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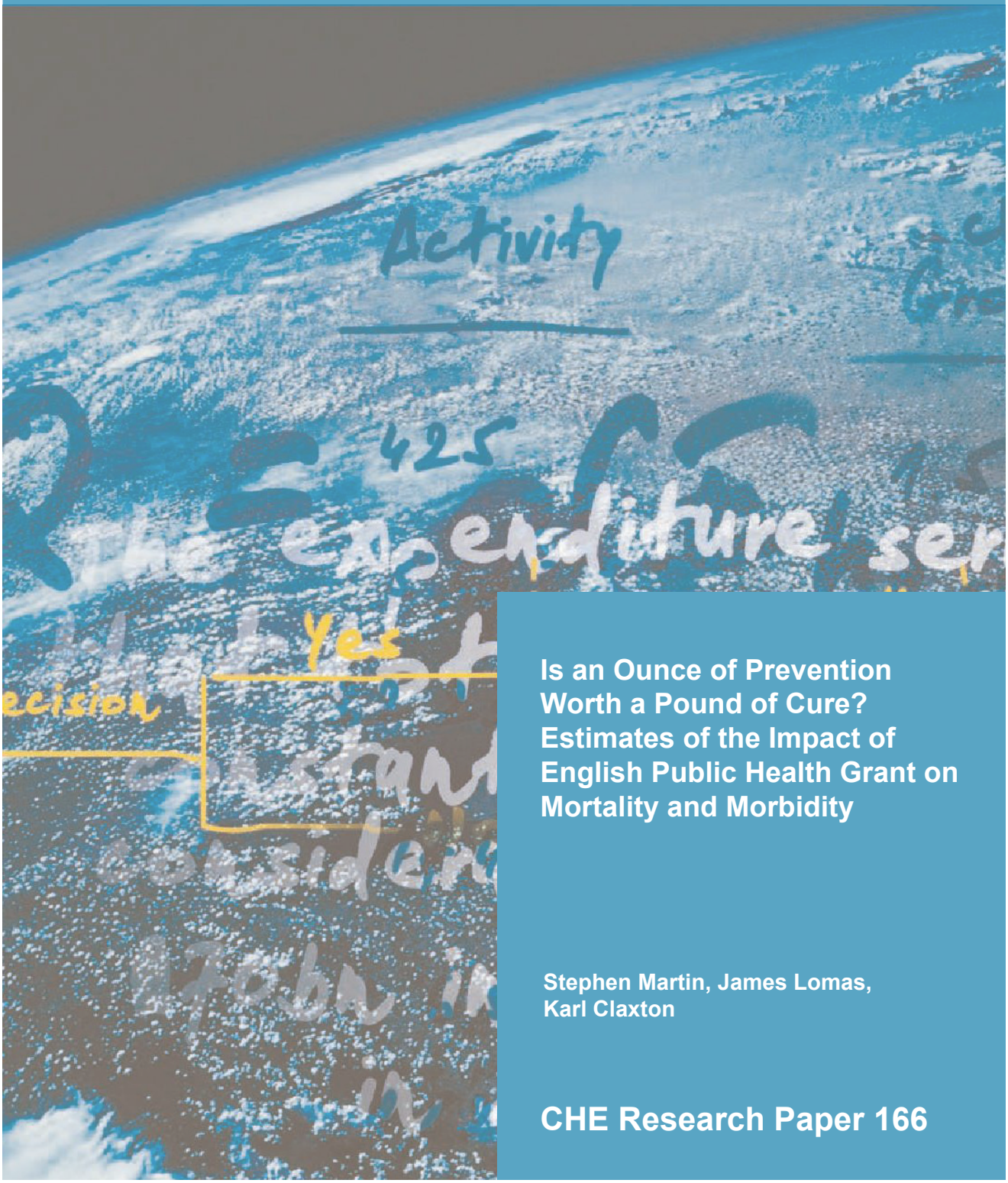

Is an Ounce of Prevention Worth a Pound of Cure? Estimates of the Impact of English Public Health Grant on Mortality and Morbidity

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Is an ounce of prevention worth a pound of cure? Estimates of the impact of English public health grant on mortality and morbidity

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No ethical approval was needed.

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Abstract

Most previous attempts to estimate the marginal productivity of English health care expenditure have employed instruments that rely on statistical tests alone for their justification. A new approach to instrumentation has proposed the use of 'funding rule' variables as instruments, which can be justified on theoretical grounds. We exploit the availability of a funding formula for local authority (LA) public health expenditure in England to investigate the relationship between such expenditure and mortality. Although there have been many studies of the impact of specific health promotion activities on outcomes, we are not aware of any successful attempts to relate English public health expenditure to mortality. Moreover, by converting healthcare (treatment) expenditure to a local authority geography, we are also able to estimate an outcome specification that includes both treatment (healthcare) and prevention (public health) expenditure. This enables us to identify the relative contribution of both types of expenditure to reductions in mortality. Previously published work has linked effects on disease specific mortality to changes in quality-adjusted life years. We use these estimates to report the cost per quality-adjusted life year (QALY) for both treatment and public health (prevention) expenditure.

1. Introduction

Recent studies of the marginal productivity of National Health Service (NHS) expenditure in England suggest a cost per quality-adjusted life year (QALY) of between £5,000 and £15,000 (Claxton et al, 2015; Lomas et al, 2018). These estimates imply that this expenditure provides good value for money when compared with the cost effectiveness threshold used by the National Institute for Health and Care Excellence (NICE) for the adoption of new health care technologies (between £20,000 and £30,000 per QALY). These estimates also suggest that marginal increases in health expenditure, whether funded through additional taxation, borrowing or reallocation from other spending departments, appear good value when compared to estimates of the equivalent consumption value of health (recent reviews suggest that £30,000 per QALY might represent a reasonable lower bound for this (Vallejo-Torres et al (2016); Ryen and Svensson (2015))).

That NHS healthcare expenditure offers good value for money might be one reason why the current government's austerity programme affects almost all government spending, yet the NHS continues to be protected from direct spending cuts. Although the NHS has fared relatively well, the public health grant to local authorities is not part of the ring-fenced NHS. Instead, this element of public health expenditure is currently in the fourth year of a five-year funding squeeze that will see real spending per person fall by nearly one-fifth between 2015/16 and 2019/20 (Finch, 2018 and DH, 2019).

One justification for the simultaneous protection of the NHS budget and the reduction in the public health grant might be that expenditure on prevention offers relatively few health benefits. However, the available evidence appears to contradict this. For example, Public Health England (PHE) maintains a 'health economic evidence resource' (HEER) tool (available at https://www.gov.uk/government/publications/health-economics-evidence-resource). This resource takes the form of a spreadsheet that reviews over 250 studies that examine the cost-effectiveness and return on investment associated with the activities that are ring-fenced within the English public health grant. The studies included in this resource suggest that public health activities provide generous returns.

For those interested in the cost per QALY, Owen et al (2018) report the cost per QALY associated with public health interventions assessed by NICE over two five-year periods (between 2005 and 2010, and between 2011 and 2016). Owen et al report that 85% of the public health interventions assessed by NICE during the first period were cost-effective at a threshold of £20,000 per QALY, and that the median cost per QALY was £1,053. During the second period, 63% of assessed interventions were cost-effective and the median cost per QALY was £7,843. Owen et al argue that the decline in the proportion of cost-effective interventions reflects the types of interventions and topic areas assessed in the two periods, rather than any underlying decline in the cost-effectiveness of public health interventions generally (Owen et al, 2018, p559).

For those interested in the return on investment in public health interventions, Masters et al (2017) undertook a systematic review of 2,957 potentially relevant titles and ultimately included 52 studies published over four decades in their report. The *local* public health programmes included studies of fall prevention, smoking cessation and water fluoridation. The median return on investment (ROI) for all 29 local public health interventions was 4.1 to 1, and the median cost-benefit ratio (CBR) was 10.3. The *national* public health programmes included studies of HIV/AIDS prevention, measles vaccination, and road safety campaigns, and generated even better returns (the median ROI for all 28 nationwide public health interventions was 27.2 to 1, and the median CBR was 17.5).

