of the intervention.

We estimate baseline inequality in the distribution of expected lifetime health in the general population by extending the economic evaluation model to incorporate differential all-cause mortality rates by age, sex and social class as observed in the ONS longitudinal study [40]. We additionally include the differences in morbidity by using health related quality of life data by age and sex based on UK norms for EQ5D [41] and further adjusted for social class using the differences between life-expectancy and disability free life expectancy as observed in the ONS general lifestyle survey [42]. Plugging this data into the model and producing a health distribution for the population, assuming no screening programme exists, results in the baseline distribution of quality adjusted life expectancy (QALE) shown in Figure 1 below. The health quintiles in the figure are calculated by ordering the predicted lifetime health of each individual as calculated by the model, from least to most healthy, splitting the individuals into five equally sized groups and calculating the average level of health of each group.

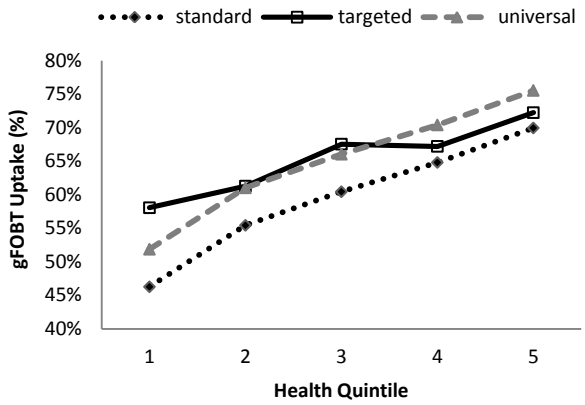
Figure 1: Baseline health distribution



Having demonstrated the nature of the baseline distribution of health across the population we next focus our attention on the impact of our screening interventions on this health distribution. Analysis of the results from the pilot study of the national screening programme suggests that the uptake of the screening programme varies by area level deprivation, area level ethnic diversity and sex of the participants [9]. Area level deprivation is based on index of multiple deprivation (IMD) quintiles, and ethnic diversity is based on area based quintiles measuring the proportion of people originating from the Indian subcontinent (IS): in

the data significant differences are observed between the most ethnically diverse quintile (IS5) and the four least ethnically diverse quintiles (IS1-4). Area level variables are based on data at lower super output area (LSOA) level, small areas containing approximately 1,500 individuals. We use these variables in the model to distinguish the uptake level of twenty distinct subgroups, comprising of all possible combinations of the two sexes, five deprivation levels and two ethnic diversity levels. The data from the pilot study allows us to calculate the average uptake of gFOBT and follow up colonoscopy for each of the twenty different groups adjusting for the correlations between the groups. We were unable to estimate the proportion of the population in each of the twenty groups from the pilot study as the necessary information on correlation was not reported. Instead we simply assume independence in the distribution of the characteristics. Data from the pilot are used to extrapolate to the population at large by further assuming that the population in the pilot study is representative of the population in general. Using this information we calculated the distribution of gFOBT uptake under each of our three screening options as shown in Figure 2 below. The quintiles used in this figure are based on those for the baseline health distribution. (The distribution of follow up colonoscopy uptake can be found in the appendix and this is assumed to be the same between the interventions).

Figure 2: gFOBT uptake distribution



We can see in Figure 2 that there is a clear relationship between gFOBT uptake and baseline health, with uptake being higher for those who are already more healthy regardless of the specific form of the screening programme we look at. The strategy involving the sending of a universal basic reminder in addition to the screening programme results in a parallel shift in gFOBT uptake as compared to the standard screening programme with uptake increasing by the same amount (6%) in each health quintile. The strategy involving the sending of a targeted enhanced reminder in additional to the screening programme on the other hand flattens the uptake gradient between the health quintiles resulting in a higher uptake in the lower health quintiles and a lower uptake in the higher health quintiles as compared to the universal reminder strategy.

