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Research Article

Accounting for Needs in Geographical Health Care Resource Allocation

Ben Barr[1*] Chris Kypridemos[1] Anna Head[1] Miqdad Asaria[2] Laura Anselmi[3] Matt Sutton[3] Chris Bentley[4] and Richard Cookson[5]

[1]Department of Public Health, Policy and Systems, University of Liverpool, Liverpool, UK
[2]Department of Health Policy, London School of Economics and Political Science, London, UK
[3]Division of Population Health, Health Services Research and Primary Care, School of Health Sciences, University of Manchester, Manchester, UK
[4]Independent Consultant
[5]Centre for Health Economics, University of York, York, UK

[*]**Corresponding author** benbarr@liverpool.ac.uk

Published April 2026
DOI: 10.3310/GJBB0820

Abstract

Background: Many countries use geographical funding formulae to distribute public funds for health care to local planning areas in proportion to need. In England, these aim to distribute resources in proportion to all healthcare needs regardless as to whether these are currently met or unmet. The National Health Service also has an additional objective to allocate resources to reduce health inequalities (i.e. differences in health between socioeconomic groups). Adjusting for unmet needs could help achieve this second objective, if a greater proportion of needs are unmet in disadvantaged socioeconomic groups with poorer health compared to more advantaged socioeconomic groups. Alternatively, if there are greater unmet needs for relatively expensive conditions that tend to affect older age groups (e.g. cancer), this could lead to a greater proportion of needs being unmet in more advantaged socioeconomic groups, who will tend to be older due to greater life expectancy. Adjusting for unmet needs would then lead to allocation of a greater share of resources to these more affluent populations with better health, potentially increasing health inequalities. It is, however, unclear how met and unmet healthcare needs should be measured in these formulae and how better accounting for unmet needs influences health inequalities.

Aim: We outline a framework for estimating the relative need in geographical healthcare resource allocation and show how the distribution of needed resources between local health planning areas in England changes when accounting for unmet needs due to underdiagnosis for 11 long-term conditions.

Design: We derive a synthetic data set for all people aged ≥ 30 years in England, in 2018, including age, sex, socioeconomic deprivation, region, local health planning area and whether people have diagnosed or undiagnosed long-term conditions. We calculated the annual primary and secondary care costs for each condition using linked electronic healthcare record data, then estimated needed expenditure for each health planning area for two scenarios: (1) when only accounting for diagnosed cases and (2) including all cases (diagnosed and undiagnosed). We examine how the distribution of need between places changes between these scenarios and the consequences of this for health inequalities.

Results: Based on the estimates of underdiagnosis used, areas with the lowest overall needs tended to have a greater proportion of their needs unmet. Adjusting resource allocation by accounting for these unmet needs due to underdiagnosis would move resources from areas with the highest level of needs to areas with lower overall needs. Moving to this 'fair share distribution' would tend to benefit less deprived areas more than more deprived areas, potentially widening health inequalities.

Conclusion: We show how accounting for unmet needs due to underdiagnosis in allocating resources could widen health differences between more and less deprived areas when underdiagnosis and treatment costs increase with age. Further research is needed to confirm our provisional estimates, but we provide a useful framework for improving

This article should be referenced as follows:
Barr B, Kypridemos C, Head A, Asaria M, Anselmi L, Sutton M, *et al.* Accounting for Needs in Geographical Health Care Resource Allocation. *Health Soc Care Deliv Res* 2026;**14**(17):39–54. https://doi.org/10.3310/GJBB0820

assessments of relative need for healthcare resource allocation. Alternative approaches are likely to be needed where resource allocation policy additionally aims to reduce health inequalities.
Funding: This article presents independent research funded by the National Institute for Health and Care Research (NIHR) Health and Social Care Delivery Research programme as award number NIHR130258.
A plain language summary of this research article is available on the NIHR Journals Library Website https://doi.org/10.3310/GJBB0820.

Introduction

Many countries use geographical funding formulae to distribute public funds for health care to provinces, regions or planning areas.[1] The primary aim of these is to distribute healthcare resources in proportion to need[2] so that each geographical area receives a fair share of funding. For example, Australia, Canada, New Zealand, Italy, Canada and the UK all use geographical funding formula, with the aim of achieving this objective.[1]

There is, however, much debate about what is meant by need for healthcare resources and how it should be measured for the purposes of geographical resource allocation.[3] This is further complicated when considering that some need for healthcare resources is currently met (e.g. receiving appropriate treatment) and some is unmet (e.g. underdiagnosis and underprovision of care). The ethical and practical challenges of unmet need are problematic, because estimations of the amount of need are often based on historical healthcare utilisation data and these data only capture met needs. Systematic biases in estimating relative differences in the amount of need between geographical areas will mean resource allocation fails to respect the fair shares principle of distribution in proportion to need and may lead to discrimination against various groups of people – for example, by socioeconomic status, ethnicity, age, rurality and other equity-relevant characteristics – being baked into and perpetuated by resource allocation policy.

The first geographical resource allocation formula was developed in the 1970s by the English NHS, but relatively, little attention has been applied to defining 'need' in the context of resource allocation either then or since. In 1976, the Resource Allocation Working Party proposed a novel formula for allocating NHS resources to subnational areas in response to 'need', rather than 'supply' or 'demand', using standardised mortality as a measure of need. Need, however, was not explicitly defined nor was it clear how this related to mortality.[2] The current formulae used by the NHS and in other countries to estimate relative differences in need between geographical areas are based on the 'utilisation approach'.[4] This uses data from electronic health records (EHRs) along with estimates of healthcare costs and measures of healthcare supply to estimate need as the predicted annual healthcare cost for each individual, conditional on supply (i.e. holding supply constant). A frequent criticism of this approach is that, as it relies on data from people who have accessed health care, it will only reflect the distribution of needs that are usually met by the health system and this may differ from the distribution of all needed expenditure if some groups systematically have unmet needs, for example if they are undiagnosed.[5–7] It should be noted that as the utilisation approach adjusts for differences in supply, it does account for some unmet needs, where variation in undertreatment is driven by differences in the availability of health care between places. Some biases in the approach will remain, however, particularly in relation to patterns of underdiagnosis. This has led people to propose an alternative 'epidemiological approach', which directly estimates the numbers of people with specific health conditions (diagnosed and undiagnosed) from epidemiological data (e.g. population surveys, risk factor measurements and mortality data). Need is then estimated as the sum of the number of cases in each area, weighted by an estimate of the needed costs associated with each condition.[5,6] The epidemiological approach has also been criticised, largely because data limitations lead to uncertain estimates with limited disaggregation (e.g. by place, age, sex, deprivation, ethnicity and disease severity).[5] It is also unclear what cost weights should be applied when aggregating across cases. Vallejo-Torres *et al.*[5] criticise the approach for assuming costs are undifferentiated across different types of cases when they likely vary, for example, due to differences in severity. But, this is not a necessary assumption of the epidemiological approach but rather follows on from the first limitation of sparse data. In theory, if epidemiological approaches could estimate case prevalence with sufficient granularity (e.g. by age, sex, social class, ethnicity, region, severity and comorbidity) and appropriately differentiated cost weights could be applied, then this criticism would no longer hold.