This distinction – between local and national public health programmes – is also reflected in the funding for public health expenditure in England. The public health grant delegates responsibility for local public health expenditure decisions to local commissioners (to local authorities). National public health programmes (eg for national immunisation and national screening programmes) are the responsibility of the NHS Commissioning Board. In 2013/14 the public health grant for local commissioning was £2.5bn, and the national public health functions exercised by the NHS Commissioning Board attracted a budget of £2.2bn (DH, 2012a). Here, our focus is on the impact of the public health grant because we do not have data for expenditure on national programmes by local area.

The studies reported by PHE, and discussed by Masters et al, typically focus on individual public health interventions, whereas the UK's austerity programme imposes a reduction in the total public health grant to local authorities. Any evaluation of this policy will need to quantify the benefits forgone through the reduction in the totality of expenditure, rather than the losses associated with reductions in individual parts of the public health programme. The only readily available health outcome measure that is potentially applicable to the public health grant is mortality and hence, in this paper, we seek to estimate the relationship between this outcome indicator and variations in the public health grant across local authorities.

We readily acknowledge that, for some public health expenditure, the health benefits might arise many years after the expenditure has occurred. This is particularly likely to be the case where expenditure is directed at encouraging healthy lifestyles, where some benefits may occur two or three decades after the actual expenditure. However, this study is constrained by the available public health expenditure data and comparable mortality data. Implicitly, we are assuming that the data represent a quasi long-run equilibrium situation, that relative expenditure levels and health outcomes within each LA have been reasonably stable over a period of time, and that any lag of effect of current expenditure on future mortality is offset by the impact of previous expenditure on current mortality. These seem to be not unreasonable assumptions in the English context, and Brown reports that, in his Californian study, just over half of the cumulative lives saved as a result of a single year of public health spending occurred in the two years immediately following that expenditure (Brown, 2016, p.1480). Although there are several American studies of the relationship between mortality and public health expenditure at the US county level (see, for example, Brown (2014) and Leider et al (2018)), we are not aware of any British studies on this topic. Moreover, given the very different healthcare system in the UK, the American results might not be relevant for Britain.

Studies of the relationship between mortality and any type of health expenditure often struggle with the endogeneity of expenditure. Two recent developments enable us to overcome this issue. First, a recent paper proposed the use of 'funding rule' variables as instruments for expenditure when estimating the relationship between healthcare expenditure and mortality (Andrews et al, 2017). However, this approach relies on the existence of a 'funding formula' that allocates the national budget across local commissioners and, before 2013/14, there was no specific funding formula for the public health grant. Second, the Health and Social Care Act 2012 transferred responsibility for local public health expenditure from local healthcare commissioners (Primary Care Trusts) to local government (to single and 'upper tier' local authorities). This transfer took effect from April 2013 and, at the same time, a 'funding formula' was introduced. This formula split the national public health grant between the 152 LAs and provides analysts with potential instruments for this public health expenditure (DH, 2012b).

In this paper, we exploit the availability of a funding formula for the public health grant to investigate the relationship between such expenditure and mortality The most recent mortality data

available at a local level is for 2013/2014/2015 combined, and hence we relate expenditure in 2013/14 to a measure of mortality for these three years. Although there have been many studies of the impact of specific health promotion activities on outcomes, we are not aware of any successful attempts to relate English public health expenditure to mortality. Moreover, by converting healthcare (treatment) expenditure as reported by Clinical Commissioning Groups (CCGs) to a local authority geography, we are also able to estimate an outcome specification that includes both treatment (healthcare) and prevention (public health) expenditure. This enables us to identify the relative contribution of both types of expenditure to reductions in mortality. Previously published work has linked effects on disease specific mortality to changes in quality-adjusted life years (eg Claxton et al, 2015). We use these estimates to report the cost per quality-adjusted life year (QALY) for both treatment and public health (prevention) expenditure.

The structure of this paper is as follows. Section 2 provides information about the definition of public health expenditure used here, together with details of the institutional arrangements for healthcare and public health provision in England during the study period. Section 2 also provides details of the outcome equation to be estimated, together with our estimation strategy. The dataset is discussed in section 3 and results are presented in section 4. The results are discussed in section 5 with some concluding remarks in section 6.

2. The institutional context, public health and healthcare expenditure, and estimation strategy

Institutional context

The English National Health Service (NHS) is a largely centrally planned and publicly funded health care system. Its income comes almost entirely from national taxation. Access to the Service is usually via general practitioners who act as gatekeepers to secondary care and pharmaceuticals. With some minor exceptions, the service is free at the point of consumption for patients. The Service is organised geographically, with responsibility for the local management of the NHS delegated to local health authorities. For our study year (2013/14), each authority (CCG) was assigned a fixed annual budget by the national ministry (the Department of Health), within which they were supposed to meet expenditure on most types of health care except primary care, specialised commissioning and public health. Primary care, specialised commissioning and national public health programmes were administered centrally. Responsibility for local public health was delegated to local government with each 'unitary' or upper tier authority receiving a fixed annual budget, ring-fenced for public health activities.

Public health expenditure

According to the UK's National Audit Office (NAO), public health is about helping people to stay healthy, and protecting them from threats to their health. In England, public health activities include protecting the public's health from hazards and infectious diseases, improving the public's health via the encouragement of healthier lifestyles, and reducing health inequalities (HC 888, 2014, p11).[1]

In 2013/14, the public health grant from the Department of Health, enabled local authorities to spend over £2,500m on public health services including £630m on sexual health services (eg for STI testing and treatment, and for contraception), £800m on substance (drugs and alcohol) misuse services, £150m on stop smoking and tobacco control services, and £240m on health programmes for children aged 5-19 (see MCHLG, 2015). In addition, £2,203m was made available for national public health programmes, including those for immunisation (eg for Hepatitis B, BCG, and MMR) and for screening (eg for exposure to HIV and for cervical cancer) (see DH (2012a) for further details).

Healthcare expenditure

As noted above, the Health and Social Care Act 2012 replaced Primary care trusts (PCTs) with CCGs as commissioners of local healthcare and stripped them of their responsibility for primary care, specialised commissioning, and public health Nevertheless, this still left CCGs with a budget of £65bn for 2013/14 and we use their reported expenditure from the programme budgeting dataset as a measure of local healthcare expenditure (NHS England, 2015).

In this study we sometimes refer to public health expenditure as 'preventative' and healthcare expenditure as 'treatment' (for ill-health). This is more out of a desire to avoid repetition rather than any belief that all expenditure funded by the public health grant is preventative and/or that all healthcare expenditure is solely for treatment. For example, some expenditure from the public health grant could be considered as treatment (eg expenditure on substance misuse treatment

[1] On this definition, public health activities will neither be confined to the Department of Health nor rely on government expenditure Expenditure by other government departments, such as those responsible for housing and transport, will also impact on public health. Similarly, changes to national regulations that involve little or no government spending (such as the introduction of plain packaging for cigarettes and the Soft Drinks Industry levy) will also impact on public health. Both of these aspects of policy are beyond the scope of this study.

services) and some expenditure by CCGs will be preventative (eg on medication for blood pressure and blood cholesterol).

As one very rough guide to the volume of preventative expenditure by CCGs, programme budgeting data for 2013/14 reports a total spend of £411m in the 'Healthy Individuals' programme of which £151m is for 'prescribing in primary care' and £190m is for 'community and integrated care' (NHS England, 2015). In principle, we could add this expenditure (£411m) to that from the public health grant (£2,500m) to obtain an overall measure of public health spend. However, as the precise set of activities covered by this CCG 'Healthy Individuals' expenditure is unclear and there are always issues about how consistently different CCGs allocate activity to different programme budget categories, we prefer to focus on the public health grant as our measure of public health expenditure. We include the 'Healthy Individuals' spend as part of the total measure of healthcare (treatment) expenditure. Our estimates of the impact of the public health grant and CCG expenditure will largely reflect 'prevention' and 'treatment' effects respectively, but we acknowledge that there will be relatively small elements of treatment expenditure in the prevention measure, and relatively small elements of prevention expenditure in the treatment measure.