The final factor we need to determine before we can use our model to estimate the distribution of health for the population is the distribution of the opportunity costs of the screening programme. We assume that the

total costs of screening come out of a fixed health budget and that the opportunity cost due to the disinvestment of these funds from other uses within the NHS is £20,000 per QALY. Not having any further information on how these opportunity costs are distributed we assume that they are distributed equally across all groups in the population.

Incorporating these three sets of adjustments to the model: the distribution of factors impacting baseline health; the distribution of factors impacting screening uptake; and the distribution of opportunity cost, and assuming that all other factors in the model (in particular, CRC incidence levels) remain constant between the different groups in the population, we are able to estimate the modelled distribution of health net of opportunity costs. The assumption that CRC incidence levels are equal across sub-groups, rather than being correlated with lifetime health, is a conservative assumption made due to data limitations and will likely result in us underestimating the true effects on variation in expected lifetime health. Figure 3 below shows the incremental net health benefit estimated for the screened population (per 1 million individuals invited for screening) under each of the three suggested configurations of the screening programme as compared to the population with no screening. Figure 4 shows the incremental net health gains estimated from the two interventions to increase screening uptake over the standard screening programme. We see from Figure 3 that screening is health improving across the entire health distribution, regardless of which configuration of the screening programme is selected, and that all forms of the screening programme increase health inequality by benefiting relatively healthy groups more than relatively unhealthy groups. Turning to Figure 4 we see that compared to standard screening both the interventions designed to increase uptake also result in health improvements across the distribution, with the universal intervention benefiting the least healthy quintiles least and the most healthy quintiles most and the targeted intervention having the opposite effect. We can draw two main conclusions from these results. First, screening in general increases health inequality as seen in Figure 3. Second, the standard screening programme can be redesigned using targeted reminders to ameliorate this effect to some extent, whereas redesign using universal reminders further exacerbates health inequality, as seen in Figure 4.

Figure 3: Health compared to no screening (per million of population invited for screened)

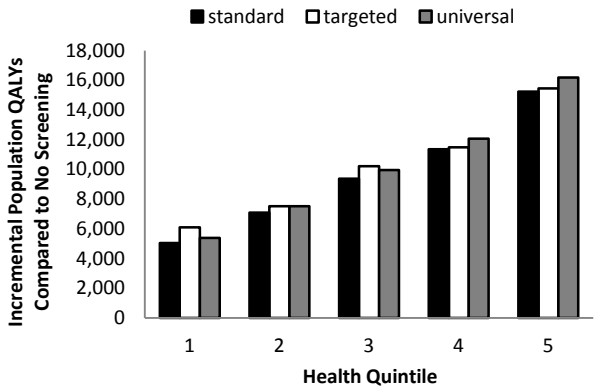
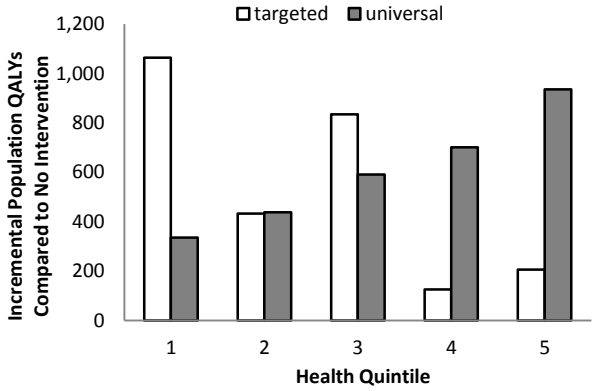


Figure 4: Health compared to standard screening (per million of population invited for screening)



