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Universal or targeted cardiovascular screening? Modelling study using a sector-specific distributional cost effectiveness analysis

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ABSTRACT

Distributional cost effectiveness analysis is a new method that can help to redesign prevention programmes by explicitly modelling the distribution of health opportunity costs as well as the distribution of health benefits. Previously we modelled cardiovascular disease (CVD) screening audit data from Liverpool, UK to see if the city could redesign its cardiovascular screening programme to enhance its cost effectiveness and equity. Building on this previous analysis, we explicitly examined the distribution of health opportunity costs and we looked at new redesign options co-designed with stakeholders. We simulated four plausible scenarios: a) no CVD screening, b) 'current' basic universal CVD screening as currently implemented, c) enhanced universal CVD screening with 'increased' population-wide delivery, and d) 'universal plus targeted' with top-up delivery to the most deprived fifth. We also compared assumptions around whether displaced health spend would come from programmes that might benefit the poor more and how much health these programmes would generate. The main outcomes were net health benefit and change in the slope index of inequality (SII) in QALYs per 100,000 person years. 'Universal plus targeted' dominated 'increased' and 'current' and also reduced health inequality by −0.65 QALYs per 100,000 person years. Results are highly sensitive to assumptions about opportunity costs and, in particular, whether funding comes from health care or local government budgets. By analysing who loses as well as who gains from expenditure decisions, distributional cost effectiveness analysis can help decision makers to redesign prevention programmes in ways that improve health and reduce health inequality.

1. Introduction

There is an international agenda around cardiovascular disease (CVD) prevention, with substantial screening programmes in many countries including Japan, Scotland and the United States. However, the optimal composition and implementation of a CVD screening programme remains unclear. One such example is in England ("NHS Health Checks") where there is a debate over whether the programme is cost effective and/or equitable. There are concerns that screening programmes may tend to increase health inequalities, insofar as uptake is disproportionately higher among people from socially advantaged groups, a phenomenon known as 'intervention generated inequality' (Lorenc et al., 2013).

1.1. NHS Health Checks

The English cardiovascular screening programme (NHS Health Checks), has been implemented in England from April 2009 onwards and around 5.8 million people in England participated from April 2014–May 2018, 37% of those eligible (Public Health England, 2018). Cardiovascular screening is offered on a cycle, with people invited once every five years starting from their 40th birthday. Most local government public health teams commission this programme from local General Practitioners (GPs, family doctors).

One of the objectives of cardiovascular screening is to tackle health inequalities but the true equity impact of these programmes has not been established. In the present study we looked at equity impacts as well as overall effectiveness, as recommended by several methods

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Table 1
Detail of Modelled Health Check scenarios with 4 sets of alternate assumptions around health production costs.

Scenario	Main assumptions	Intervention costs	Health production costs
Current (all assumptions were based on evidence from local audit)	Coverage: 13.8% Uptake: 32.3% Prescription rate: 9.1% (low risk) 25.8% (middle risk) 41.7% (high risk)	£5.11 per invitation £13.28 per participant	1a. £13000/QALY unadjusted for deprivation 1b. £13000/QALY adjusted for deprivation 2a. Hybrid of £13000/QALY NHS medical spend and £2000/QALY Public Health spend, unadjusted for deprivation
Increased (coverage and uptake assumptions were based on existing targets)	Coverage increased from 13.8% to 20% Uptake increased from 32.3% to 66% Prescription: 9.1% (low risk) 25.8% (middle risk) 41.7% (high risk)	£5.11 per invitation £15.00 per participant	2b. Hybrid of £13000/QALY NHS medical spend and £2000/QALY Public Health spend, adjusted for deprivation
Universal plus targeted (includes current) (based on existing targets to deprived areas)	Coverage: 20% for the most deprived national IMD fifth and 13.8% for all other fifths Uptake: 66% for the most deprived national IMD fifth and 32.3% for all other fifths Assumes risk profile of attendees in the most deprived national IMD is similar to risk profile of the population. Prescription: 9.1% (low risk) 25.8% (middle risk) 41.7% (high risk)	£5.11 per invitation £15.00 per participant	