Estimation strategy

Studies estimating the relationship between any form of health expenditure and mortality typically estimate an outcome equation of the form:

$$\ln(\text{mortality rate}) = \ln(\text{health expenditure per person}) + \text{controls for need} + e \quad (1)$$

where expenditure is likely to be endogenous, the controls reflect the need for health expenditure, and e reflects everything not included elsewhere in the specification (Andrews et al, 2017; Claxton et al, 2018). We want to estimate this specification, first with public health as the sole expenditure variable, and then with both public health and healthcare expenditure as two separate variables.

One issue with the estimation of (1) is that the endogeneity of expenditure will necessitate the use of instruments for this variable. The resource allocation formula for the public health grant to local authorities has three components – for mandatory services, for non-mandatory services, and for substance misuse services – and each component has its own formula. Although the precise formula differs for each component, overall, the public health budget per person can be expressed as:

$$\text{local budget per person} = (\text{national budget per person}) \times (\text{local age index}) \times (\text{local additional needs index}) \times (\text{local input price index}) \times (\text{local DFT Index}) \quad (2)$$

where: (a) the age index reflects the demographic profile of the local population; (b) the additional needs index reflects local deprivation and other factors likely to influence the need for public health expenditure; (c) the input price index (MFF) reflects prices in the local health economy; and (d) the distance from target (DFT) index reflects how far each LA's actual budget allocation is from its target allocation The latter reflects the fact that, periodically, the national ministry revises the funding formula and this, together with routine data updates, generates a new target budget allocation for each LA. For some LAs, the new funding rule might generate a large change in its target allocation and, to avoid sudden large reductions in actual allocations (budgets), such changes are phased into actual budgets over a number of years in accordance with the Department of Health's 'pace of change' policy (see DH (2012b) for details).

Two of the four adjustment factors in equation (2) – the MFF and the DFT – are relevant for all three components of the public health resource allocation formula for 2013/14 and provide instruments for expenditure if there is no direct connection between them and our measure of mortality. The local input price index (MFF), which will reflect characteristics of the local (health) economy, could be correlated with unmeasured determinants of mortality. However, we have over a dozen potential socio-economic covariates (including the Index of Multiple Deprivation) in the baseline mortality equation and, hence, it is difficult to imagine what effect the input price index would detect that our covariates do not.[2] The DFT variable will largely reflect: (i) the level of PCT expenditure in 2010/11 associated with those public health activities that were transferred to local authorities in 2013/14;[3] (ii) the public health grant funding formula for 2013/14; and (iii) the 'pace of change' policy for the 2013/14 allocations. The latter two factors will be policy choices but it is not obvious that the resulting DFT will be endogenous with respect to mortality. Moreover, any correlation between our two instruments and the error term in equation (1) is likely to be detected by the Hansen-Sargan test. Hence we use the public health grant MFF and DFT as instruments for public health expenditure when estimating equation (1).

Theory provides little guidance as to the identity of the appropriate controls in equation (1) so, following previous studies, we identify a dozen socio-economic variables -- such as the proportion of the working-age population employed in managerial and professional occupations, and the proportion of owner-occupied households – as potential controls for the need for public health expenditure (Claxton et al, 2018) We start by estimating (1) with all socio-economic variables included as controls. The least significant regressor is removed from the specification and the equation is re-estimated. This process – of dropping the least significant regressor and re-estimating -- continues until there are only significant controls remaining (the expenditure term is forced to be ever-present). This specification becomes our preferred result if it also passes the appropriate statistical tests (eg the instruments are valid and the instruments are strong) but, if this is not the case, the specification is adjusted (eg an invalid instrument is removed) and the equation re-estimated. When the specification requires no further adjustment it becomes our preferred specification.

Initially, equation (1) is estimated using the above strategy with public health as the sole health expenditure variable. We then re-estimate (1) – again using the above strategy – but this time including healthcare expenditure as an additional endogenous regressor. This variable is instrumented in a similar way to public health. However, the identification of the relevant funding rule variables is slightly complicated because of the changes imposed by the Health and Social Care Act 2012. Usually, funding formulae are updated every year but the impending abolition of PCTs meant that the weighted capitation formula was frozen for 2012-13, with all PCTs receiving the same (3%) growth rate over their 2011/12 allocations. As CCG responsibilities in 2013/14 differed from those for PCTs (eg they lost responsibility for public health, specialised services, and primary care), there was a baseline exercise in 2012 which stripped out actual expenditure on these components and, for 2013-14, each CCG was given an uplift of 2.3% on these 2012 baselines (DH, 2018).

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[2] Of course, if a locality gets a larger budget to compensate for the higher cost of supplying healthcare, as happens with the local price index, and this adjustment exactly compensates for additional costs, then there is no reason why this additional spending should improve health because it does not correspond to an increase in real spending. In reality, of course, the cost adjustment will not be perfect. Some local authorities will be over compensated and hence receive 'too much' funding; others will be under compensated and receive 'too small' a budget. This imperfect adjustment for local conditions provides the link between this instrument, expenditure and mortality. The same argument applies to the use of the age index as an instrument for healthcare expenditure discussed later.

[3] A baseline survey was undertaken in 2011 to establish how much each PCT spent in 2010/11 on those public health activities that were to be transferred to local authorities in 2013/14. This was to ensure that each LA would be able to at least match the expenditure level recorded by PCTs.

The implication of these developments for this study is that the best funding rule variables we can identify for CCG healthcare expenditure in 2013/14 are drawn from the 2011/12 allocations for PCTs, appropriately mapped to the new (CCG) geography. These allocations reflect three separate funding formulae (one for Hospital and Community Services (HCHS), one for prescribing, and one for primary care), and we select three funding rule variables employed in these formulae which we believe are uncorrelated with mortality. In particular, our funding rule variables for healthcare expenditure are: (i) the DFT for the total allocation to PCTs for 2011/12; (ii) the MFF for the HCHS component of the total allocation; and (iii) the age index from the prescribing component of the total allocation. The DFT variable is available from the Department of Health's website at https://www.networks.nhs.uk/nhs-networks/health-investment-network/news/2012-13-programme-budgeting-data-is-now-available (accessed 09 January 2019), and the MFF and age indices are available from the exposition books for the 2011/12 allocations at https://www.gov.uk/government/publications/exposition-book-2011-2012 (accessed 09 January 2019).

Andrews et al provide no explicit arguments in support of their instruments for healthcare expenditure but this omission is easily remedied. First, our measure of mortality and the age index instrument are both standardised for age, and so the age index is unlikely to be correlated with the error from equation (1). Second, and as already noted when discussing the instruments for public health expenditure, the local input price index will reflect characteristics of the local (health) economy that can be correlated with unmeasured determinants of mortality. However, we have over a dozen potential socio-economic covariates in the baseline mortality equation and hence it is difficult to imagine what effect the MFF would detect that our covariates do not. Third, the DFT variable for healthcare allocations will reflect the various funding formulae and 'pace of change' policies implemented under several governments of various political persuasions over the past thirty years. It is certainly the case that the 'pace of change' and the consequent DFT are policy choices but it is not obvious that the latter will be endogenous with respect to mortality. And, as noted above for the instruments for public health expenditure, any correlation between our instruments and the error term in equation (1) is likely to be detected by the Hansen-Sargan test.

3. Data

Unitary and upper tier local authorities (n=152) are the unit of analysis in this study but one of them (the Isles of Scilly) is so small that the mortality data for this authority is rarely disclosed by the ONS so this leaves 151 authorities for analysis. In addition, the healthcare expenditure data for one CCG (Wiltshire) for 2013/14 has not been reported (reliability issues) so that, when both expenditure variables are included in the estimating equation, there are 150 observations for analysis.