Both approaches to estimation aim to estimate the levels of need as a function of (1) the numbers of people with various sets of characteristics (e.g. health conditions) and (2) the expected expenditure needed to meet the healthcare needs of people with those characteristics. These estimates of needed healthcare expenditure are then used to allocate budgets to geographical areas according to their share of total national needed healthcare expenditure, that is if a region has 10% of the total estimated

national needed healthcare expenditure, then they should receive 10% of the budget.

Unmet need can be defined as the shortfall between the resources needed by a population to provide a health system's standard package of care to all in the population who can benefit and the healthcare expenditure allocated to that population.[8] Unmet needs in this context is composed of two components – underdiagnosis and undertreatment (or underprovision of care). In other words, there may be a shortfall in the amount of resources allocated to a population because the health system has failed to identify people in the population who can benefit from the standard package of care. Alternatively the health system may have correctly identified people who can benefit but have failed to allocate sufficient resources for all of those identified to receive all of the standard package of care from which they can benefit. Here, underdiagnosis and undertreatment can be defined broadly, with underdiagnosis including failure to identify any relevant characteristics, including risk factors and diseases, and undertreatment including insufficient provision of any services within the standard package, including preventative services, or the provision of services of an inadequate quality. These two components are reflected in the two components of resource allocation formulae – the population characteristics that are predictors of need and the costs associated with these characteristics. A shortfall between resources needed and resources allocated results from allocation formulae not accounting for some characteristics that are predictors of need (e.g. undiagnosed conditions) and/or underestimation of the costs associated with these characteristics. Refinements in this measurement aim to improve the identification of appropriate characteristics and/or more accurate measurement of the expected needed healthcare costs associated with those characteristics (e.g. removing supply-induced patterns of costs). These improvements should then shift the distribution of resources to equalise the proportion of needs that are unmet between populations, so resource distribution is closer to a 'fair share', where resources are allocated in proportion to needs. In the analysis within this paper, we only focus on unmet needs related to underdiagnosis, as an illustration of this approach.

Distribution of resources in proportion to need is, however, not the only objective of geographical public healthcare funding policy. In England, the NHS additionally has an objective of allocating resource to geographical areas to reduce health inequalities[9] (differences in health between more and less socially advantaged groups that are systematic, avoidable and unfair).[10] Accounting for unmet needs and allocating resources to reduce health inequalities are often wrongly assumed to be one and the same issue. For example, in the UK, a simple formula adjustment using avoidable mortality, applied to 10–15% of the budget, conflates the two issues.[3] This adjustment was originally introduced to 'contribute to the reduction of avoidable health inequalities'. At the time, it was highlighted that this objective was not necessarily compatible with the distribution of resources in proportion to need, nor with the objective of maximising health gain. Subsequently, this adjustment has been referred to as an adjustment for both unmet need and health inequalities even though these objectives may conflict, as we highlight later.

The extent to which addressing unmet needs in resource allocation will affect health inequalities (i.e. whether it narrows or widens the gap in health status between more deprived populations with poorer health and more affluent populations with better health) will depend on the distribution of the shortfall between actual expenditure and needed expenditure between these populations. It may be the case that more deprived populations in the UK have worse access to health care, leading to a lower probability of diagnosis when people develop health conditions, and subsequently, inadequate treatment once diagnosed, and there is a greater gap between actual expenditure and needed expenditure in these populations compared to more affluent populations. Assuming that healthcare expenditure leads to some health benefits, then allocating a greater share of resources to these deprived populations to account for these unmet needs would reduce health inequalities. It could, however, be the case that people with health conditions, that are more prevalent at older ages (e.g. dementia and cancer), have a lower chance of being diagnosed and adequately treated. This could mean that there is a greater shortfall between actual expenditure and needed expenditure in older populations, particularly if diagnosing and treating these unmet needs are relatively more expensive compared to other conditions. As more affluent populations with better health and high life expectancy will tend to have older populations, adjusting for these unmet needs would allocate a greater share of resources to these more affluent populations to account for these unmet needs, leading to further health benefits that would increase health inequalities. Improving resource allocation to achieve an aim of allocating resource in proportion to need could therefore conflict with and potentially exacerbate health inequalities.

This paper is part of a wider study investigating multiple approaches for adjusting NHS allocation formula to account for unmet needs. This wider programme of work included involvement of the public to support the plain English description of the aims and methods used in the

NHS resource allocation process. In this paper, we aim to clarify definitions of need for health care relevant to the geographical allocation of resources within a publicly funded healthcare system, such as the NHS, that aims to share resources in proportion to need. We then present a simple framework for thinking about estimating relative need in geographical healthcare resource allocation. We provide a simulation using data on diagnoses, estimates of underdiagnosis and costs from linked national healthcare data for 11 chronic conditions, showing how accounting for unmet needs in allocating resources in proportion to need changes the current distribution in resources between places. We discuss how achieving the objective of allocating resources in proportion to need may conflict with the objective of reducing health inequalities.

Methods

Defining need for health care

A useful starting point for defining the need for healthcare resources is the concept of 'capacity to benefit'.[11] For a healthcare need to be present, the marginal productivity of health care must be positive. That is there should be an expectation of health benefit from consuming further healthcare resources.[12,13] Culyer and Wagstaff highlight that while 'capacity to benefit' is a necessary condition of need, it does not indicate *how much* health care someone needs. They propose a definition for the amount of needed health care as the expenditure required to exhaust a person's capacity to benefit to zero. If marginal capacity to benefit is zero, the amount of need is, according to this notion, also zero.[12,13] This definition is a useful upper bound on the amount of need, but it is a 'Rolls Royce' concept of need that is only attainable for a subset of individuals in society. Within publicly funded universal health systems, there is, however, generally some notion of a standard set of health services that are (or should be) available to all citizens and a set of best practice quality standards. This will vary between health systems and over time. This 'standard package'[8] of health care will be subject to a number of constraints relating to definitions of 'health care' (as opposed to social care e.g.) and to the costs and effectiveness of specific procedures and treatments. This may not be explicitly defined, and policy is often developed 'assuming that whatever is currently on average delivered by the healthcare system is de facto the standard'.[8] We therefore define the need for health care within a publicly funded healthcare system as the resources required to provide this standard package of care for all people in the population who can benefit.

Providing the standard package of health care to everyone who could benefit will likely cost more than the current expenditure, because (1) a proportion of people who could benefit from the standard package of care are not identified by the health system and therefore receive no treatment (undiagnosed need) and (2) some people diagnosed will only receive a proportion of the treatment included in the standard package of care (undertreatment). We, therefore, define unmet need as the relative difference between the resources needed to provide the standard package of care to all in the population who can benefit and the healthcare expenditure allocated to that population.[8]

Estimating needed health care

Estimating the absolute amount of needed healthcare expenditure for each individual in the population can be decomposed into two components. Firstly, a matrix of characteristics (P_{ij}) for each individual i in each subnational area j, indicating, for example, age, sex, morbidities, social characteristics and area-based characteristics of residence, which place them at risk of needing various kinds of care during the year. This could also include intersections between characteristics, for example comorbidities, age–sex interactions and so on. Secondly, a vector of cost weights ($\boldsymbol{w}$) indicating the expected marginal increase in costs from receiving needed services within the standard package associated with each of these characteristics. The absolute needed expenditure for each subnational area (N_j) within a health system is then given by the formula shown in *Figure 1*.

$$N_j = \sum_{i=1}^{n} P_{ij} * w$$

FIGURE 1 Formula showing estimation of needed health care.