guides (Claxton et al., 2014; Sanders et al., 2016). Cookson et al. (2017) outlined the main methodologies for incorporating equity impacts into cost effectiveness analysis (CEA): equity impact analysis, where distributional impacts on different groups are analysed; and equity trade-off analysis, where trade-offs between improving total health and reducing health inequality are explicitly quantified, for example by counting the total health opportunity cost of pursuing a more equitable policy or by using an equity parameter that represents commissioners' degree of concern for reducing health inequality. There are examples of equity trade-offs with programmes like bowel cancer screening being a ‘win-lose’ - cost effective but increasing inequalities (Asaria et al., 2015), while treatments for mesothelioma may be a ‘lose-win’, having a high incremental cost per QALY, but reducing inequalities (Shah et al., 2013). The challenge is identifying whether current or future Health Checks scenarios are ‘win-wins’; ‘win-lose’; ‘lose-win’; or ‘lose-lose’.

In the present analysis, we build on our previous study which found that targeting health checks to deprived populations would be more cost effective and equitable than having a universal offer (Kypridemos et al., 2018). Our previous study modelled change in slope index of inequality (SII) and incremental cost effectiveness ratios (ICERs) but did not factor in health foregone from healthcare spend. The present study goes further by including sector-specific estimates of health foregone from taking money away from other medical and public health programmes. In England, this health production cost ratio may be around £2000/QALY for public health programmes (Owen et al., 2011, 2017) which are typically commissioned by local government, and around £13000/QALY for medical interventions in the NHS (Claxton et al., 2013). However, few studies consider differential sectoral health production costs in this way. Health production costs may also be adjusted for deprivation as people from deprived areas use more health resources, for example NHS spending is 20% higher in the most deprived quintile group, so for every unit of cost diverted, a greater proportion of the health foregone may fall to this group (Asaria et al., 2016). We wanted to test whether assumptions about sector-specific health production costs, and socioeconomic group-specific health production costs would change the results of which scenario was most cost effective. Often, health foregone from diverted spend is not factored into cost effectiveness analysis in this way, including in our previous study (Asaria et al., 2016).

This study therefore aims to show how this novel set of methods can be used in practice to redesign a city-wide cardiovascular screening programme.

2. Methods

2.1. Overview

The $\text{IMPACT}_{\text{NCD}}$ model is a dynamic, stochastic, microsimulation model with health economic outcomes (costs and QALYs) measured across socioeconomic groups (deprivation quintiles or fifths). It has been described and validated previously (Kypridemos et al., 2016).

2.2. Data sources

The $\text{IMPACT}_{\text{NCD}}$ model was populated with data projecting Liverpool demographics (by age, sex, and national Index of Multiple Deprivation quintile groups, QIMD). A subsample of Health Survey for England (HSE) participants living in Northwest England was utilised to estimate current and past population exposures to seven CVD risk factors; inadequate fruit & vegetable consumption, physical inactivity, smoking, excess body mass index (BMI), hypertension, high cholesterol, and diabetes mellitus, for years 2002 to 2014. Then, past risk factor exposures were projected to the year 2040 stratified by age, sex, and QIMD to estimate future population exposures. Subsequently, the different scenarios were modelled through their effect on these risk factors for selected individuals or the whole synthetic population.

2.3. Co-production of scenarios

Four performance scenarios were designed in collaboration with stakeholders from Liverpool City Council to reflect the real-world decision challenges that they were grappling with. These four scenarios varied the coverage – the proportion of the population invited for a health check every year, and the uptake – the proportion of invitees attending cardiovascular screening. Optimal annual performance would be coverage of 20% (as it is a rolling five year programme with 20% of the population invited each year) and uptake of 100%. However, we used 20% coverage and 66% uptake as a maximum that was considered to be achievable. We compared a ‘no health checks’ scenario with the ‘current’ performance scenario of cardiovascular screening performance in Liverpool (where coverage was 13.8% per year, uptake was 32.3%); a hypothetical scenario of ‘increased’ performance (coverage increased to 20%, uptake increased to 66%); and a hypothetical ‘universal plus targeted’ top-up scenario, where coverage in the most deprived fifth would increase to 20% per year and uptake would increase to 66% per year, but coverage and uptake in the rest of the population would not increase (Table 1).