With the exception of the CCG healthcare expenditure and the instruments for this variable, all of the dataset is readily available at the local authority (LA) level. The healthcare expenditure and instrument data have been converted to a LA basis using a mapper which uses population levels in mid-2012 to allocate (parts of) CCGs to LAs. As LAs vary greatly in size, we weight all observations in our analysis by their population size. In addition, we use the logarithms of all variables in the empirical analysis so that regression coefficients can be interpreted as elasticities.

Table 1 reports descriptive statistics for the variables employed in this study. Average expenditure per person from the public health grant in 2013/14 was £53 and this varied between £18 and £186 per person.[4] Average per capita expenditure on healthcare was £1,152. The mortality measure employed in this study is the (age) standardised under 75 years of life lost rate (SYLLR). The latest release of mortality data (for 2013/14/15 combined) is available via the NHS Digital Indicator portal at https://indicators.hscic.gov.uk/webview/. This mortality rate varies considerably across the country, ranging between 267 (City of London) and 776 (Blackpool) years of life lost per 10,000 population.

The DFT instrument for public health expenditure averages just over 1.00 but its range suggests that at least one LA budget is 46% under its target allocation and another LA budget (the City of London) is 562% above its target allocation. The MFF instrument for public health expenditure reveals that some LAs face unit costs between 8% lower and 21% higher than the average. The instruments for healthcare expenditure also reveal considerable geographic variation with, for example, some LAs being 7% below and others being 23% above their target allocations.[5]

The dozen potential socio-economic controls for the need for health are also listed in Table 1. These census-based variables are constructed using the 2011 census. They show that, for example, on average, 13% of all residents are born outside the European Union, 31% of the working-age population are employed in managerial and professional occupations, and 62% of households are owner occupied. Again, these averages mask considerable variation across local authorities; the proportion of residents born outside the EU varies from less than 2% to more than 50%, and the extent of owner occupation ranges between 26% and 81% of all households.

[4] The expenditure figure for 2013/14 is before children's (aged 0-5 years) public health services were transferred from central administration (NHS England) to local administration (LAs). This took place in October 2015 and, in the first full year (2016/17) under LA responsibility, these services accounted for £930m of expenditure.

[5] It should be emphasised that all instruments are designed to reflect the position in 2013/14 and not the current (2018/19) situation.

Table 1 Descriptive statistics for study variables

Variable description	Observations	Mean	Std. Dev.	Minimum	Maximum
Health expenditure variables					
Public health grant: expenditure per person, £, 2013/14	152	52.6	25.2	18.5	186.2
Healthcare spend per person, £, 2013/14	151	1152.1	75.8	1019.9	1479.1
Mortality variable					
Standardised years of life lost rate, 2013/14/15	151	443.3	85.0	267.5	775.9
Instruments for expenditure					
Distance from target (public health), 2013/14	152	1.0667	0.5362	0.5392	6.6247
Market Forces Factor (public health), 2013/14	152	1.0122	0.0790	0.9151	1.2076
Distance from target (healthcare: total), 2013/14	152	1.0055	0.0515	0.9282	1.2250
Age index (healthcare: prescribing), 2013/14	152	0.9776	0.1283	0.6422	1.3007
Market Forces Factor (healthcare: HCHS), 2013/14	152	1.0063	0.0643	0.9319	1.1416
Socio-economic controls					
Proportion of all residents born outside the European Union	152	0.1281	0.1147	0.0144	0.5060
Proportion of population in white ethnic group	152	0.8364	0.1626	0.2897	0.9882
Proportion of population providing unpaid care	152	0.1008	0.0138	0.0651	0.1289
Proportion of population aged 16-74 with no qualifications	152	0.2469	0.0606	0.0720	0.3874
Proportion of households without a car	152	0.2862	0.1248	0.0899	0.6940
Proportion of households that are owner occupied	152	0.6190	0.1152	0.2611	0.8086
Proportion of households that are one pensioner households, 2011	152	0.1206	0.0208	0.0596	0.1667
Proportion of households that are lone parent households with dependent children	152	0.0745	0.0185	0.0208	0.1436
Proportion of population aged 16-74 that are permanently sick	152	0.0424	0.0149	0.0086	0.0879
Proportion of those aged 16-74 that are long-term unemployed	152	0.0183	0.0058	0.0043	0.0367
Proportion of those aged 16-74 in employment that are working agriculture	152	0.0064	0.0099	0.0003	0.0572
Proportion of those aged 16-74 in managerial and professional occupations	152	0.3114	0.0769	0.1835	0.6674
Index of multiple deprivation (2010)	152	23.0753	8.6040	5.4466	43.4465

4. Results

With the public health grant as the only expenditure variable

Estimation of equation (1) with public health as the sole expenditure variable generates the result shown in column 1 of Table 2. The corresponding first-stage result can be found in column 1 of Table A1 in the appendix. Application of the backward selection process generates the more parsimonious specification shown in column 2 of Table 2. Public health expenditure has the anticipated negative association with mortality but this specification fails the reset test and the instrument set is invalid (the Hansen-Sargan test statistic p-value<0.100). The addition of IMD 2010 squared to the specification resolves the reset test but not the instrument validity issue (column 3). The result in column 4 omits that instrument (the MFF index) which is the most significant when added as a control to the second-stage equation. The significant positive coefficient (0.252) on the 'white ethnicity' variable might reflect a lifestyle effect but, in the interests of clarity, we re-estimate without this variable and obtain the result shown in column 5. The coefficient on the 'permanently sick' variable increases considerably (from 0.265 to 0.475) and the coefficient on the 'working in agriculture' variable is no longer significant. Re-estimation without the latter variable generates our preferred specification shown in column 6. In this, public health expenditure has a modest but statistically significant negative association with mortality, expenditure is endogenous, there is no evidence of weak instruments (the Kleibergen-Paap F statistic exceeds the rule-of-thumb threshold value (=10)), and the specification passes the reset test.

With both the public health grant and healthcare as the expenditure variables: backward selection

Estimation of equation (1) with both public health and healthcare expenditure as endogenous regressors generates the result shown in column 1 of Table 3. This specification includes five instruments (two for public health expenditure and three for healthcare expenditure). The corresponding first-stage results can be found in column 1 (for public health) and in column 2 (for healthcare) in Table A2 in the appendix.

Some authors have expressed concern about the inclusion of weak instruments (for example, Small, 2007) and hence we re-estimate the 'full' specification without the two insignificant MFF instruments (see column 2 of Table 3). Application of the backward selection process generates the more parsimonious result shown in column 3 but the instrument set is invalid at the 1% level. On checking to see if any of the deleted variables or their squared values are significant when added as a control to the second-stage, we found that the 'permanently sick' variable is both significant and resolves the weak instrument issue for healthcare expenditure. Again, in the interests of clarity, we tried re-estimating the specification in column 4 without the 'white ethnicity' variable. This generates the plausible result shown in column 5 where both expenditure variables have the anticipated negative association with mortality, they are endogenous, the instrument set is valid, and the instrument sets for both endogenous variables are individually strong (the Sanderson-Windmeijer F-statistics are around ten or better).