The results of quantitatively assessing this distribution of health using a battery of standard indices of inequality and social welfare are shown Table 2 below. This table of results is split into three sections. The first section describes relative measures of inequality; those that measure the proportional changes in health across the distribution. These range from simple measures focusing only on the extremes of the distribution, such as the relative gap index, to more sophisticated measures assessing the entire distribution and allowing for different levels of relative inequality aversion such as the Atkinson index [43]. The second section of the table shows absolute measures of inequality; those that measure the absolute changes in health across the distribution. These also range from simple extreme group measures, such as the absolute gap index, to more sophisticated measures assessing the entire distribution and allowing for different levels of absolute inequality aversion such as the Kolm index [44]. The final section shows social welfare indices which combine concerns for maximising population health and concerns for minimising health inequality [45]. These indices are calibrated on the same scale by calculating an "equally distributed equivalent" (EDE) level of health for the health distribution. By this we mean the level of health each person in the population would need to receive in a hypothetically perfectly equal health distribution for society to be indifferent between that equal distribution of health and the actual unequal distribution of health. We calculate these measures of social welfare by combining the mean level of health for the population with the Atkinson and Kolm inequality indices at different levels of relative and absolute inequality aversion (ε or α respectively). In the case of no concern for inequality the social welfare indices just collapse to the mean level of health. The difference between the mean health and the EDE health for each strategy indicates the average decrement in health per person society is willing to sacrifice in order to achieve a perfectly equal distribution of health given the current health distribution.

All the measures of absolute and relative inequality reported in Table 2 rank the health distribution produced by screening with the targeted enhanced reminder as the least unequal strategy, and the health distribution produced by screening with the universal basic reminder as the most unequal of the three screening strategies compared. Turning next to the social welfare indices, in the case where we have no interest in health inequality we can limit our focus to mean health from which we can conclude, as we saw from the cost-effectiveness results, that the universal basic reminder is the preferred strategy. The remaining indices combine our concerns of maximising health and minimising health inequality in various ways, showing for different levels of absolute and relative inequality aversion the equally distributed equivalent levels of health. As we would expect, at low levels of inequality aversion we care more about improving health overall than about reducing health inequality and so the universal basic reminder is the preferred strategy. However, as the level of inequality aversion increases our concern for minimising health inequality starts to dominate over our concern for maximising health and the targeted enhanced reminder becomes the preferred strategy. The standard screening programme with no additional reminder is never the preferred strategy in terms of social welfare.

Table 2: Measures of inequality and social welfare

Relative Inequality Indices	*standard gFOBT*	*gFOBT + targeted*	*gFOBT + universal*
Relative Gap Index (ratio)	***0.17146***	***0.17139***	***0.17151***
Relative Index of Inequality (RII)	***0.18238***	***0.18230***	***0.18242***
Gini Index	***0.03040***	***0.03038***	***0.03040***
Atkinson Index (ε= 1)	***0.00165***	***0.00165***	***0.00165***
Atkinson Index (ε= 5)	***0.00887***	***0.00886***	***0.00888***

ε=1 represents low relative inequality aversion while ε=5 represents high relative inequality aversion

Absolute Inequality Indices	*standard gFOBT*	*gFOBT + targeted*	*gFOBT + universal*
Absolute Gap Index (range)	***10.69781***	***10.69398***	***10.70081***
Slope index of inequality (SII)	***12.55470***	***12.54979***	***12.55832***
Kolm Index (α= 0.025)	***0.19344***	***0.19328***	***0.19354***
Kolm Index (α= 0.125)	***1.07182***	***1.07101***	***1.07234***

α=0.025 represents low absolute inequality aversion while α=0.125 represents high absolute inequality aversion

Social Welfare Indices	*standard gFOBT*	*gFOBT + targeted*	*gFOBT + universal*
Mean Health	***68.83853***	***68.84119***	***68.84153***
Atkinson EDE (ε= 1)	***68.72511***	***68.72787***	***68.72806***
Atkinson EDE (ε= 5)	***68.22774***	***68.23091***	***68.23047***
Kolm EDE (α= 0.025)	***68.64509***	***68.6479***	***68.64799***
Kolm EDE (α= 0.125)	***67.76671***	***67.77018***	***67.76918***

Most preferred  Least preferred 

5. Cost-equality analysis - assuming some variation in health fair

The basic version of the cost-equality analysis described above assumed that we consider all variation in the distribution of health to be unfair. If however our inequality concern does not apply to all sources of variation in health – for example, if some determinants of individual ill health are deemed to be a matter of unavoidable bad luck or individual responsibility – then further analysis is required in order to isolate just the variation in health deemed to be unfair.