Estimating fair shares

The target allocation fair share (S_j) for subnational area j is then estimated as the needed expenditure in area j divided by the sum of needed expenditure across all individuals in all subnational areas. This would allocate budgets to geographical areas in proportion to need, meaning that all areas will experience the same relative level of unmet need.

The current distribution of funding may differ from this 'fair share' allocation as shown by the orange line in *Figure 2*. Adjusting the current resource distribution to one that is in proportion to need would increase funding in the areas where current allocation is below the fair shares

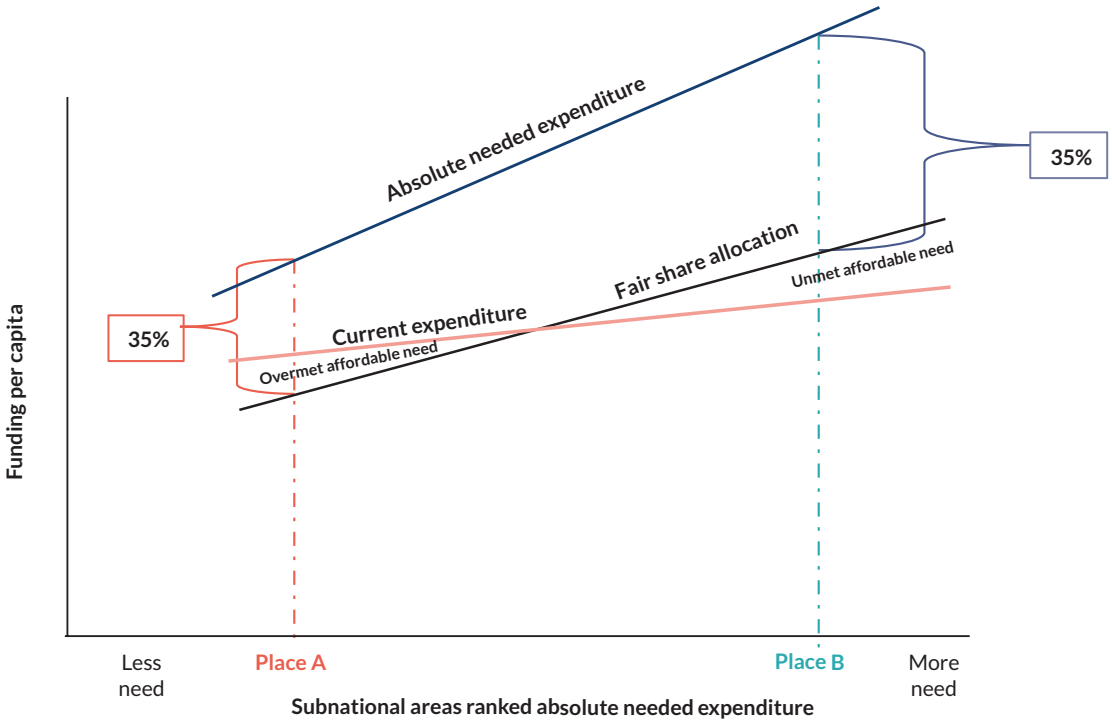

FIGURE 2 Absolute needed healthcare expenditure, fair share allocation based on the proportional approach, overmet and unmet affordable need relative to a hypothetical current allocation. **Note:** This illustrative example assumes a perfectly smooth and linear relationship between absolute needed expenditure and the rank of places, whereas in practice, the relationship is likely to be irregular and non-linear. We also assume that funding is adjusted for unavoidable differences in the cost of providing health care between local sub national areas.

allocation (e.g. Place B) while decreasing funding where current allocation is above the fair shares allocation (e.g. Place A). In the hypothetical example in *Figure 2*, places with greater absolute needed expenditure also have more unmet affordable needs, but this is not necessarily the case. It could be the other way round or there may be a non-linear relationship between current allocation and fair share allocation, as we will see below.

The empirical challenge is then to estimate P_{ij} sufficiently differentiated by relevant characteristics and $\boldsymbol{w}$, adequately reflecting the absolute needed expenditure associated with each characteristic. In current utilisation approach used by the NHS, P_{ij} is derived from EHRs and often includes a very rich set of characteristics (over 700 variables in the case of the secondary care formula in the NHS in England), and $\boldsymbol{w}$ is derived from the average influence of these characteristics in P_{ij} on expenditure conditional on differences in supply between places.[4] The extent that estimated shares reflect the target fair share distribution (as shown in *Figure 2*) will depend on whether P_{ij} includes all relevant characteristics of individuals that influence their need for health care and/or whether the cost weights ($\boldsymbol{w}$) reflect the needed cost (based on the standard package of care) associated with each of those characteristics. Criticism of current utilisation approach used by the NHS is that it is missing data from P_{ij}, for example on people who have not been diagnosed.

Deriving a synthetic data set for diagnosed and undiagnosed conditions (P_{ij})

To illustrate how the geographical distribution of needed healthcare expenditure for 11 conditions (diabetes, hypertension, anxiety/depression, coronary heart diseases, stroke, chronic obstructive pulmonary disease, dementia, breast cancer, prostate cancer, lung cancer and colorectal cancer) may change when additionally accounting for the needed healthcare costs of undiagnosed cases compared to just diagnosed cases, we simulate a data set using empirical estimates of diagnosed prevalence for all individuals aged ≥ 30 years in England from the Clinical Practice Research Datalink (CPRD) and estimates of the probability of disease among the undiagnosed derived from previous research.[14] We focus is on these 11 diseases with a high burden on the UK population according to the Global Burden of Disease project. Not all NHS expenditures can be attributed to specific diseases; the last exercise that attempted to do this was the 2013–4 programme budgeting exercise and based on that data, these conditions account for 80% of all NHS expenditure that could be attributed to specific diagnoses.[15]

Following formula 1 above, we estimate P_{ij} as a set of flags for these 11 conditions for each individual (*i*) in each subnational planning areas (*j*) in England in 2018 [at the time, these were known as Clinical Commissioning Groups (CCGs)]. We use data from 2018 because these were the latest data available for estimates of the probability of diagnosis derived from previous research.[14] We derive this synthetic data set for all people in England in 2018, including information on their age group (30–49, 50–59, 60–69, 70–79, 80+ years), sex (male/female), deprivation quintile of the lower-layer super output area (LSOA) in which they live, their CCG and nine regions (East Midlands, East of England, London, North East, North West, West Midlands, South West, South East, Yorkshire and the Humber). We start with Office for National Statistics population estimates for age and sex groups within each LSOA in England in 2018 and link this with information on the CCG of residence based on 2018 geography, region of residence and level of deprivation for each LSOA using the 2015 Indices of Multiple Deprivation (IMDs). LSOAs are small geographical areas covering the whole of England (32,844 in total), with an average population of 1500 each. The IMD score was split into five quintiles. This provided a data set of 28 million individuals aged ≥ 30 years. We excluded people under 30 years, as diagnosis of these conditions at younger ages may be unreliable. We then imputed into this data set diagnostic flags for each of the 11 conditions based on the diagnosed prevalence taken from CPRD for 450 population segments defined by age group × sex × IMD quintile × region. The individual flags were drawn from a Bernoulli distribution, with the probability reflecting the prevalence rate in the respective population segment. In a similar manner, undiagnosed cases were imputed into this data set for each of the 11 conditions based on the probability of having each condition, conditional on not having a diagnosis for the same 450 population segments defined by age group × sex × IMD quintile × region. Methods for deriving these estimates of underdiagnosis are reported elsewhere using a novel dynamic simulation model.[14] For this illustrative example, we assume that the distribution of these conditions is independent.