Table 2 Derivation of preferred specification for public health expenditure, 2013/14

	(1) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model instrument PH spend weighted IV second stage full specification	(2) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model instrument PH spend weighted IV second stage new derivation	(3) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model instrument PH spend weighted IV second stage new derivation revised1	(4) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model instrument PH spend weighted IV second stage new derivation revised2	(5) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model instrument PH spend weighted IV second stage new derivation revised2	(6) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model instrument PH spend weighted IV second stage new derivation revised2
VARIABLES					**SA_1**	**SA_2**
Public health spend per person	-0.084**	-0.122***	-0.108**	-0.119***	-0.116**	-0.115**
	[0.041]	[0.046]	[0.043]	[0.043]	[0.047]	[0.048]
IMD 2010	0.203***	0.152**	-0.271*	-0.374**	-0.509***	-0.505***
	[0.075]	[0.063]	[0.141]	[0.146]	[0.163]	[0.157]
Proportion of all residents born outside the EU	-0.016					
	[0.018]					
Proportion of population in white ethnic group	0.246***	0.261***	0.249***	0.252***		
	[0.060]	[0.039]	[0.038]	[0.038]		
Proportion of population providing unpaid care	-0.439***	-0.346***	-0.271***	-0.235***	-0.235***	-0.231**
	[0.167]	[0.088]	[0.083]	[0.084]	[0.090]	[0.091]
Proportion of population aged 16-74 with no qualifications	-0.034					
	[0.112]					
Proportion of households without a car	-0.062					
	[0.072]					
Proportion of households that are owner occupied	0.129*					
	[0.071]					
Proportion of households that are one pensioner households	-0.082					
	[0.084]					
Lone parent households with dependent children	0.056					
	[0.060]					
Proportion of population aged 16-74 that are permanently sick	0.315***	0.319***	0.284***	0.265***	0.475***	0.475***
	[0.070]	[0.077]	[0.071]	[0.072]	[0.067]	[0.068]

Proportion of those aged 16-74 that are long-term unemployed	0.039					
	[0.057]					
Proportion of those aged 16-74 working agriculture	-0.015	-0.025***	-0.020***	-0.016**	0.001	
	[0.010]	[0.007]	[0.007]	[0.007]	[0.007]	
Proportion of those aged 16-74 in professional occupations	-0.201***	-0.268***	-0.243***	-0.230***	-0.204***	-0.205***
	[0.077]	[0.044]	[0.046]	[0.047]	[0.050]	[0.049]
IMD 2010 Squared			0.078***	0.100***	0.093***	0.092***
			[0.026]	[0.027]	[0.029]	[0.028]
Constant	5.532***	5.895***	6.514***	6.710***	7.941***	7.936***
	[0.649]	[0.349]	[0.393]	[0.402]	[0.397]	[0.402]
Observations	151	151	151	151	151	151
Endogeneity test statistic	11.369	10.449	8.572	15.109	13.881	10.579
Endogeneity p-value	0.001	0.001	0.003	0.000	0.000	0.001
Hansen-Sargan test statistic	14.750	10.957	14.408			
Hansen-Sargan p-value	0.000	0.001	0.000			
Kleibergen-Paap LM test statistic	26.821	34.909	35.502	34.884	34.868	32.762
Kleibergen-Paap p-value	0.000	0.000	0.000	0.000	0.000	0.000
Kleibergen-Paap F statistic	69.320	88.578	99.555	192.280	185.421	120.521
Pesaran-Taylor reset statistic	10.116	6.248	0.599	0.469	2.422	2.456
Pesaran-Taylor p-value	0.001	0.012	0.439	0.493	0.120	0.117

Robust standard errors in brackets
***** p<0.01, ** p<0.05, * p<0.1**

Table 3 Derivation of preferred specification for public health expenditure with healthcare expenditure, backward selection, 2013/14

	(1) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage backward selection full specification	(2) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage backward selection full specification	(3) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage backward selection derived specification	(4) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage backward selection derived specification	(5) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage backward selection derived specification
VARIABLES	**five instruments**	**three instruments**	**three instruments**	**revised**	**revised**
Public health spend per person, 2013/14	-0.024	-0.052	0.010	-0.037	-0.081**
	[0.037]	[0.038]	[0.033]	[0.034]	[0.034]
Healthcare spend per person, 2013/14	-0.551	-0.076	-0.869***	-0.662***	-0.672***
	[0.413]	[0.355]	[0.233]	[0.204]	[0.233]
IMD 2010	0.253***	0.231***	0.271***	0.281***	0.221***
	[0.062]	[0.078]	[0.067]	[0.063]	[0.063]
Proportion of all residents born outside the EU	-0.043*	-0.023	-0.054***	-0.042**	-0.084***
	[0.024]	[0.023]	[0.020]	[0.019]	[0.019]
Proportion of population in white ethnic group	0.226***	0.237***	0.192***	0.185***	
	[0.051]	[0.058]	[0.034]	[0.036]	
Proportion of population providing unpaid care	-0.399***	-0.466***	-0.376***	-0.372***	-0.479***
	[0.144]	[0.165]	[0.099]	[0.096]	[0.096]
Proportion of population aged 16-74 with no qualifications	-0.111	-0.089			
	[0.105]	[0.124]			
Proportion of households without a car	-0.033	-0.091			
	[0.087]	[0.083]			
Proportion of households that are owner occupied	0.090	0.103			
	[0.075]	[0.074]			

Proportion of households that are one pensioner households	-0.023	-0.035			
	[0.079]	[0.087]			
Lone parent households with dependent children	-0.048	0.023			
	[0.082]	[0.090]			
Proportion of population aged 16-74 that are permanently sick	0.237***	0.281***	0.176**	0.910***	1.187***
	[0.068]	[0.070]	[0.077]	[0.343]	[0.331]
Proportion of those aged 16-74 that are long-term unemployed	0.085	0.069			
	[0.060]	[0.067]			
Proportion of those aged 16-74 working agriculture	-0.007	-0.012			
	[0.013]	[0.010]			
Proportion of those aged 16-74 in professional occupations	-0.259***	-0.243***	-0.244***	-0.223***	-0.194***
	[0.072]	[0.083]	[0.039]	[0.040]	[0.045]
Proportion of population aged 16-74 that are permanently sick, squared				0.111**	0.138***
				[0.053]	[0.052]
Constant	8.714***	5.636**	10.645***	10.605***	11.286***
	[2.852]	[2.502]	[1.379]	[1.132]	[1.409]
Observations	150	150	150	150	150
Endogeneity test statistic	5.928	9.295	6.089	9.906	17.683
Endogeneity p-value	0.052	0.010	0.048	0.007	0.000
Hansen-Sargan test statistic	20.849	9.099	6.810	6.458	1.667
Hansen-Sargan p-value	0.000	0.003	0.009	0.011	0.197
Kleibergen-Paap LM test statistic	9.027	6.363	16.219	15.540	16.034
Kleibergen-Paap p-value	0.060	0.042	0.000	0.000	0.000
Kleibergen-Paap F statistic	2.323	2.663	9.390	8.971	8.979
Pesaran-Taylor reset statistic	1.405	6.440	0.528	0.330	0.175
Pesaran-Taylor p-value	0.236	0.011	0.467	0.565	0.676
Sanderdson-Windmejer Public health spend F-statistic	70.796	36.048	51.105	78.626	70.796
Sanderdson-Windmejer Public health spend p-value	0.000	0.000	0.000	0.000	0.000
Sanderdson-Windmejer Healthcare spend F-statistic	13.469	3.008	4.288	13.427	13.469
Sanderdson-Windmejer Healthcare spend p-value	0.000	0.021	0.016	0.000	0.000
Robust standard errors in brackets					

*** p<0.01, ** p<0.05, * p<0.1

With both the public health grant and healthcare as the expenditure variables: forward selection

The use of backward selection to identify relevant covariates, when theory provides little guidance, does not always meet with universal approval, and hence we also report results using forward selection (see Table 4). Column 1 shows the result with the inclusion of the most significant single control ('permanently sick') with the same five instruments from the 'full' specification in Table 3. The Hansen-Sargan test statistic suggests that the instrument set is not valid and, in response to this, we re-estimate without the two insignificant MFF instruments. This re-estimation (see column 2, Table 4) largely resolves the instrument validity issue. Further re-estimation, with the inclusion of additional significant controls, generates the results shown in columns 3, 4 and 5. No further additional significant controls could be found and, as the result in column 5 is both in line with both our theoretical priors and passes the appropriate statistical tests, this is our preferred specification using forward selection.