We can isolate this health distribution of interest by undertaking multivariate analysis on our raw health distribution through which estimates of total health are adjusted to control for fair variation in health in order to leave a distribution of health reflecting only the unfair variation – this process has been referred to as "direct unfairness" in the literature [46]. This fairness adjusted distribution of health is then evaluated in place of the unadjusted distribution by way of inequality and social welfare measures. Alternative judgements about which variation in health is considered fair or unfair can lead to different conclusions as to which intervention strategy is preferred, and so the sensitivity of the decision to alternative sets of reasonable social value judgements regarding fairness should be assessed. In the current case study we must decide whether or not we deem health variation associated with sex, area based level of deprivation and area based ethnic diversity to be fair. There are eight possible sets of social value judgements we can make on these three variables ranging from variation in health associated with any of them being deemed unfair (as was assumed in the previous section) to variation in health associated with any of them being

deemed to be fair (resulting in the trivial case where there is no variation in health in the adjusted distribution). Table 3 below shows the full range of social value judgements that we can make and the sensitivity of our decision under the different social welfare indices to these alternative sets of social value judgements.

Table 3: Sensitivity of preferred screening strategy decision to the choice of social value judgements

Social Value Judgment			**Preferred Strategy based on Social Welfare Index** S = standard screening U = screening + universal basic reminder T = screening + targeted enhanced reminder			
IMD	**Ethnic Diversity**	**Sex**	**Atkinson EDE (ε= 1)**	**Atkinson EDE (ε= 5)**	**Kolm EDE (α= 0.025)**	**Kolm EDE (α= 0.125)**
Fair	Fair	Fair	U	U	U	U
Fair	Unfair	Fair	U	U	U	U
Fair	Fair	Unfair	U	U	U	U
Fair	Unfair	Unfair	U	U	U	U
Unfair	Fair	Fair	U	T	U	T
Unfair	Unfair	Fair	U	T	U	T
Unfair	Fair	Unfair	U	T	T	T
Unfair	Unfair	Unfair	U	T	U	T

As an example to demonstrate the adjustment process we take the case where we make the social value judgement that variation in health associated with area based social deprivation as measured by IMD is considered unfair whilst variation associated with sex or area based ethnic diversity is considered fair (the shaded line in Table 3). To apply this social value judgement we adjust our health distribution to only reflect unfair variation in health by estimating the health of the population using reference values for the variables associated with variation deemed fair while preserving the population values for the variable associated with the health variation deemed unfair i.e. in this example we estimate a health distribution where everybody has the health level associated with being male and from an area with a low level of ethnic diversity but allow variation in health with respect to area based IMD quintiles. The resulting adjusted health distribution showing only the variation deemed unfair by our social value judgements is shown in Figure 5 below. Having adjusted out variation due to sex and ethnic diversity, there is now a complete overlap between our adjusted health quintiles and the underlying IMD quintiles (though the numbering of these quintiles is reversed with adjusted health quintile 1 corresponding to IMD quintile 5). Figure 6 shows the gFOBT uptake gradient as we saw earlier in Figure 2 but now grouped by IMD quintile. Looking at gFOBT for the targeted strategy in this figure we can see that for both of the lower two adjusted health quintiles (corresponding to IMD quintiles 4 and 5) uptake increases by 12% compared to standard screening i.e. everybody in these two quintiles is targeted, whereas for the remaining three adjusted health quintiles uptake increases by much less as targeting only impacts the subset of this population that live in the most ethnically diverse areas (IS5).

