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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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Patient and public involvement statement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination of our research.

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All data are in the public domain.

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Abstract

Objectives

The UK government is proposing to cease cutting the local authority public health grant by re-allocating part of the treatment budget to preventative activity. This study examines whether this proposal is evidenced-based and, in particular, whether these resources are best re-allocated to prevention, or whether this expenditure would generate more health gains if used for treatment.

Methods

Instrumental variable regression methods are applied to English local authority data on mortality, healthcare and public health expenditure to estimate the responsiveness of mortality to changes in healthcare and public health expenditure in 2013/14. Using a well-established method, these mortality results are converted to a quality-adjusted life year (QALY) basis, and this facilitates the estimation of the cost per QALY for both National Health Service (NHS) healthcare and local public health expenditure.

Results

Saving lives and improving the quality of life requires resources. Our estimates suggest that each additional quality-adjusted life year (QALY) costs about £3,800 from the local public health budget, and that each additional QALY from the NHS budget costs about £13,500. These estimates can be used to calculate the number of QALYs generated by a budget boost. If we err on the side of caution and use the most conservative estimates that we have, then an additional £1bn spent on public health will generate 206,398 QALYs (95% CI 33,128 to 379,702 QALYs), and an additional £1bn spent on healthcare will generate 67,018 QALYs (95% CI 20,544 to 113,491 QALYs).

Conclusions

Additional public health expenditure is very productive of health and is more productive than additional NHS expenditure. However, both types of expenditure are more productive of health than the norms used by NICE (£30,000 per QALY) to judge whether new therapeutic technologies are suitable for adoption by the NHS.

Strengths and limitations of this study

- Cross-sectional analysis of the impact of public health and healthcare expenditure on mortality.
- The endogenous nature of expenditure is accommodated via the use of instrumental variable methods.
- The analysis includes potential effect modifiers and mediating factors.
- The estimated mortality effects are converted into quality-adjusted life year effects.
- There may be other mediating factors beyond those included in this study.

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1. Introduction

The UK's NHS spends about 5% of its annual budget on preventative activity with most of the remainder on treatment.[1] However, most observers agree that prevention is better than cure and two recent government publications emphasise the importance of prevention if the government's target gains in life expectancy by 2035 are to be realised.[2 3 4] The government's 2019 Spending Review announced that cuts to the public health grant will cease and that a real-terms increase from 2019/20 to 2020/21 will be achieved by a reprioritisation within the Department of Health's budget.[5 6] Although there is some debate about whether the increased funding will even compensate for increased costs,[7] this re-prioritisation raises the issue of whether these resources are best re-allocated to prevention, or whether this expenditure would generate more health gains if used for treatment.

There is considerable evidence that specific individual preventative interventions generate substantial health benefits. For example, a study of the cost per quality adjusted life year (QALY) associated with public health interventions assessed by the National Institute for Health and Care Excellence (NICE) over two five-year periods reported that the median cost per QALY was £1,053 between 2005 and 2010, and £7,843 between 2011 and 2016.[8] Both of these cost per QALY figures are far below the £30,000 threshold that NICE uses for the approval of new therapeutic treatments within the NHS.[9]

Studies of individual public health interventions are useful but, if budgets are re-allocated, we need to know the health gains associated with the increased spending on public health across *all* types of investments and the health losses associated with reduced spending on treatment (again, across *all* programmes that are likely to be curtailed). In other words, we need to know the health effects at the margin of changes in the totality of the public health and healthcare budgets.

There is some American evidence on the effect of public health expenditure on mortality but the relevance of this for the UK is limited because the US healthcare system is very different and these studies do not simultaneously account for the impact of treatment expenditure.[10]

There is considerable evidence about the marginal productivity of English NHS healthcare (treatment) expenditure.[11 12] However, we want to investigate the marginal productivity of preventative expenditure while simultaneously controlling for treatment expenditure, and the inclusion of prevention expenditure in the health outcome specification may affect the estimated marginal productivity of treatment expenditure.

Here we exploit the availability of a funding formula for the public health grant. This determines how much of the total national budget is allocated to each local authority. Some components of this formula are exogenous, i.e., they are not related to health outcomes except through their influence on the level of expenditure, and this makes it possible to identify the causal effect of changes in expenditure on mortality.

At the time of this study, the most recent mortality data available at a local level was for 2013/2014/2015 combined, and hence we relate expenditure in 2013/14 to a measure of mortality for these three years. Moreover, by converting healthcare (treatment) expenditure as reported by Clinical Commissioning Groups (CCGs) to a local authority geography, we are also able to estimate a health 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.

2. Methods

2.1 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 organized 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.