Table 4 Derivation of preferred specification for public health expenditure with healthcare expenditure, forward selection, 2013/14

	(1) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage forward selection round 1	(2) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage forward selection round 1	(3) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage forward selection round 2	(4) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage forward selection round 3	(5) All causes 2013/14 PH & PB spend SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage forward selection round 4
VARIABLES	**five instruments**	**three instruments**	**three instruments**	**three instruments**	**three instruments**
Public health spend per person, 2013/14	-0.006	-0.004	-0.128***	-0.107***	-0.144***
	[0.025]	[0.028]	[0.040]	[0.041]	[0.040]
Healthcare spend per person, 2013/14	-1.012***	-1.394***	-0.949***	-1.190***	-0.837***
	[0.244]	[0.266]	[0.238]	[0.263]	[0.269]
Proportion of population aged 16-74 that are permanently sick	0.554***	0.603***	0.697***	0.707***	0.601***
	[0.031]	[0.035]	[0.046]	[0.046]	[0.051]
Proportion of population providing unpaid care			-0.289***	-0.571***	-0.547***
			[0.081]	[0.134]	[0.122]
Proportion of all residents born outside the EU				-0.059***	-0.070***
				[0.021]	[0.019]
Proportion of those aged 16-74 that are long-term unemployed					0.156***
					[0.040]
Constant	15.008***	17.848***	14.831***	15.692***	13.666***
	[1.756]	[1.913]	[1.719]	[1.742]	[1.762]
Observations	150	150	150	150	150
Endogeneity test statistic	6.137	17.111	21.226	20.194	22.853
Endogeneity p-value	0.046	0.000	0.000	0.000	0.000
Hansen-Sargan test statistic	23.780	2.997	0.032	1.702	1.465
Hansen-Sargan p-value	0.000	0.083	0.857	0.192	0.226

Kleibergen-Paap LM test statistic	24.002	19.635	19.756	17.814	18.331
Kleibergen-Paap p-value	0.000	0.000	0.000	0.000	0.000
Kleibergen-Paap F statistic	7.220	10.806	12.647	11.051	11.627
Pesaran-Taylor reset statistic	0.073	0.054	0.069	0.005	0.466
Pesaran-Taylor p-value	0.788	0.816	0.793	0.946	0.495
Sanderdson-Windmejer Public health spend F-statistic	100.608	183.202	76.326	66.169	57.002
Sanderdson-Windmejer Public health spend p-value	0.000	0.000	0.000	0.000	0.000
Sanderdson-Windmejer Healthcare spend F-statistic	9.052	16.288	19.070	16.633	17.375
Sanderdson-Windmejer Healthcare spend p-value	0.000	0.000	0.000	0.000	0.000

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

5. Discussion

The estimation of a mortality equation that includes both public health and healthcare expenditure has generated an outcome elasticity for public health expenditure of -0.081 using backward selection and an elasticity of -0.144 using forward selection. The mid-point of these two elasticities is almost identical to the elasticity estimated without the inclusion of health care expenditure (=-0.115). Although statistically significant, these elasticities appear relatively modest when compared with the elasticity associated with healthcare expenditure (which, in this paper, is several times larger than the public health elasticity). However, this comparison is misleading because it fails to allow for the relative size of the two budgets.

The coefficient on public health expenditure from column 6 of Table 1 implies that a 1% increase in such expenditure (=£25.107m) in 2013/14 is associated with a 0.115% decline in the number of life years lost. However, a change in expenditure, which has an observed effect on mortality, is also likely to have effects on a more complete measure of health which captures the impact on survival and quality of life. Therefore, to convert the estimated all-cause elasticity into a likely QALY effect of public health expenditure we would ideally require evidence of the effects of public health expenditure on both all-cause mortality and on QALYs.

Direct estimates of the QALY effects of public health expenditure are not available. However, previous work has estimated the mortality and QALY effects of changes in NHS healthcare expenditure and these can be used to give some indication of the possible QALY effects of public health expenditure. For example, NHS healthcare expenditure can be divided between 23 care programmes (PBCs) and, for those (10) programmes with a mortality indicator, an outcome equation similar to equation (2) can be estimated (Claxton et al, 2015). Drawing on a number of data sources, Claxton et al estimate the QALY burden of disease for each 3-digit ICD10 code within each PBC.[6] They calculate the QALY burden of disease for each PBC by summing (over all relevant ICD10 codes) the product of the per patient QALY burden and the size of the population with the disease (prevalent and incident) in one year. For each PBC with a mortality based outcome elasticity, the estimated change in QALYs associated with, say, a 1% change in total expenditure is the product of the outcome elasticity for total expenditure and the QALY burden for the PBC (i.e., effects on the mortality burden of disease are used as a 'surrogate' for effects on the broader QALY burden).[7] For those PBCs without an outcome indicator, Claxton et al (2015) calculate the average proportionate effect of a change in expenditure on the mortality burden of disease in those PBCs where mortality-based outcome elasticities can be estimated, and this average is used as a proxy for the outcome elasticity for those PBCs without a directly estimated outcome elasticity (i.e., the proportionate effects on burden of disease are extrapolated from where they can be observed to where they cannot).

Using the same approach to estimating the QALY burden of disease, and the same surrogacy and extrapolation assumptions, Lomas et al (2018) update the Claxton et al (2015) results. Lomas et al

[6] Data from WHO global burden of disease study was used to estimate the duration and incidence of disease (by age and gender), ONS data provided mortality conditional life expectancies by age and gender, quality of life norms by age and gender were based on data from the Health Survey for England and the impact of disease on these quality of life norms were provided by Health Outcomes Data Repository (HODaR) supplemented with information from the Medical Expenditure Panel Survey (MEPS).

[7] Claxton et al (2015) use own programme expenditure rather than all programme expenditure in their outcome equations, and they also estimate an expenditure equation for each PBC. The latter reveals what proportion of any change in total expenditure is spent in that PBC. Therefore, the PBC outcome elasticity for total expenditure, which is applied to the QALY burden of diseases within the PBC, is the product of the outcome and expenditure elasticities estimated in Claxton et al (2015).

report that, in 2012/13, a 1% change in total healthcare expenditure generates 65,773 QALYs across all disease areas. Although Lomas et al (2018) do not directly estimate an all-cause mortality elasticity, the programme-specific elasticities that they do estimate imply an all-cause mortality of -1.028. This suggests that a 1% reduction in all-cause mortality is associated with a gain of 63,981 QALYs (65,773/1.028). Therefore, a 1% increase in public health expenditure (£25.107m), which reduces all-cause mortality by 0.115% maybe associated with a gain of 7,358 QALYs (0.115 x 63,981). This 7,358 QALY gain, together with the additional expenditure of £25.107m, implies a cost per QALY for public health of £3,412.

Similar calculations can be made for the two other public health elasticities (-0.081 and -0.144) reported in Table 5, and the implied cost per QALY estimates are £4,845 and £2,725 respectively. Moreover, we can use the same information from Lomas et al (2018) to convert the all-cause healthcare elasticities in Table 5 into cost per QALY estimates. The backward selection elasticity (=-0.672) implies a cost per QALY of £14,912, while the forward selection elasticity (=-0.837) implies a cost per QALY of £11,973.

Table 5 Mortality elasticities and cost per quality adjusted life year estimates for public health and healthcare expenditure, 2013/14

Outcome specification	Mortality elasticty associated with public health expendiure	Mortality elasticty associated with healthcare expendiure	Cost per QALY	
			public health	healthcare
With public health spend only:				
backward selection	-0.115	n/a	£3,412	n/a
	[0.048]	n/a		
With public health and healthcare spend				
(a) backward selection	-0.081	-0.672	£4,845	£14,912
	[0.034]	[0.233]		
(b) forward selection	-0.144	-0.837	£2,725	£11,973
	[0.040]	[0.269]		

If we compare the average of the backward and forward selection estimates, then public health expenditure appears to be about three to four times more productive than healthcare expenditure (that is, the prevention cost per QALY is about £3,800 whereas the treatment cost per QALY is £13,500). This finding – that public health offers a much better return than healthcare at the margin – is also reported by other (American) studies (eg by Brown, 2014 and by Leider et al, 2018). We can also compare our (marginal) cost per QALY estimates for the public health grant with the median cost per QALY associated with public health interventions assessed by NICE between 2005 and 2010, and between 2011 and 2016 (Owen et al, 2018). Owen et al report a median cost per QALY of £1,053 for the first period and £7,843 for the second period. Our estimate of the marginal cost per QALY (about £3,800) is about halfway between the two Owen et al figures.