Estimating costs weights (*w*) associated with each condition in each population segment

To derive an estimate of the needed healthcare expenditure, including diagnosed and undiagnosed cases and the current expenditure on diagnosed cases, we calculated primary and secondary care costs for each condition using linked CPRD–Hospital Episode Statistics (HES) data. For primary care costs, we calculated individual annual costs based on prescriptions and the number of primary care in-person, home, telephone and telephone triage appointments. All costs are 2019–20 costs. We used Personal Social Services Research Unit 2020 costs per hour of patient contact for general practitioners (GPs) and nurses to cost appointments.[16] We applied these to the latest estimates available for the average length of visit for each appointment type.[16–20] Where the type of staff was unknown, we applied GP costs as per the Productivity of the English National Health Service reports produced by the Centre for Health Economics at the University of York.[21]

For prescription data, we used the NHS Business Authority *British National Formulary* (BNF) SNOMED mapping database to map SNOMED codes to BNF codes,[22] and then for each BNF presentation code, we applied the mean prescription item cost from the 2019–20 prescription cost analysis (PCA). Where BNF codes could not be matched (12% of all prescriptions), we applied the overall mean prescription cost from the PCA (£8.20 per prescription).[23]

For secondary care costs in line with the NHS general and acute formula approach,[24] we applied a cost to each inpatient spell, outpatient attendance and accident and emergency attendance recorded during the financial year 2018–9 (1 April 2018–31 March 2019). We used National Tariff prices 2018–9, where available, or reference costs, or, when also the latter was missing, specialty average. We removed inpatient spells and outpatient attendances with a health resource group, treatment function code or well-baby flag eligible for maternity tariff. We truncated costs at £100,000 to remove outliers, likely removing very high costs associated with specialised care (see *Appendix 1* for validation of costs' estimates).

To derive condition-specific costs within each population segment, we fitted linear regression models in the CPRD linked to HES data, with annual cost as the dependent variable, and region, gender, age group, deprivation quintile, disease diagnosis (binary) and the interactions of disease diagnosis, with age group and deprivation quintile as the predictors. We predicted from these models the cost of each condition within each region/gender/age group/deprivation quintile stratum.

Modelling fair shares

The estimated needed expenditure for each CCG was then estimated as the sum of $P_{ij} * w$, the set of flags for these conditions for each individual (*i*) in each population segment multiplied by the respective cost estimate for each condition (*w*) within each respective population

segment for each CCG (*j*) in England. We initially did this by only including diagnosed cases and then including all cases (diagnosed and undiagnosed) and we examined how the distribution of need across CCGs changes. Assuming a fixed budget (i.e. the expenditure on diagnosed cases), we then allocate this total budget to each CCG based on its share of absolute needed healthcare expenditure and compare the initial distribution (only including diagnosed cases) to this 'fair share' distribution. To investigate potential consequences for health inequalities for such an adjustment, we plot the change in funding that each CCG would experience moving from the current funding to fair shares by the level of deprivation of each CCG. Deprivation was measured by the average IMD[25] of each CCG.

Results

Figure 3 shows the estimated costs (*w*) for each disease by age group and deprivation. Annual costs per case of disease tended to increase with age and deprivation, with large differences between conditions, with some cancers having high costs and less difference by age and deprivation in the average costs per case. The regional pattern (data not shown) shows higher costs in London across all conditions and, to a lesser extent, higher costs in the North West.

Figure 4 shows the absolute estimated needed expenditure, taking into account diagnosed and undiagnosed prevalence and costs associated with each condition (panel 1 – purple line) and the distribution of this expenditure when just based on diagnosed cases (panel 1 – orange line). The total expenditure needed to treat all cases (diagnosed and undiagnosed) is much higher than the expenditure required to just treat those currently diagnosed. Around 63% of needs are currently met and 37% are unmet. Treating these unmet needs would require an 60% increase in the budget. Assuming a fixed budget, however, and sharing out the existing national expenditure on diagnosed cases in proportion to the absolute needed expenditure for each CCG, accounting for diagnosed and undiagnosed cases,