Figure 5: Adjusted health distribution no screening

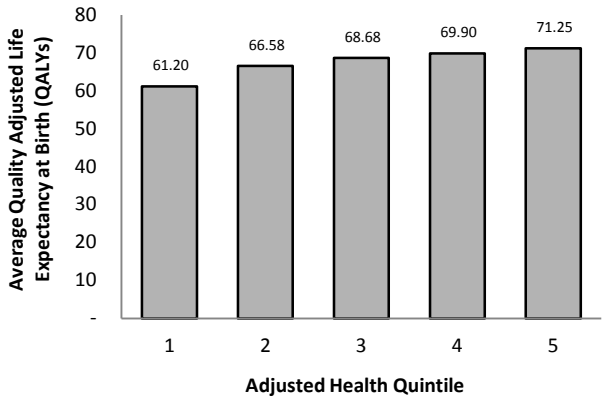
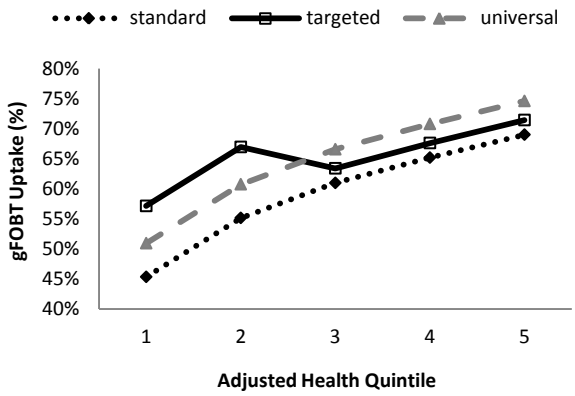


Figure 6: Adjusted gFOBT uptake distribution



Turning next to the modelled results comparing the three screening configurations for the adjusted health distribution (shown in Figure 7) we find that each of our screening strategies increases unfair health inequalities by benefiting the most healthy groups in the population (in this adjusted case those living in the least deprived areas) more than they benefit the least healthy groups in the population (in this adjusted case those living in the most deprived areas). Comparing the two strategies to increase uptake against standard screening in Figure 8 we see that the universal basic reminder remains health improving across the adjusted health distribution and increases unfair health inequality as compared to standard screening. The targeted enhanced reminder however, is now health improving only for the least healthy two adjusted health quintiles with the remaining three adjusted health quintiles incurring health losses due to the incremental opportunity costs of this strategy but deriving none of the health benefits from it.

Figure 7: Adjusted health compared to no screening (per million of population invited for screening)

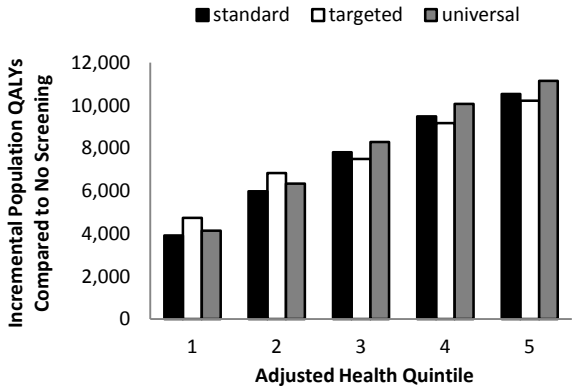
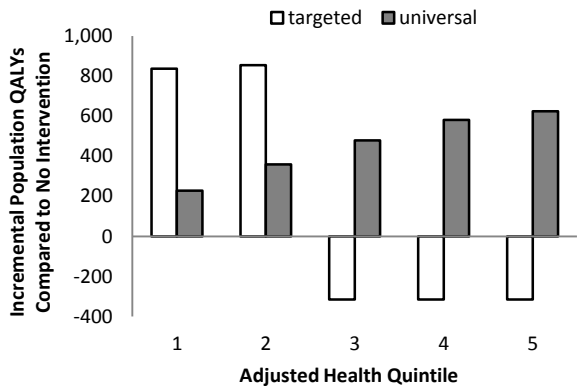


Figure 8: Adjusted health compared to standard screening (per million of population invited for screening)