2.4. Intervention costs

The intervention cost in the 'current' scenario was £5.11 per invitation and £15.00 per attendance. Our stakeholders suggested that the extra effort involved for the hypothetical 'increased' and 'universal plus targeted' scenarios would attract slightly higher costs of £15.00 per attendance than the current cost of £13.28 per attendance. For the 'increased' and 'universal plus targeted' scenarios, changes in performance occurred from 2017 onwards (see Appendix and previous paper for full details of modelling methods).

2.5. Outcomes

The main outcomes were net health benefits (Stinnett and Mullahy, 1998), and change in slope index in inequalities (SII) per 100,000 person-years. We also looked at ICERs (incremental cost effectiveness ratios – incremental net cost per QALY gained) and gross health benefits. QALYs in the model were measured across the whole population aged 30–84 and the quality of life decrements were deficit measures for CVD and diabetes only. We did not include people under 30 or over 84 as CVD prevention has limited impact in those age groups. The costs were intervention costs, and ongoing CVD and diabetes health and social care costs. Costs and QALYs were discounted at 3.5% per annum and adjusted for inflation to 2016 pounds sterling. For socioeconomic status, we used national quintile groups (IMD fifths) of index of multiple deprivation (IMD) scores, based on the small area (lower layer super output area) where individuals lived. We used IMD 2010 which was current when the simulation begins in 2011. When capturing trends, older versions of the IMD were used and assumed to be similar to 2010 version. The dynamic model was run for a 30-year time horizon from 2011 to 2040. This time horizon was chosen to give cardiovascular screening time to imbed and produce health gains.

Net health benefits were calculated in the standard way by combining changes in QALYs with changes in net costs, converted into QALYs based on a health production cost (Kypridemos et al., 2016). For this study, we made two enhancements to standard health economic methods. First, we compared a standard health production cost with a sector-specific hybrid health production cost, to account for the differential health impact of the money diverted from NHS medical budgets, and local government public health budgets. The English Cardiovascular screening programmes are paid for out of local government budgets – the same budgets which also pay for public health programmes like the Healthy Child Programme, drug and alcohol treatment, and smoking cessation. At a broader level, local government also pay for child and adult social care, and contribute to education and policing. For each of the three uptake scenarios we tested four different sets of health production cost assumptions to calculate net health benefits (Table 1). One assumption used £13000 per QALY for all medical and public health costs based on Claxton et al., 2013, while a hybrid assumption used £13000 NHS medical spend per QALY lost and £2000 local government public health spend per QALY lost, with the latter based on the median cost/QALY for public health interventions modelled for NICE from 2006 to 2016 (Owen et al., 2011).

Secondly, we tested whether the results changed if we weight health production costs by deprivation. This recognises that deprived groups use up healthcare more quickly, so any budget diverted may come disproportionately from deprived groups. Therefore, for the two health production cost assumptions (£13000 and hybrid) two additional alternative adjustments were explored for the socioeconomic distribution of health production costs. First, unadjusted, which assumed an equal health burden across IMD fifths, and second, adjusted, where health production costs were based on estimates of the ratio of NHS resource use across IMD quintile groups from 2014/15 (Asaria, 2017). When the health production costs are adjusted for inequalities it means that, when £13000 of health spend was diverted across the whole population, the most deprived fifth lose 12% more of this spend and the resulting QALYs that could have been produced. The rate at which healthcare spend is used is £11,564 per QALY gained in the most deprived fifth, compared with £14,471 in the least deprived fifth. Or in the hybrid scenario when £2000 of public health spend was diverted across the whole, every £1779 diverted takes away a QALY from the most deprived fifth, compared with £2226 per QALY in the least deprived fifth (Stinnett and Mullahy, 1998).

So all together this gave four alternative assumptions for health production costs; 1a. £13000/QALY for both medical and public health spend, unadjusted for inequalities; 1b. £13000/QALY average for both medical and public health spend, adjusted for inequalities; 2a. hybrid of £13000/QALY for medical spend and £2000/QALY for public health spend, unadjusted for inequalities; 2b. hybrid of £13000/QALY for medical spend and £2000/QALY for public health spend, adjusted for inequalities.