We can also compare our cost per QALY estimates for the public health grant with the return on investment associated with the public health interventions studied by Masters et al (2017). Across both local and national interventions, Masters et al report a median return on investment (ROI) of 14.3 to 1. Putting aside average versus marginal differences, we can convert the cost per QALY associated with the public health grant (of about £3,800) into a societal ROI of about 15 to 1, if we assume that the value of a QALY is about £60,000.[8] Thus our cost per QALY estimates are very much

[8]The UK's Department of Health and HM Treasury have adopted a value of £60,000 per QALY based primarily on the value of a statistical life from revealed preference studies.

in line with the findings from other studies (such as Owen et al and Masters et al) that have used very different data sets and different approaches to estimation.

Our findings suggest that, at the margin, public health expenditure is very productive of health and more productive than NHS expenditure. This suggests that the reallocation of resources from NHS to public health is likely to improve health outcomes overall, and that the squeeze on the public health grant, while protecting NHS expenditure, over recent years is likely to have reduced health outcomes. It also means that the health opportunity costs of the public health grant are high, so new investments in public health interventions and programmes need to offer less than £3,800 per QALY to be accommodated within current levels of funding. However, this analysis also shows that NHS expenditure is also productive of health and the health opportunity costs faced are higher than those implied by the norms used to judge whether new technologies are cost-effective. The cost per QALY for NHS expenditure reported here is similar to previous estimates where public health expenditure was excluded (Claxton et al 2018, Lomas et al 2018). This suggests that including other categories of health expenditure in the outcome equation is unlikely to materially change estimates of the marginal productivity of NHS expenditure.

However, linking the estimated effects on mortality to QALYs requires a number of assumptions (Claxton et al 2015 and Lomas et al 2018). The plausibility of these assumptions has been examined through structured elicitation from clinical experts (Soares et al 2018), and suggests that these are likely to be conservative with respect to the QALY effects of changes in expenditure, i.e., the cost per QALY is likely to be lower. Applying the QALY effects associated with changes in mortality from Lomas et al 2018 assumes the mortality effects of public health expenditure is distributed across disease areas in a similar way to NHS expenditure. However, in so far as public health expenditure tends to have greater effects on mortality in areas of high QALY burden of disease, such as respiratory and cardiovascular disease then the QALY effects will tend to be higher. Therefore, although there remains uncertainty about the cost per QALY associated with NHS and public health expenditure, the broad implications appear robust.

Although our results are plausible, this study is not without its limitations. First, our focus is on the impact of the public health grant (£2.5bn in 2013/14). This delegates responsibility for local public health expenditure decisions to local commissioners (to local authorities). National public health programmes (eg for national immunisation and national screening programmes) are the responsibility of the NHS Commissioning Board and the impact of these is not considered here because we do not have data for expenditure on national programmes by local area. In addition, there will be some treatment expenditure within the public health grant, and there will be some prevention spend within the measure of CCG healthcare expenditure but we believe that this cross-contamination will be relatively small.

Second, and perhaps most importantly, equation (1) is static in the sense that it assumes that all health benefits occur contemporaneously with expenditure. However, our empirical implementation of (1) does slightly better than this, because our outcome measure reflects not only mortality in the same year as expenditure but also in the two subsequent years. Moreover, Brown reports that, in his Californian study, just over half of the cumulative lives saved as a result of a single year of public health spending occurred in the two years immediately following that expenditure (Brown, 2016, p.1480). Nevertheless, we readily acknowledge that, for some public health expenditure, the health benefits might arise many years after the expenditure has occurred. This is particularly likely to be the case where expenditure is directed at encouraging healthy lifestyles, where some benefits may occur two or three decades after the actual expenditure.

However, this study is constrained by the available public health expenditure data which are almost exclusively cross-sectional (a funding formula for public health was first introduced in 2013/14). Implicitly, we are assuming that the data represent a quasi long-run equilibrium situation, that relative expenditure levels and health outcomes within each LA have been reasonably stable over a period of time, and that any lag of effect of current expenditure on future mortality is offset by the impact of previous expenditure on current mortality. These seem to be not unreasonable assumptions in the English context but they are just assumptions, and they might be less appropriate for other geographies where, for example, relative outcomes have changed through time.

6. Concluding remarks

Previous studies of the return to public health expenditure have tended to focus on particular interventions (eg the MMR vaccine). Most studies of total public health expenditure have used American data where the health care system is very different to that in the UK. In this paper we have exploited the introduction of a 'funding formula' for the English public health grant in 2013/14 to estimate the responsiveness of mortality to variations in this component of public health expenditure and, by drawing on previous studies, we have been able to convert these mortality effects into broader QALY effects.

Our cost per QALY estimate (about £3,800) for the totality of the public health grant is broadly consistent with the average effect identified by two recent reviews of specific public health interventions. This similarity gives us confidence in our results. Although our results suggest that the outcome elasticity for the public health grant is relatively modest compared with that for healthcare expenditure, this is a misleading comparison because it ignores the relative size of the two budgets. Cost per QALY calculations reveal that public health expenditure, at about £3,800 per QALY, appears to be about three to four times more productive at the margin than healthcare expenditure (which costs about £13,500 per QALY). Thus Benjamin Franklin's axiom – that 'an ounce of prevention is worth a pound of cure' – is correct in this context in the sense that prevention is more productive than cure but, with 16 ounces to the pound, the adage rather exaggerates the size of this advantage.

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Appendix

First-stage regression results for the second-stage specifications reported in the main body of the text.

Table A1 First-stage regression results for derivation of preferred specification for public health expenditure, 2013/14

	(1) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS full specification	(2) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS new derivation	(3) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS new derivation revised1	(4) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS new derivation revised2	(5) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS new derivation revised2	(6) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS new derivation revised2
VARIABLES					**SA_1**	**SA_2**
DFT index_Public health_1314	0.729***	0.747***	0.762***	0.759***	0.759***	0.739***
	[0.062]	[0.056]	[0.054]	[0.055]	[0.056]	[0.067]
MFF Index_Public health_1314	-0.655*	-0.559	-0.565			
	[0.350]	[0.348]	[0.352]			
IMD 2010	0.122	0.139	-0.590	-0.548	-0.599*	-0.931**
	[0.137]	[0.113]	[0.388]	[0.357]	[0.357]	[0.388]
Proportion of all residents born outside the EU	0.031					
	[0.050]					
Proportion of population in white ethnic group	0.309*	0.020	0.028	0.095		
	[0.178]	[0.083]	[0.080]	[0.071]		
Proportion of population providing unpaid care	-0.113	-1.099***	-1.008***	-0.903***	-0.904***	-1.150***
	[0.393]	[0.161]	[0.167]	[0.151]	[0.155]	[0.180]
Proportion of population aged 16-74 with no qualifications	-0.277					
	[0.185]					
Proportion of households without a car	0.141					
	[0.136]					
Proportion of households that are owner occupied	-0.179					
	[0.157]					

Proportion of households that are one pensioner households	-0.439*					
	[0.238]					
Lone parent households with dependent children	-0.001					
	[0.112]					
Proportion of population aged 16-74 that are permanently sick	0.326**	0.532***	0.489***	0.471***	0.550***	0.573***
	[0.133]	[0.120]	[0.124]	[0.124]	[0.103]	[0.116]
Proportion of those aged 16-74 that are long-term unemployed	0.046					
	[0.099]					
Proportion of those aged 16-74 working agriculture	-0.070***	-0.080***	-0.074***	-0.066***	-0.060***	
	[0.021]	[0.013]	[0.013]	[0.012]	[0.011]	
Proportion of those aged 16-74 in professional occupations	-0.339**	-0.100	-0.052	-0.115	-0.105	-0.008
	[0.146]	[0.095]	[0.096]	[0.098]	[0.096]	[0.100]
IMD 2010 Squared			0.133**	0.132**	0.129**	0.204***
			[0.064]	[0.059]	[0.060]	[0.064]
Constant	2.542**	2.020***	3.146***	3.191***	3.658***	3.929***
	[1.116]	[0.578]	[0.829]	[0.804]	[0.683]	[0.753]
Observations	151	151	151	151	151	151