We use their reported expenditure from the programme budgeting dataset as a measure of local healthcare expenditure.[13] Primary care, specialised commissioning and *national* public health programmes were administered centrally. £2,203m was made available for these nationally funded 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).[14]

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. Here, our focus is on the impact of the local public health grant because we do not have data for expenditure on national programmes by local area. In 2013/14 local authorities spent 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.[15]

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 services) and some expenditure by CCGs will be preventative (eg on medication for blood pressure and blood cholesterol). This issue is discussed further in the online appendix (see section A1).

2.2 Estimation strategy

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

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

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.[16 17] 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 actual observed expenditure might be in part determined by outcomes. To circumvent this potential endogeniety and permit a causal interpretation of the estimated effect of expenditure, we first predict expenditure using exogenous elements in the funding formula (instruments) and then consider the relationship between the predicted (exogenous) variation in expenditure and health outcomes.

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:

local budget per person= (national budget per person) x (local age index) x (local additional needs index) x (local input price index) x (local DFT Index) (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.[16] The DFT index 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.[18]

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. We use these variables as instruments to predict expenditure, and then consider the relationship between this predicted level of expenditure and health outcomes. The MFF and DFT are valid instruments if they are not related to health outcomes (except through their influence on expenditure) or an unobserved confounder.[16 17]

The local input price index (MFF), which will reflect characteristics of the local (health) economy, could be correlated with unmeasured determinants of mortality (i.e., an unobserved confounder). 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 (see online appendix A2 for further discussion of this instrument). 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; (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.[17] 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 (backward selection). 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. Further details of this estimation process and the instruments for healthcare expenditure are in the online appendix A3. As a sensitivity analysis, we repeat our estimation strategy using forward selection to identify relevant controls when we have both public health and healthcare expenditure in the health outcome equation.

2.3 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 is not available 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. 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 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.

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)	152	1.0667	0.5362	0.5392	6.6247
Market Forces Factor (public health)	152	1.0122	0.0790	0.9151	1.2076
Distance from target (healthcare: total)	152	1.0055	0.0515	0.9282	1.2250
Age index (healthcare: prescribing)	152	0.9776	0.1283	0.6422	1.3007
Market Forces Factor (healthcare: HCHS)	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

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. All specifications are estimated using the *ivreg2* command in *Stata*.[19]

3. Results

3.1 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 is in column 1 of table A2 in online appendix A4. Application of the backward selection process generates the more parsimonious specification shown in column 2 of table 2. 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. Details of the intermediate estimations associated with this backward selection process are in the online appendix A4.

3.2 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 3 of table 2. 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 A4 in the online appendix A4.

Application of the backward selection process generates the more parsimonious result shown in column 4 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). Details of the intermediate estimations associated with the backward selection process are in the online appendix A4.

3.3 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 results are also reported using forward selection (see table 2, columns 5 and 6). Column 5 shows the result with the inclusion of the most significant single control ('permanently sick') with the same five instruments from the 'full' specification in column 3. Further re-estimation, with the inclusion of additional significant controls, generates the result shown in column 6. No further additional significant controls could be found and, as the result in column 6 is both in line with both our theoretical priors and passes the appropriate statistical tests, this is our preferred specification using forward selection. Details of the intermediate estimations associated with the forward selection process are in the online appendix.

The estimation of a mortality equation that includes both public health and healthcare expenditure generates 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 (£65bn for healthcare and £2.5bn for public health in 2013/14). The coefficient on public health expenditure from column 2 of table 2 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 that 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.

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

VARIABLES	(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 derived specification	(3) All causes **2013/14 PH & PB spend** SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage full specification **backward selection**	(4) All causes **2013/14 PH & PB spend** SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage derived specification **backward selection**	(5) All causes **2013/14 PH & PB spend** SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage initial specification **forward selection**	(6) All causes **2013/14 PH & PB spend** SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage derived specification **forward selection**
Public health spend per person	-0.084**	-0.115**	-0.024	-0.081**	-0.006	-0.144***
	[0.041]	[0.048]	[0.037]	[0.034]	[0.025]	[0.040]
Healthcare spend per person			-0.551	-0.672***	-1.012***	-0.837***
			[0.413]	[0.233]	[0.244]	[0.269]
IMD 2010	0.203***	-0.505***	0.253***	0.221***		
	[0.075]	[0.157]	[0.062]	[0.063]		
Proportion of all residents born outside the EU	-0.016		-0.043*	-0.084***		-0.070***
	[0.018]		[0.024]	[0.019]		[0.019]
Proportion of population in white ethnic group	0.246***		0.226***			
	[0.060]		[0.051]			
Proportion of population providing unpaid care	-0.439***	-0.231**	-0.399***	-0.479***		-0.547***
	[0.167]	[0.091]	[0.144]	[0.096]		[0.122]
Proportion of population aged 16-74 with no qualifications	-0.034		-0.111			
	[0.112]		[0.105]			
Proportion of households without a car	-0.062		-0.033			
	[0.072]		[0.087]			
Proportion of households that are owner occupied	0.129*		0.090			
	[0.071]		[0.075]			
Proportion of households that are one pensioner households	-0.082		-0.023			
	[0.084]		[0.079]			
Lone parent households with dependent children	0.056		-0.048			
	[0.060]		[0.082]			
Proportion of population aged 16-74 that are permanently sick	0.315***	0.475***	0.237***	1.187***	0.554***	0.601***
	[0.070]	[0.068]	[0.068]	[0.331]	[0.031]	[0.051]