To measure equity impacts we used the adjusted reduction in slope index of inequality (SII, the linear regression coefficient) of rates of incremental net health benefit per 100,000 person years across IMD fifths. To account for population size differences in each fifth, each IMD fifth (quintile group) was characterized by a ridit value that corresponds to the average cumulative frequency of the IMD fifth (Bross, 1958). So for example an SII reduction of 0.5 means that the gradient (the estimated linear regression coefficient reflecting the difference between the most and least deprived person) has reduced by 0.5 QALYs/100,000 population. Liverpool has around 60% of its population in the most deprived quintile group. Because the Liverpool population had less than 0.5% of its population in the least deprived IMD fifth nationally (quintile 1), comparisons were made only on IMD fifths 2–5, where 5 was the most deprived (see chart in Appendix). This was because even with a 30-year time horizon, the outcomes in quintile 1 were subject to a high level of stochastic uncertainty.

3. Results

The ICERs were reported in our previous paper and appendices and are shown in Table 2 (Kypridemos et al., 2018a). Compared with a 'no Health Checks' scenario over a time horizon of 30 years from 2011 to 2040, the incremental cost effectiveness ratio (ICER) of the current Health Checks scenario was approximately £11,000 per QALY, £7400 per QALY for the 'increased' scenario, and £1500 per QALY for the 'universal plus targeted' scenario. Reducing the time horizon to 20 years increased these ICERs to around £21,000 per QALY for the current scenario, £13000 per QALY for the 'increased' scenario, and £14,000 per QALY for the 'universal plus targeted' scenario. Compared with the current Health Checks scenario over a 30 year time horizon, the ICER for the 'increased' scenario was dominant (£1900 saved per QALY gained), while the 'universal plus targeted' scenario was also dominant – it was cheaper (cost £2million less) and more effective (delivered 280 more QALYs). The 'universal plus targeted' scenario also dominated the 'increased' scenario – it cost around £3million less and delivered 150 more QALYs. Over 20 years, 'increased' was dominant when compared to 'universal plus targeted', indicating that the 'universal plus targeted' scenario takes more than 20 years to become the dominant scenario. These results are presented in more detail in the previously published findings paper, which also includes additional scenarios (Kypridemos et al., 2018a).

3.1. Change in outcomes when using different health production costs

Fig. 1 shows the gross health benefits (total QALYs gained per 100,000 person years only, irrespective of costs) and SII reduction for the three scenarios with 50% uncertainty intervals, or interquartile ranges. The gross health benefits ranged from 2.4 QALYs (95% Uncertainty Interval −4.5 to 11.1) per 100,000 person years for the

Table 2

Modelled results of scenarios: Net health benefits (QALYs gained per 100,000 person-years), change in SII in net health benefits (QALYs per 100,000 person years), median net costs, median incremental QALYs gained, and median ICER, for three Health Check scenarios (current, increased, universal plus targeted [shown as 'targeted']), compared with 'No Health Checks'. Modelled data for Liverpool, 2011-040. Shown for £13000 per QALY health production cost, and hybrid health production cost (£2000 for Public Health and £13000 for NHS medical spend).

Scenario	Health production cost				Median net costs	Median incremental QALYs gained	Median ICER
	£13000		Hybrid				
	Median change in SII in NHB (QALYs per 100,000 person years)	Median net health benefit (QALYs per 100,000 person years)	Median change in SII (QALYs per 100,000 person years)	Median net health benefit (QALYs per 100,000 person years)			
Current unadjusted	−6.469	−0.493	12.495	−19.45	£3,438,881	218	£10,608
Current adjusted	−7.259	−0.755	6.472	−21.01			
Increased adjusted	−0.649	−0.043	13.448	−37.65	£4,397,549	360	£6654
Increased unadjusted	0.431	0.226	23.706	−34.84			
Targeted adjusted	11.780	4.497	−14.896	−27.58	£1,277,495	498	£1436
Targeted unadjusted	11.787	4.476	−6.322	−24.84			

All scenarios are compared with counterfactual of no Health Checks.
Median ICERs are based on joint distribution of costs and incremental QALYs, which is why they do not equal [median costs] divided by [median QALYs].
QALYs; quality adjusted life years.
ICER; Incremental Cost Effectiveness Ratio (cost per QALY gained).
SII; slope index of inequality.
NHB; net health benefit.