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table A2 First-stage regression results for derivation of preferred specification for public health expenditure with healthcare expenditure, backward selection, 2013/14

	(1) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification	(2) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification	(3) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification	(4) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification	(5) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification	(6) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification	(7) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification	(8) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification	(9) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification	(10) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification
VARIABLES	**five instruments**	**five instruments**	**three instruments**	**three instruments**	**three instruments**	**three instruments**	**revised**	**revised**	**revised**	**revised**
DFT index_Public health_1314	0.727***	-0.029	0.724***	-0.028	0.748***	0.018	0.750***	0.017	0.746***	0.017
	[0.056]	[0.021]	[0.057]	[0.022]	[0.054]	[0.027]	[0.052]	[0.028]	[0.056]	[0.028]
Healthcare_DFT_index	0.427	0.351**	0.360	0.410***	0.715**	0.614***	0.548*	0.671***	0.403	0.669***
	[0.437]	[0.138]	[0.407]	[0.146]	[0.312]	[0.153]	[0.330]	[0.161]	[0.343]	[0.155]
Prescribing_Age_index	-1.067***	0.016	-1.201***	0.037	-1.490***	0.208***	-1.380***	0.169**	-1.233***	0.172**
	[0.271]	[0.083]	[0.263]	[0.082]	[0.240]	[0.074]	[0.269]	[0.078]	[0.242]	[0.069]
MFF Index_Public health_1314	1.264	0.490								
	[1.106]	[0.378]								
HCHS_MFF_index	-1.921	-0.240								
	[1.232]	[0.388]								
IMD 2010	0.126	-0.018	0.179	-0.046	0.132	0.028	0.215*	-0.000	0.162	-0.001
	[0.137]	[0.054]	[0.134]	[0.055]	[0.105]	[0.057]	[0.112]	[0.059]	[0.116]	[0.056]
Proportion of all residents born outside the EU	0.014	-0.034**	0.003	-0.037***	0.022	-0.042***	0.019	-0.041***	-0.021	-0.041***
	[0.049]	[0.013]	[0.049]	[0.013]	[0.033]	[0.013]	[0.034]	[0.013]	[0.029]	[0.013]
Proportion of population in white ethnic group	0.284	0.007	0.322*	-0.025	0.239**	-0.007	0.209*	0.004		
	[0.175]	[0.041]	[0.182]	[0.042]	[0.098]	[0.041]	[0.109]	[0.042]		

Proportion of population providing unpaid care	0.024	-0.029	0.128	-0.080	-0.123	-0.275***	-0.136	-0.270***	-0.303	-0.273***
	[0.328]	[0.105]	[0.344]	[0.109]	[0.221]	[0.088]	[0.222]	[0.087]	[0.199]	[0.078]
Proportion of population aged 16-74 with no qualifications	-0.212	-0.055	-0.252	-0.048						
	[0.154]	[0.063]	[0.157]	[0.064]						
Proportion of households without a car	0.095	0.124***	0.082	0.112***						
	[0.137]	[0.039]	[0.140]	[0.040]						
Proportion of households that are owner occupied	-0.042	-0.000	-0.057	-0.036						
	[0.127]	[0.049]	[0.123]	[0.047]						
Proportion of h'holds that are one pensioner households	-0.052	0.080	-0.042	0.073						
	[0.283]	[0.057]	[0.268]	[0.060]						
Lone parent households with dependent children	-0.010	-0.162***	-0.061	-0.143***						
	[0.116]	[0.037]	[0.103]	[0.037]						
Proportion of aged 16-74 that are permanently sick	0.342***	0.030	0.331**	0.034	0.487***	0.030	1.285**	-0.246	1.542***	-0.242
	[0.128]	[0.055]	[0.128]	[0.057]	[0.124]	[0.066]	[0.572]	[0.217]	[0.492]	[0.207]
Proportion of those 16-74 that are long-term unemployed	0.055	0.089***	0.056	0.093***						
	[0.084]	[0.033]	[0.086]	[0.033]						
Proportion of those aged 16-74 working agriculture	-0.038*	0.019***	-0.034*	0.015**						
	[0.019]	[0.006]	[0.019]	[0.006]						
Proportion of those aged 16-74 in professional occupations	-0.298**	-0.097**	-0.351**	-0.069	-0.157*	-0.063*	-0.105	-0.081**	-0.079	-0.080**
	[0.132]	[0.047]	[0.135]	[0.047]	[0.092]	[0.037]	[0.102]	[0.038]	[0.104]	[0.037]
Proportion of 16-74 that are permanently sick, squared							0.132	-0.046	0.161**	-0.045
							[0.089]	[0.034]	[0.080]	[0.033]
Constant	3.987***	7.244***	3.774***	7.249***	4.584***	6.254***	5.539***	5.923***	5.737***	5.927***
	[1.015]	[0.401]	[1.017]	[0.399]	[0.680]	[0.347]	[0.886]	[0.438]	[0.854]	[0.428]
Observations	150	150	150	150	150	150	150	150	150	150

Robust standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

Table A3 First-stage regression results for derivation of preferred specification for public health expenditure with healthcare expenditure, forward selection, 2013/14

	(1) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 1	(2) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 1	(3) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 1	(4) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 1	(5) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 2	(6) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 2	(7) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 3	(8) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 3	(9) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 4	(10) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 4
VARIABLES	**five instruments**	**five instruments**	**three instruments**	**three instruments**	**three instruments**	**three instruments**	**three instruments**	**three instruments**	**three instruments**	**three instruments**
DFT index_Public health_1314	0.729***	0.025	0.728***	0.026	0.725***	0.024	0.723***	0.009	0.715***	0.007
	[0.055]	[0.026]	[0.056]	[0.026]	[0.058]	[0.025]	[0.061]	[0.025]	[0.059]	[0.026]
MFF Index_Public health_1314	0.832	0.550								
	[1.006]	[0.416]								
Healthcare_DFT_index	0.633**	0.579***	0.504*	0.552***	0.373	0.457***	0.383	0.526***	0.447	0.542***
	[0.291]	[0.127]	[0.272]	[0.116]	[0.279]	[0.119]	[0.277]	[0.114]	[0.285]	[0.115]
Prescribing_Age_index	-1.591***	0.143**	-1.530***	0.147***	-1.326***	0.296***	-1.338***	0.206***	-1.263***	0.225***
	[0.146]	[0.059]	[0.095]	[0.039]	[0.199]	[0.068]	[0.228]	[0.067]	[0.235]	[0.070]
HCHS_MFF_index	-1.335	-0.729								
	[1.119]	[0.450]								
Proportion of 16-74 that are permanently sick	0.639***	0.065***	0.673***	0.073***	0.711***	0.101***	0.710***	0.094***	0.654***	0.080***
	[0.049]	[0.018]	[0.030]	[0.012]	[0.042]	[0.016]	[0.044]	[0.015]	[0.054]	[0.022]
Proportion of population providing unpaid care					-0.260	-0.189***	-0.268	-0.250***	-0.304	-0.259***
					[0.193]	[0.067]	[0.193]	[0.069]	[0.193]	[0.071]
Proportion of all residents born outside the EU							-0.004	-0.030***	-0.016	-0.033***
							[0.026]	[0.010]	[0.027]	[0.011]

Proportion of 16-74 that are long-term unemployed									0.091	0.023
									[0.058]	[0.028]
Constant	5.844***	7.257***	5.958***	7.286***	5.490***	6.945***	5.458***	6.708***	5.534***	6.727***
	[0.157]	[0.057]	[0.096]	[0.040]	[0.357]	[0.125]	[0.388]	[0.146]	[0.395]	[0.144]
Observations	150	150	150	150	150	150	150	150	150	150

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1