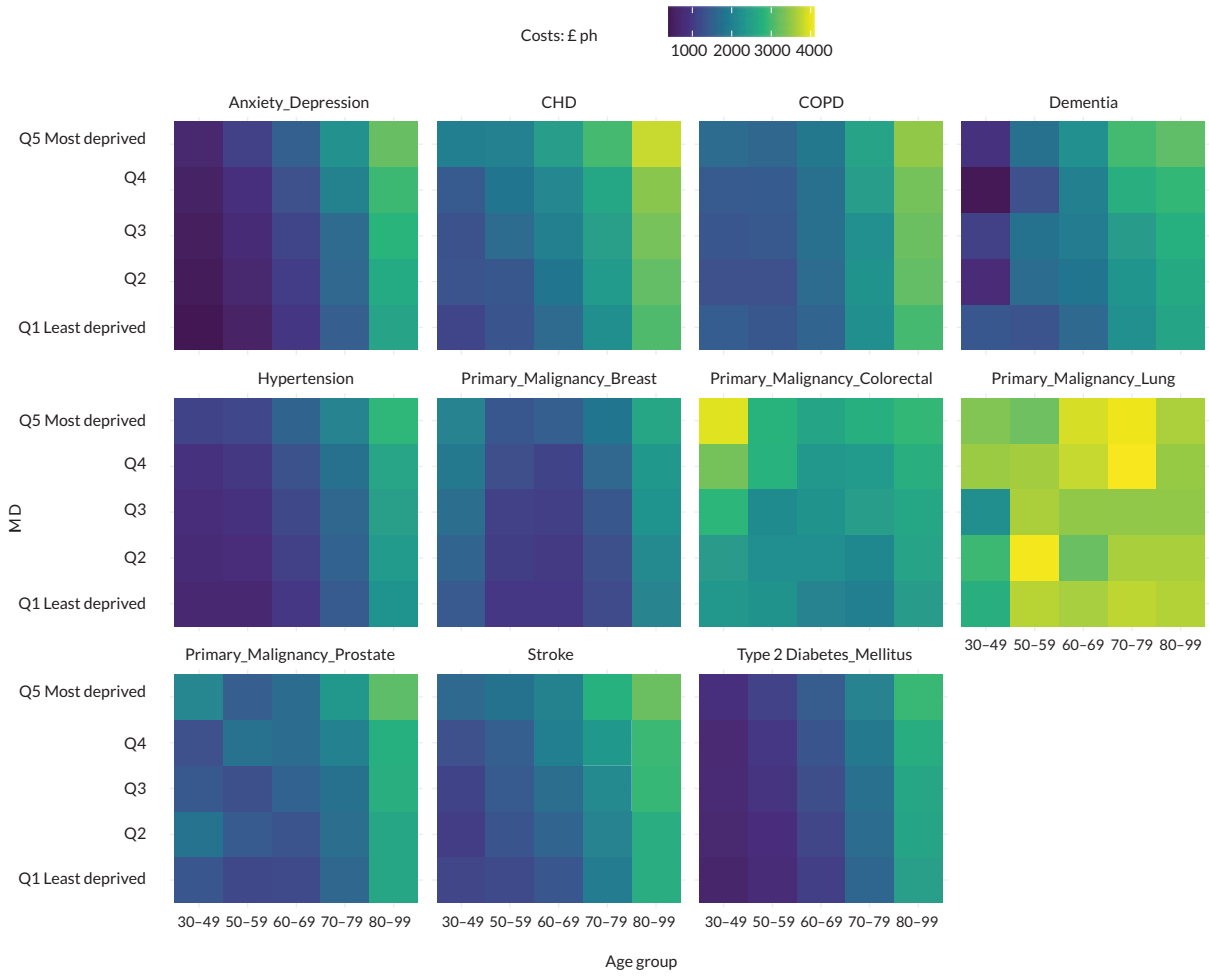

FIGURE 3 Total primary and secondary average annual care per person, with each condition for each age group/deprivation quintile stratum. CHD, coronary heart disease; COPD, chronic obstructive pulmonary disease.

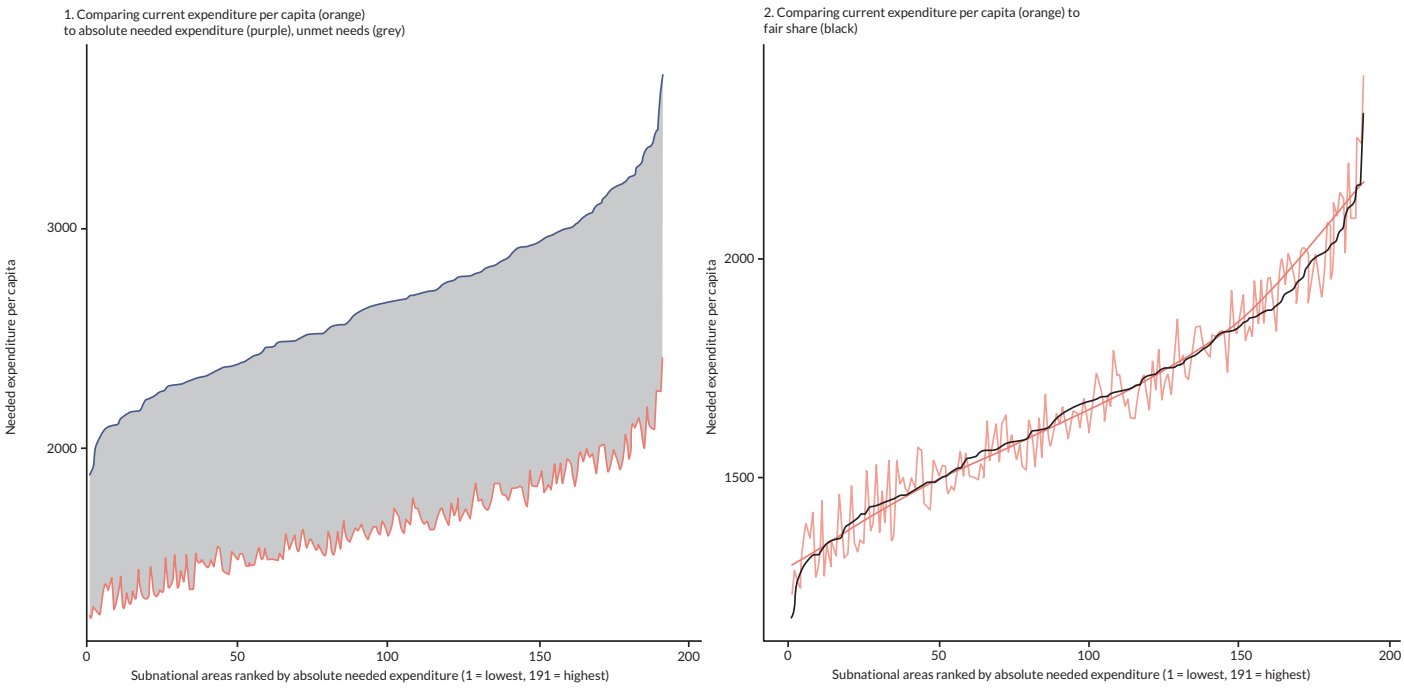

FIGURE 4 Comparing expenditure on diagnosed cases of 11 conditions in each CCG to absolute needed expenditure and fair shares additionally accounting for undiagnosed cases in each CCG.

give the black line in panel 2. The distribution of expenditure based on diagnosed cases is not hugely different from this fair share distribution. It is slightly higher than the fair share distribution for those CCGs with the highest needs and slightly lower than the fair share for CCGs with lower levels of need, although there is quite a lot of variation between individual CCGs. So high-need CCGs, in this example, actually have overmet affordable needs, and lower-need CCGs have unmet affordable needs. Adjusting resource allocation towards one that is in proportion to needs by accounting for these unmet needs due to underdiagnosis would move resources to these lower-need CCGs from CCGs with the highest level of needs.

Figure 5 shows the relative change in funding for each CCG that would result from shifting to an allocation accounting for unmet needs, by the average level of deprivation in each CCG. There is a strong negative relationship with deprivation. Moving to this fair share distribution would tend to benefit less deprived CCGs and shift resources away from the most deprived CCGs.

Figure 6 shows the geographical pattern of estimated unmet needs due to underdiagnosis, that is, the relative shortfall between current spending on diagnosed cases and absolute needed expenditure when accounting for undiagnosed cases. The estimated proportion of needs unmet due to underdiagnosis varies between 32% and 41%. The model indicates lower levels of unmet need due to underdiagnosis in London and lower levels in the North West and higher levels in South outside London.

Discussion

We outline a simple framework for estimating the relative need in geographical healthcare resource allocation, decomposing this into a matrix of characteristics and a set of cost weights. The utilisation and epidemiological approaches to resource allocation are alternative approaches of measuring these two components. Our simulation is illustrative, and it is not intended to provide an alternative to the current NHS formulae used in England.