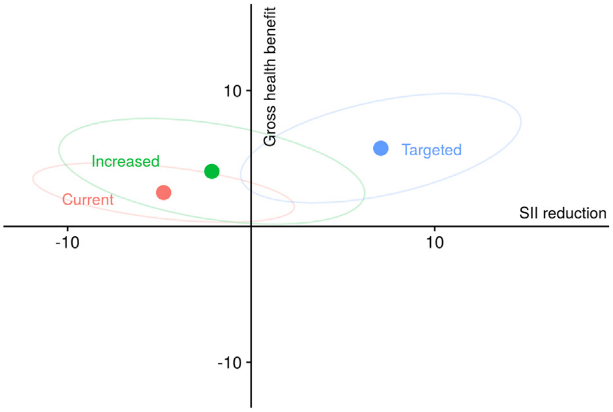

Fig. 1. Gross health benefits (Net QALYs gained per 100,000 person-years) and change in SII in net QALYs gained per 100,000 person years for three Health Check scenarios (current, increased, universal plus targeted [shown as 'targeted']), compared with 'No Health Checks' scenario. Modelled data for Liverpool, 2011–2040. Ellipses depict 50% uncertainty intervals.

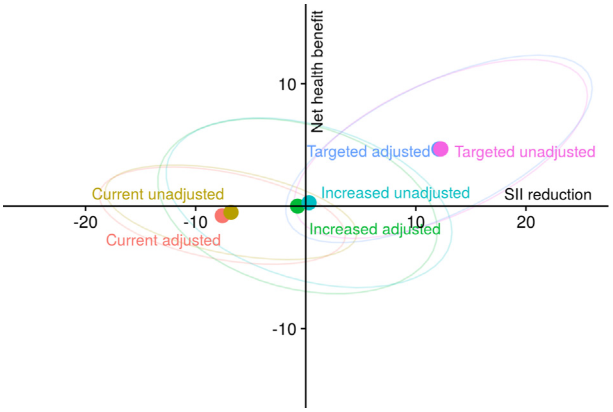

Fig. 2. Net health benefits (QALYs gained per 100,000 person-years) and change in SII in net health benefits (QALYs per 100,000 person years) for three Health Check scenarios (current, increased, universal plus targeted [shown as 'targeted']), compared with 'No Health Checks'. Modelled data for Liverpool, 2011–040. Ellipses depict 50% uncertainty intervals. Note: based on £13000 per QALY health production costs adjusted and unadjusted for deprivation (assumption 1a and 1b).

current scenario to 3.9 (−6.2 to 16.5) for the 'increased' scenario and 5.6 (−4.2 to 18.7) for the 'universal plus targeted' scenario. The gross health benefits were greater for the 'universal plus targeted' than the 'increased' scenario because the 'universal plus targeted' actually engages with a larger number of people who are high risk of CVD in the city. While all three scenarios improve health overall, only 'universal plus targeted' has a positive SII reduction, i.e. it will reduce health inequalities.

Using sector-specific health production costs changed the direction of results. Figs. 2 and 3 show the net health benefit at different health production costs, adjusted and unadjusted for deprivation. With a health production cost of £13000/QALY for both public health and medical spend, the net health benefit for the current scenario was negative (−0.49 QALYs per 100,000 person years) the 'increased' is close to zero (0.23 QALYs/100,000 person-years), while the net health benefit for the 'targeted' scenario is positive at 4.5 QALYs/100,000 person-years.

Using the sector-specific hybrid health production cost of £2000 for public health spend and £13000 for medical spend means that all net health benefit values are negative, meaning that cardiovascular screening would be reducing total population health because the CVD-related health benefits and cost savings would be less than the value of investing in something else. In this sector-specific hybrid scenario the equity impact is reversed; the 'universal plus targeted' moves from being in the North East 'win-win' quadrant in Fig. 2, to the South West 'lose-lose' quadrant in Fig. 3; this is because at £2000 per QALY, the value of the health lost through spend is much more heavily weighted in the equation than the value of the health gains. In the hybrid scenario the 'increased' and 'universal plus targeted' would be assessed as inferior to the 'current' or indeed to a 'no health checks' scenario because the 'increased' and 'universal plus targeted' involve more total public health spend producing a negative return on investment, and therefore the potential health loss is greater.