Turning next to Table 4 showing the inequality and social welfare measures for the adjusted distribution of health we see that as before across all relative and absolute inequality measures listed the targeted enhanced reminder is ranked as the least unequal of the three strategies while the universal basic reminder is ranked as the most unequal of the three. We also note in comparing with Table 2 that the each of the inequality indices has decreased for every strategy, this is to be expected as we have adjusted out variation that we deemed to be fair in the adjustment process and so are now only measuring unfair inequality rather than all

inequality. Finally turning to the social welfare indices we note that as in the unadjusted analysis the universal strategy remains preferred at low levels of relative and absolute inequality aversion with the targeted strategy preferred at the higher levels of inequality aversion. In calculating these adjusted social welfare indices we combine the mean levels of health for each screening strategy calculated from the unadjusted health distribution with the level of unfair inequality for each strategy calculated from the adjusted health distribution - the purpose of the adjustment process being solely to assess the level of unfair inequality in our distributions of health. We further note that social welfare is now higher as reported by all our measures in this adjusted analysis as compared to social welfare in our unadjusted analysis – this is due to the decrease in the inequality measures used in the calculations of social welfare now that our inequality concern has been restricted to only unfair variation in health rather than all variation in health.

Table 4: Measures of inequality and social welfare for fairness adjusted distributions

Relative Inequality Indices	*standard gFOBT*	*gFOBT + targeted*	*gFOBT + universal*
Relative Gap Index (ratio)	***0.16465***	***0.16454***	***0.16468***
Relative Index of Inequality (RII)	***0.17334***	***0.17321***	***0.17337***
Gini Index	***0.02889***	***0.02887***	***0.02890***
Atkinson Index (ε= 1)	***0.00160***	***0.00160***	***0.00160***
Atkinson Index (ε= 5)	***0.00867***	***0.00866***	***0.00867***

ε=1 represents low relative inequality aversion while ε=5 represents high relative inequality aversion

Absolute Inequality Indices	*standard gFOBT*	*gFOBT + targeted*	*gFOBT + universal*
Absolute Gap Index (range)	***10.08010***	***10.07434***	***10.08208***
Slope index of inequality (SII)	***11.71065***	***11.70215***	***11.71315***
Kolm Index (α= 0.025)	***0.18070***	***0.18048***	***0.18077***
Kolm Index (α= 0.125)	***1.00993***	***1.00875***	***1.01032***

α=0.025 represents low absolute inequality aversion while α=0.125 represents high absolute inequality aversion

Social Welfare Indices	*standard gFOBT*	*gFOBT + targeted*	*gFOBT + universal*
Mean Health	***68.83853***	***68.84119***	***68.84153***
Atkinson EDE (ε= 1)	***68.72843***	***68.73122***	***68.73159***
Atkinson EDE (ε= 5)	***68.24187***	***68.24524***	***68.24465***
Kolm EDE (α= 0.025)	***68.65783***	***68.66071***	***68.66076***
Kolm EDE (α= 0.125)	***67.82860***	***67.83244***	***67.83121***

Most preferred Least preferred

6. Discussion

Our results have shown that while the national bowel cancer screening programme has a small average individual benefit this benefit is substantial at a population level. This is to be expected for a population health intervention such as this where the majority of people screened will not have bowel cancer and many of the people who develop bowel cancer may not participate in screening, so the large individual benefits accruing to the relatively small number of people both participating in screening and having bowel cancer are averaged across the whole population giving a small expected per person benefit.

Strategies to increase uptake of bowel cancer screening whether targeted or universal appear to be worthwhile both in terms of improving population health and in terms of improving social welfare as compared to the standard screening programme alone. In our analysis the universal basic reminder resulted in the greatest population health improvement of the three strategies compared and despite being the least attractive in terms of its impact on increasing health inequalities, it would be the preferred intervention under the standard cost-effectiveness based resource allocation decision making framework.

While all the three configurations of the screening programme compared are health inequality increasing, augmenting the current screening programme with a targeted enhanced reminder reduces screening generated population health inequality whereas augmenting the current screening programme with a universal basic reminder increases screening generated population health inequality as compared to the standard screening programme alone. It is important to acknowledge that while some aspects of the "intervention generated inequality" due to the screening programme are amenable to redesign of the programme, focusing on equalising uptake of gFOBT and follow up colonoscopy for example, other aspects such as the inequalities arising through differing rates of morbidity and other cause mortality (factors not related to bowel cancer directly) interact with the screening programme but fall out with the scope of any redesign of the programme.