There are several limitations that would need to be overcome before such an approach could be incorporated into resource allocation. Firstly, the matrix of characteristics in our example is relatively simple, with only 11 conditions being differentiated by age, sex, region and deprivation quintile, with no account taken of the clustering of comorbidities. Given that the patterns of unmet need were different among the disease we included, it is likely that adding more conditions in our modelling could alter the overall patterns of unmet need. However, given that the diseases we modelled were those with the highest burden and expenditure, adding additional diseases may not have had a large effect. In comparison, however, the current NHS formula includes over 700 characteristics. The strength of

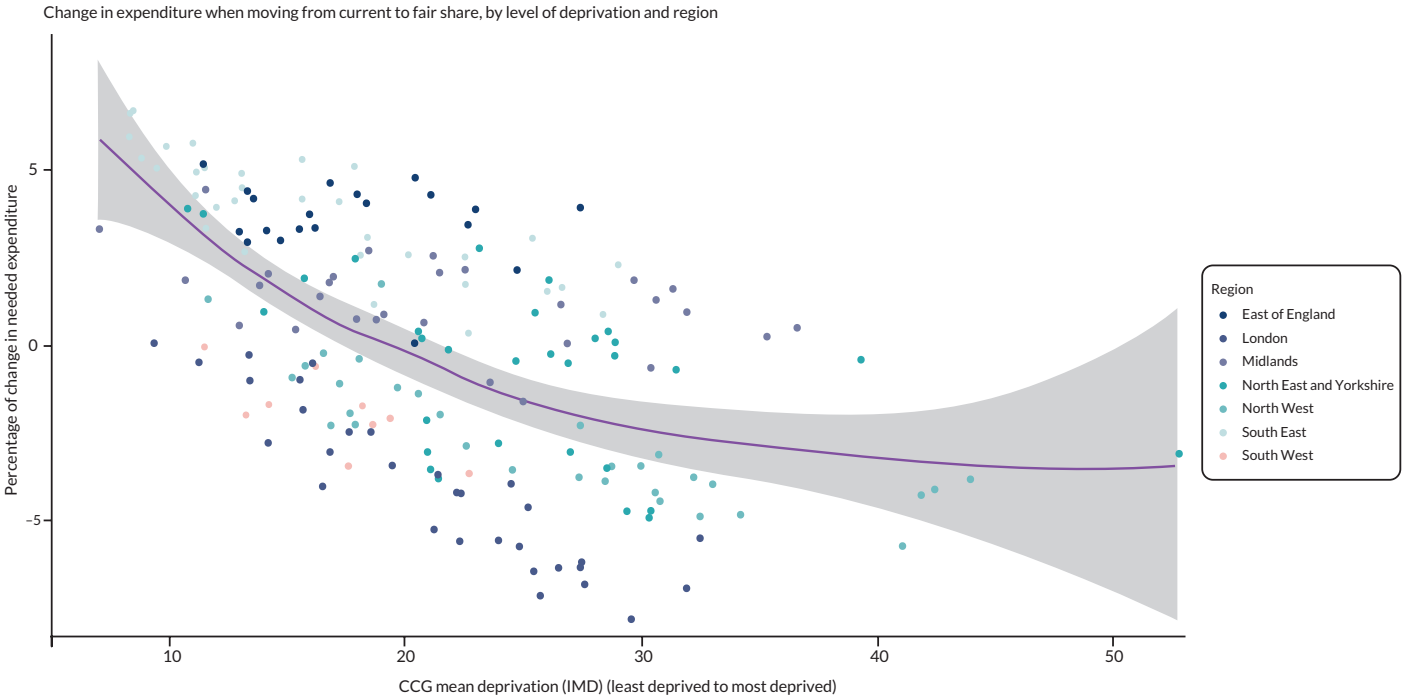

FIGURE 5 Relative change in expenditure in each CCG by level of deprivation when moving from current expenditure to fair share allocation accounting for undiagnosed cases.

using EHRs in these formulae is the richness of the data they provide. It is unlikely that epidemiological models will ever be able to estimate patterns of underdiagnosis to the same level of granularity. Although there will always be a higher level of uncertainty when estimating needs that are missing from EHRs, this is not a reason to not include this information when it is available. There is no reason why utilisation data and epidemiological estimates of underdiagnosis cannot be combined, for example by weighting diagnostic flags in utilisation data by the inverse probability of being diagnosed. This would mean that the current utilisation based formulae could be adjusted for levels of underdiagnosis for specific conditions in specific population groups.

Secondly, we assume that the needed costs for each person with each condition in each population segment are the same as the average costs for people with the same characteristics. This is broadly the same as the approach used in the national formula. The national formula does additionally adjust for differences in costs related to supply, while we were not able to do this, as we did not have indicators of supply in the CPRD data we used. This issue could, however, be addressed relatively easily using data that are available to the NHS. The bigger issue is that average costs may not reflect patterns of needed costs. For example, if some conditions are more likely to be undertreated than others, using average costs as costs weights ($\boldsymbol{w}$) will underestimate the relative needs in populations with higher prevalence of those conditions. This will still be true even if these average costs are conditional on supply. One way that has been proposed for estimating cost weights that better reflect needed costs is to estimate these in a subset of high-performing subregions, as these are more likely to reflect the variation in needed costs than the national average variation in costs which will be biased by poor-performing and more resource-constrained subregions.[26] A further problem when applying costs to undiagnosed cases, as in the case of our model, is that it is difficult to assess what costs would be needed for these cases if they were diagnosed and treated. We assume that these are the same as average costs, but one could argue that they should be higher as there are additional case finding costs, or alternatively lower, as they will tend to, on average, be at an earlier disease stage, than diagnosed cases.

Thirdly, our simulation depends on highly uncertain estimates of underdiagnosis.[27] The patterns observed could therefore relate to inaccuracies in these estimates. It is likely, however, that estimates of underdiagnosis will improve in accuracy and in granularity (e.g. accounting for disease stage) as further data become available; for example, the increasing availability of electronic healthcare data linked to representative biometric population sampling. Our approach, however, provides a framework for combining future estimates with current utilisation approaches to better account for unmet needs.