Changes in the SII in net health benefit between IMD fifths become slightly smaller when using deprivation-adjusted health production costs. For the 'increased' scenario at a health production cost of £13000 per QALY, adjusting for deprivation changes the direction of the SII reduction from 0.43 to −0.65. This is because the ICER for this scenario

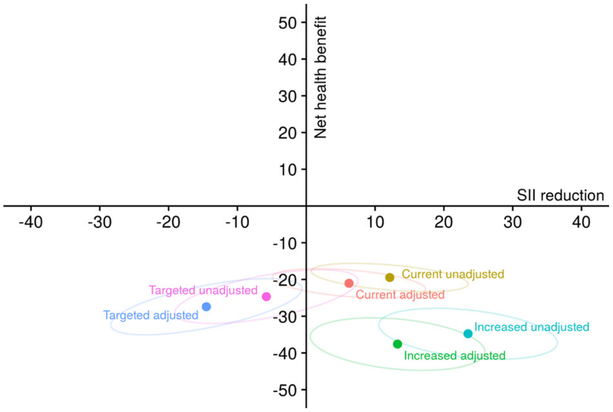

Fig. 3. Net health benefits (QALYs gained per 100,000 person-years) and change in SII in net health benefits (QALYs per 100,000 person years) for three Health Check scenarios (current, increased, universal plus targeted [shown as ‘targeted’]), compared with ‘no Health Checks’ scenario. Modelled data for Liverpool, 2011–2040. Ellipses depict 50% uncertainty intervals. Note: based on a hybrid of £13000 per QALY health production costs for medical spend and £2000 per QALY for public health spend, adjusted and unadjusted for deprivation (assumption 2a and 2b).

is very close to the health production cost (they are both around £13000). Adjusting for inequalities also slightly reduces the change in SII for the ‘targeted’ scenario but it still would be reducing inequalities.

4. Discussion

This study demonstrates how a cardiovascular screening programme might be redesigned if reducing health inequalities was a primary aim. We started with real world data for a city with a high level of CVD risk, which should be a good candidate for cardiovascular screening to improve health and reduce inequalities. Previous studies estimated that cardiovascular screening was likely to be cost effective. Cardiovascular screening in England was prospectively modelled by the Department of Health (DH) in 2008 (Department of Health, 2008) which found an incremental cost-effectiveness ratio (ICER) of £2480 per QALY which may be regarded as being very cost effective. Other papers have found ICERs from £900/QALY (Hinde et al., 2017) to around £23,000/QALY (Crossan et al., 2017). Our results were similar to this, in that cardiovascular screening is likely to be considered cost effective using the traditional NICE threshold of £20000 to £30000 per QALY gained.

However, as in other studies (Chang et al., 2019), this analysis found that the current performance of cardiovascular screening in Liverpool is not equitable and may not even be cost effective depending on the health production cost or ‘shadow price’ applied. If performance was increased (more higher risk people attending and given lifestyle advice or medication), then the programme would be more likely to be cost effective over the period studied, but would still increase inequalities (it could be a win-lose). However, if cardiovascular screening were targeted to the most deprived fifth, it could be a win-win; this would increase the cost effectiveness and reduce inequalities.

This study adds to the literature that the choice of ‘exchange rate’ between health production cost and QALYs, and the decision to consider the distribution of health production costs, can change the direction of the results. So for the current scenario of cardiovascular screening implementation if we assume that each £13000 diverted from NHS medical spend is one QALY lost (based on Claxton et al., 2013), the programme produces a net health loss. This loss becomes even greater if we combine this with an assumption that £2000 diverted from public health means one QALY lost (based on Owen et al. (2011)). Under this hybrid scenario the equity impact is reversed, because any health gains are outweighed by the more equitable health gains that may be achieved by spending the money on another public health programme. Our study is the first to apply sector-specific opportunity costs to distributional cost effectiveness analysis in this way and demonstrates how it can make a huge difference to the direction of the results.