To evaluate which of the screening strategies we prefer in our cost-equality analysis framework we combine our objectives of increasing population health and decreasing population health inequality by means of social welfare indices. Our results show that at low levels of inequality aversion the preferred screening strategy is the universal basic reminder in addition to the standard screening programme and that at higher levels of inequality aversion the preferred screening strategy is the targeted enhanced reminder in addition to the standard screening programme.

The decision of which strategy we prefer depends not only on our level of inequality aversion but also on our social value judgements about the fairness of variation associated with different population characteristics. It is important to acknowledge that the assumption that all variation in health is unfair is just one among many possible sets of value judgements (one out of eight in our case study) and is not in any way a neutral or obvious position to take. We have seen from our case study that our choice of preferred screening strategy is sensitive to both the social value judgements made and the level of inequality aversion assumed.

The cost-equality framework outlined in this paper demonstrates how distributional concerns can be taken into account when evaluating population health programmes. Transparently incorporating value judgements to focus distributional concerns on only the variation in health deemed unfair is a key part of the proposed framework. This form of analysis is particularly relevant when considering redesign options for population health programmes to ameliorate "intervention generated inequalities" as in the case of the NHS BCSP. Data requirements for such analyses are non-trivial but as we have seen, with plausible

assumptions made where necessary and appropriate use of sensitivity analysis, cost-equality analysis is possible in a real world setting. More empirical work is required to determine a realistic distribution of opportunity costs (plausibly reflecting the impact of likely disinvestment decisions in the health service) and to elicit reasonable ranges of values for societal levels of absolute and relative inequality aversion as well as social value judgements on what should be deemed as fair and unfair variations in health.

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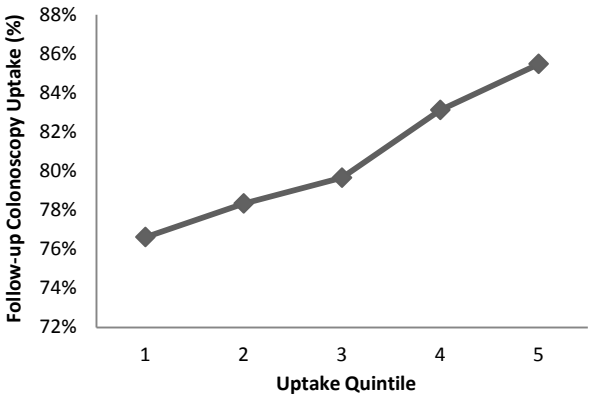
Appendix



Changes to model	Assumptions made	Data sources used
Mortality adjustment by age, sex and social class	NS SEC to IMD mapping	ONS Longitudinal Study
HRQL/Morbidity adjustment by age, sex and social class	LE to DFLE ratio can be used to make social class adjustment	Population EQ5D values ONS General Lifestyle Survey
gFOBT uptake adjustment by age, sex and ethnicity	Pilot study results can be generalised to national programme	Pilot study evaluation 3rd round
Colonoscopy adjustment by age, sex and ethnicity	Pilot study results can be generalised to national programme	Pilot study evaluation 3rd round
Population of subgroups	Independence between groups in pilot study as numbers only available by one variable at a time Population in pilot representative of population in general	Pilot study evaluation 3rd round
Distribution of opportunity cost	Equally distributed among all members of the population	No data
Intervention costs and effects	Constant costs and effects on uptake in absolute terms on all recipient population	Hewitson, P., Ward, a M., Heneghan, C., Halloran, S. P. & Mant, D. Primary care endorsement letter and a patient leaflet to improve participation in colorectal cancer screening: results of a factorial randomised trial. *British journal of cancer* **105**, 475–80 (2011)
All other factors equal between groups	Incidence, severity, costs per episode etc. all equal	No data