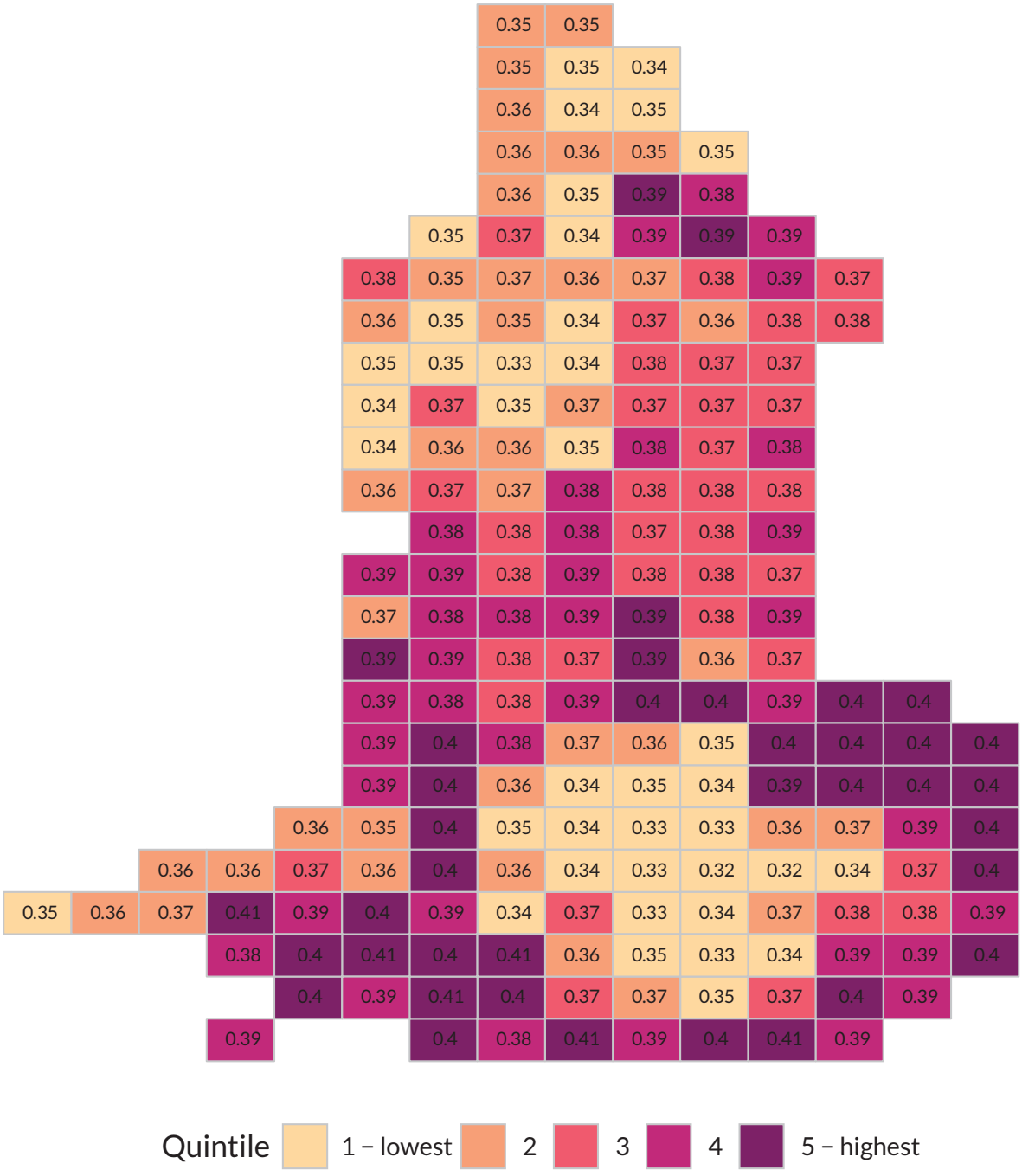

FIGURE 6 Estimates of relative unmet need due to underdiagnosis.

Fifthly, we were not able to include ethnicity in our simulation, as estimates of underdiagnosis were not available broken down by ethnicity. This, however, could be addressed as coding of ethnicity in health records is improved and more data become available to enable more precise modelling of underdiagnosis by ethnic group.

Sixthly, we have used data on diagnoses and estimates of underdiagnosis from 2018, and it is possible that patterns of a diagnosis and underdiagnosis have changed since that time. Additionally, the geographical planning areas used by the NHS in England have now changed from CCGs to larger areas called Integrated Care Boards (ICBs). The methods we outline, however, could be relatively easily updated alongside addressing the other more substantial limitations outlined above in applying this approach within the resource allocation process. The approach to resource allocation has not changed with the establishment of ICBs, with needs estimated at the individual level and then aggregated to the geographical area used in resource

allocation. The same approach could be used when applying the methods we outline here.

Our simulation suggests that unmet needs due to underdiagnosis from these conditions could be higher in less deprived places. This seemingly contradicts other research that has highlighted an inverse care law in access to health care.[28,29] Other research has, however, found that relative levels of underdiagnosis were higher in more affluent groups.[30] Work by Asthana *et al.* using a similar morbidity-based model for Coronary Heart Disease to account for unmet needs also found that this would shift resources away from deprived areas towards older and more rural populations.[6] Our finding of higher levels of unmet needs in more affluent populations is largely because our estimates of underdiagnosis[14] increased substantially with age. Lower probability of diagnosis at older age within conditions or lower probability of diagnosis for conditions that tend to effect older age groups (e.g. cancer and dementia) will tend to lead to more unmet needs in local areas with older populations, particularly if these conditions are associated with high costs. As mean age and deprivation tend to be inversely correlated, due in part to lower life expectancy in deprived areas, this will tend to lead to higher unmet needs in more affluent areas with higher life expectancy. The difference between our findings and previous research may reflect that previous research has not taken account of how unmet needs increase with age, and this may have changed over time as disease burden is increasing concentrated at older ages. As healthcare costs become increasingly concentrated at older ages and differences in life expectancy between affluent and deprived areas widen, this could mean increased unmet needs in more affluent populations with longer life expectancy relative to unmet needs in more deprived areas.

Improving resource allocation formula so that they better meet the objectives of allocating resource in proportion to need could increasingly shift resources from more deprived areas with poorer population health to less deprived areas with better health. As these resources improve health outcomes in these places,[31] this is likely to widen the health gap between more deprived and more affluent places, increasing health inequalities. The objective of equal access for equal need and the objective of reducing health inequalities may therefore conflict.

It is perhaps not surprising that these two objectives can conflict. The principle of proportionality applied in allocating resources to achieve 'equal access for equal need'[2,3] follows a different underlying logic than approaches that aim to maximise equality in health. The logic of proportionality means that everyone's needs should be met to some extent (in proportion), whereas the logic of maximisation means that some people's needs could not be met at all. This principle of proportionality is a simple application of the more general theory of fair distribution known in the philosophy literature as 'proportional satisfaction of claims'.[32,33] The implications of these divergent objectives have rarely, however, been made explicit in healthcare resource allocation policy.

One approach could be for the NHS to make explicit what proportion of the budget is to be allocated with the goal of equal access for equal need and what proportion is allocated to contribute to a reduction in health inequalities, clarifying the formula components that aim to achieve these goals. While this could be seen as a departure from the principle of equal access for equal need,[8] an alternative conception would be to recognise that while we can measure the amount of need as the expenditure needed to provide a set of services, most theories of fair distribution recognise that differences in strength of need claim should also be taken into account.[32] Areas with a greater burden of lifetime illness could be viewed as having a greater strength of need claim, having a stronger claim on the health benefits of healthcare resources than areas with a lesser burden of lifetime illness. The proportion of the budget that is set aside for these separate objectives is a political and democratic decision.[34]

In this paper, we have clarified definitions of met and unmet need for health care relevant to the geographical allocation of healthcare resources, and we present a simple framework that decomposes measurement of healthcare needs into two components – a matrix of characteristics for each individual, and a vector of cost weights indicating the expected marginal increase in costs from receiving needed services associated with these characteristics. Using a simulation, we show how estimates of underdiagnosis of conditions can be incorporated into this framework, showing how accounting for underdiagnosis in this simulation changes the distribution of needed resources. As the estimates of underdiagnosis used indicate a higher level of underdiagnosis at older ages, the effect of adjusting for these unmet needs would be to allocate a greater share of resource to less deprived areas, increasing health inequalities. This indicates that while improvements can be made to formulae to enable the more effective allocation of resources in proportion to the amount of need, these may contradict the other objective of NHS resource allocation – to reduce health inequalities. To maintain its objective to reduce health inequality, it is likely the NHS will need to continue to allocate a proportion of its budget based on a measure of poor population health.