Ongoing work to establish the true marginal cost of a QALY in a healthcare system, or in public health, will therefore be crucial for decision makers in knowing whether interventions such as cardiovascular screening represent value for money. If we assume that every £2000 of public health spend achieves one QALY, then increasing investment in cardiovascular screening would not be cost effective. And if we assume that current public health spend is used up more quickly by deprived groups, then increasing investment in cardiovascular screening will exacerbate health inequalities. A recent working paper estimated the marginal incremental cost effectiveness ratio for local authority public health spend as £3800 per QALY (Martin and Lomas, n.d.) so the true figure is likely to be closer to £2000 than £15,000.

This study has shown how considering the distribution of health gains foregone across deprivation groups can change the direction of the results in terms of the equity impact of healthcare programmes, particularly if the ICER is very close to the health production cost. In the UK, it is rare that programmes are funded out of new money. Researchers should therefore consider the losers as well as the beneficiaries from any investment that is displaced to fund a programme; for instance, cutting smoking cessation programmes to invest in cardiovascular screening. Diverting money from a programme that reduces health inequalities to one that does not means that people in deprived areas lose out twice.

Non communicable diseases like cardiovascular disease are the leading cause of death and disability globally, including now in low income countries. Health economies have got better at improving survival, but less good at prevention, hence people are living longer with multiple conditions. Preventing disease and delaying the onset of ill-health is urgently required to stem demand for health and care services. Alongside structural interventions, screening programmes like the English Health Checks programme have potential but this evidence adds to the literature that such programmes should adopt ‘proportionate universalism’ in targeting in proportion to need.

4.1. Strengths

A strength is that the dynamic model measures differences in costs and outcomes over the whole running time of the model so we can determine how long the programme takes to become cost effective. Our dynamic model may find cardiovascular screening is less effective than other studies because key CVD risk factors are generally showing a secular trend of reducing over time.

4.2. Limitations

Though the model includes risk of death from all causes, this study only uses a deficit measure comparing QALYs lost and gained from CVD and diabetes and through ageing, not from other specific diseases. Furthermore, Liverpool only has a very small number of people in the most affluent IMD fifth which means that the slope index of inequalities was only measured for fifths 2–5. One way of accounting for this would have been to use local deprivation quintiles for Liverpool instead of national. However, this was not possible as some model inputs came from national datasets.

4.3. Implications for further research

Future studies may use a social welfare function (SWF) that maps from the net health benefits for each fifth to the overall net health benefit to society. This becomes more important when choosing the best strategy from several ‘win-win’ scenarios. One study using an online survey found that the general population in England weighed health gains for the most deprived fifth around 7 times greater than in the least deprived (Robson et al., 2017).

Future studies of cardiovascular screening could model inequalities between ethnic groups, gender differences, or other PROGRESS-Plus factors (Welch et al., 2012). Understanding more about the drivers of inequalities in health spending (e.g. supply, demand, compressed years) may tell us more about how the health foregone from disinvestment varies by socioeconomic group. Understanding more about what GPs need to do to increase uptake in deprived groups, and the true additional costs of 'going the last mile' to get the most vulnerable people to attend Health Checks would be valuable.

5. Conclusions

Based on real world data from Liverpool and considering sector and deprivation specific opportunity costs, current implementation of universal cardiovascular screening does not reduce inequalities. Deprived populations could therefore lose out twice, as cardiovascular screening programmes may be favoured over other programmes that would actually reduce inequalities. In contrast, redesigning with a universal plus targeted approach might be more cost effective and would reduce inequalities. Most importantly, this study has shown that understanding the true opportunity costs for different sectors of the economy is important as it can vastly affect the cost effectiveness calculation.

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Ethics committee approval

As this paper is a synthetic population model which re-uses routine audit data and other survey data, ethics committee approval was not sought or given.

Data sharing

Data are available from the corresponding author. In addition, model methods are published online at https://github.com/ChristK/IMPACTncd_Liverpool.

Transparency declaration

The lead author (the manuscript's guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Declaration of competing interest

The authors declare that they received some funding from Liverpool City Council and from NIHR for this piece of work. Prof Cookson has received other grants from NIHR that are not relevant to this piece of work. There were no other conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.105879.

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