Additional information

CRediT contribution statement

Ben Barr (https://orcid.org/0000-0002-4208-9475): Conceptualisation, Methodology, Formal analysis, Funding acquisition, Supervision, Writing – original draft, Writing – reviewing and editing.

Chris Kypridemos (https://orcid.org/0000-0002-0746-9229): Conceptualisation, Methodology, Formal analysis, Software, Supervision, Writing – reviewing and editing.

Anna Head (https://orcid.org/0000-0002-4577-9869): Methodology, Data curation, Formal analysis, Writing – reviewing and editing.

Miqdad Asaria (https://orcid.org/0000-0002-3538-4417): Conceptualisation, Methodology, Writing – reviewing and editing.

Laura Anselmi (https://orcid.org/0000-0002-2499-7656): Conceptualisation, Writing – reviewing and editing.

Matt Sutton (https://orcid.org/0000-0002-6635-2127): Conceptualisation, Methodology, Funding acquisition, Writing – reviewing and editing.

Chris Bentley (https://orcid.org/0009-0005-9465-7867): Conceptualisation, Writing – reviewing and editing.

Richard Cookson (https://orcid.org/0000-0003-0052-996X): Conceptualisation, Methodology, Funding acquisition, Supervision, Writing – reviewing and editing.

Acknowledgements

We would like to thank the members of the Advisory Committee on Resources Allocation, its Technical Advisory Group and the NHS resource allocations team, in particular Stephen Lorrimer, Heather Ross and Elbereth Puts for their helpful feedback and advice throughout the research programme. We thank Andy Pennington and Luis Filipe for their help with reviewing the literature.

Patient data statement

This work uses data provided by patients and collected by the NHS as part of their care and support. Using patient data is vital to improve health and care for everyone. There is huge potential to make better use of information from people's patient records, to understand more about disease, develop new treatments, monitor safety, and plan NHS services. Patient data should be kept safe and secure, to protect everyone's privacy, and it is important that there are safeguards to make sure that it is stored and used responsibly. Everyone should be able to find out about how patient data is used. #datasaveslives You can find out more about the background to this citation here: https://understandingpatientdata.org.uk/data-citation.

Data-sharing statement

The study did not use any personal data. The data used were accessed through an end-user licence with CPRD. The data controller and processor for CPRD data was CPRD. All data requests should be made to www.cprd.com/data-access.

Ethics statement

The research used anonymised secondary data and did not involve any primary data collection or use of personal data. Ethics approval was therefore not needed based on the advice of the University of Liverpool Research Ethics Committee.

Information governance statement

This study only used anonymised data. As such it did not include any personal information.

Disclosure of interests

Full disclosure of interests: Completed ICMJE forms for all authors, including all related interests, are available in the toolkit on the NIHR Journals Library report publication page at https://doi.org/10.3310/GJBB0820.

Primary conflicts of interest: Ben Barr has received funds through the University of Liverpool from grants from the NIHR, Health Foundation and Economic and Social Research Council. Chris Kypridemos received grants/contracts from The Health Foundation, NIHR and the European Commission and consulting fees from National Cerebral and Cardiovascular Centre of Japan. Chris Kypridemos is a member of NIHR PHR Funding Committee; PHR Prioritisation Committee and PHR Programme Oversight Committee membership. Anna Head received grants from NIHR SPHR and University of Liverpool (PhD Studentship), and The Health Foundation REAL Centre, and received support for travel/meetings from the Society for Social Medicine and Population Health. Chris Bentley received consultancy fees from NIHR Directorate of Healthcare Inequalities Improvement, West Yorkshire Integrated Care Board, Nottingham University support to Leicester and Rutland ICB on Cancer Care; payments or honoraria from King's Fund Leadership for Population Health, Lancashire and Cumbria Population Health Academy, West Yorkshire Integrated Care Board, Liverpool University MPH. Chris Bentley holds a leadership or fiduciary role with Wirral Community Health and Care Trust and is a Member Advisory Committee on Resource Allocation and Chair to its Technical Advisory Group. Richard Cookson has received grants/contracts from Wellcome Trust, UKRI, Danish Centre for Healthy Life

and Wellbeing, University of Bergen, and consulting fees from Genentech, Roche, and Bristol Myers Squibb.

Department of Health and Social Care disclaimer

This publication presents independent research commissioned by the National Institute for Health and Care Research (NIHR). The views and opinions expressed by authors in this publication are those of the authors and do not necessarily reflect those of the NHS, the NIHR, MRC, NIHR Coordinating Centre, the Health and Social Care Delivery Research programme or the Department of Health and Social Care.

This article was published based on current knowledge at the time and date of publication. NIHR is committed to being inclusive and will continually monitor best practice and guidance in relation to terminology and language to ensure that we remain relevant to our stakeholders.

Study registration

This study is registered as researchregistry5731 www.researchregistry.com/browse-the-registry/#home/registrationdetails/5eecddb65ff3ed001789c122/.

Funding

This article presents independent research funded by the National Institute for Health and Care Research (NIHR) Health and Social Care Delivery Research programme as award number NIHR130258.

This article reports research award *Accounting for Unmet Need in Equitable Healthcare Resource Allocation*. For more information about this research, please view the award page (www.fundingawards.nihr.ac.uk/award/NIHR130258).

About this article

The contractual start date for this research was in June 2020. This article began editorial review in April 2025 and was accepted for publication in August 2025. The authors have been wholly responsible for all data collection, analysis and interpretation, and for writing up their work. The Health and Social Care Delivery Research editors and publisher have tried to ensure the accuracy of the authors' article and would like to thank the reviewers for their constructive comments on the draft document. However, they do not accept liability for damages or losses arising from material published in this article.

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List of abbreviations

BNF	*British National Formulary*
CCG	Clinical Commissioning Group
CPRD	Clinical Practice Research Datalink
EHR	electronic health record
GP	general practitioner
HES	Hospital Episode Statistics
ICB	Integrated Care Board
IMD	Index of Multiple Deprivation
LSOA	lower-layer super output area
PCA	prescription cost analysis

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Appendix 1 Cost validation

We compared our consultation costs with the University of York Centre for Health Economics estimates (*Table 1*).[21] Both estimates appear similar, with our costs being slightly lower.

We also compared our prescription costs with those from the NHS Business Services Authority PCA for England, 2019–20.[23] Here, our estimates were somewhat lower; however, the PCA includes all NHS community care settings, whereas our estimates are limited to those from GP records (*Table 2*).

TABLE 1 Comparison between our estimates of GP consultation costs and those by University of York Centre for Health Economics

Version	Contacts/person	Total costs (scaled up)	Cost/person	Cost/contact
York	5.26	11.99 billion	213	40.5
Ours	4.88	10.86 billion	193	39.7

TABLE 2 Comparison between our estimates of GP prescribing costs and those from NHS business services authority PCA

Version	Items/person	Total costs (scaled up)	Cost/person	Cost/item (£)
PCA	20.1	9.2 billion	165	8.21
Ours	16.9	6.3 billion	112	6.62