Proportion of those aged 16-74 that are long-term unemployed	0.039		0.085			0.156***
	[0.057]		[0.060]			[0.040]
Proportion of those aged 16-74 working agriculture	-0.015		-0.007			
	[0.010]		[0.013]			
Proportion of those aged 16-74 in professional occupations	-0.201***	-0.205***	-0.259***	-0.194***		
	[0.077]	[0.049]	[0.072]	[0.045]		
IMD 2010, squared		0.092***				
		[0.028]				
Proportion of population aged 16-74 permanently sick, squared				0.138***		
				[0.052]		
Constant	5.532***	7.936***	8.714***	11.286***	15.008***	13.666***
	[0.649]	[0.402]	[2.852]	[1.409]	[1.756]	[1.762]
Observations	151	151	150	150	150	150
Endogeneity test statistic	11.369	10.579	5.928	17.683	6.137	22.853
Endogeneity p-value	0.001	0.001	0.052	0.000	0.046	0.000
Hansen-Sargan test statistic	14.750		20.849	1.667	23.78	1.465
Hansen-Sargan p-value	0.000		0.000	0.197	0.000	0.226
Kleibergen-Paap LM test statistic	26.821	32.762	9.027	16.034	24.002	18.331
Kleibergen-Paap p-value	0.000	0.000	0.060	0.000	0.000	0.000
Kleibergen-Paap F statistic	69.320	120.521	2.323	8.979	7.220	11.627
Pesaran-Taylor reset statistic	10.116	2.456	1.405	0.175	0.073	0.466
Pesaran-Taylor p-value	0.001	0.117	0.236	0.676	0.788	0.495
SW_PH F-statistic	n/a	n/a	70.796	70.796	100.608	57.002
SW_PH p-value	n/a	n/a	0.000	0.000	0.000	0.000
SW_PB F-statistic	n/a	n/a	13.469	13.469	9.052	17.375
SW_PB p-value	n/a	n/a	0.000	0.000	0.000	0.000

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

Direct estimates of the QALY effects of public health expenditure are not available. However, previous work has used the estimated mortality effects of changes in NHS healthcare expenditure to calculate the QALY effects,[12] and a similar approach is employed here. It is estimated that, in 2012/13, a 1% change in total healthcare expenditure generates 65,773 QALYs across all disease areas and this result implies an all-cause mortality elasticity 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).[12] Therefore, a 1% increase in public health expenditure (£25.107m), which reduces all-cause mortality by 0.115% is 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 local public health expenditure of £3,412 (column 3, table 3).

Similar calculations can be made for the two other public health elasticities (-0.081 and -0.144) reported in table 2 and the implied cost per QALY estimates are £4,845 and £2,725 respectively (see column 3 of table 3). Using the same method, we can also use convert the all-cause healthcare elasticities in column 2 of table 2 into cost per QALY estimates. The backward selection elasticity (=-0.672) implies a cost per QALY of £14,921, while the forward selection elasticity (=-0.837) implies a cost per QALY of £11,973 (see column 4 of table 3).

Another way to look at the impact of changes in expenditure is to calculate the total health gains/losses associated with any such change. For example, two leading health charities recently estimated that (local) public health funding would have to increase by £1bn in 2020/21 for real expenditure per person to be restored to its 2015/16 level.[20] We can use our cost per QALY estimates to calculate the total health gains associated with such a budget boost. If the £1bn is allocated to public health then the total health gain will be 206,398 QALYs (=£1bn/£4,845). This calculation uses the most conservative of the two elasticities for health outcomes (-0.081) associated with public health expenditure. Alternatively, if the additional £1bn is allocated to healthcare then the total health gain will be 67,018 QALYs (=£1bn/£14,921). This calculation uses the most conservative of the two elasticities for health outcomes (-0.672) associated with healthcare expenditure.

Similar health gain calculations can be made using the (less conservative) elasticities obtained using the forward selection process. The health gain estimates for public health and NHS treatment expenditure, and for forward and backward selection, are shown in columns 5 and 6 of table 3. These health gain estimates, together with 95% confidence intervals, are illustrated graphically in figure 1.

Table 3 Mortality elasticities and cost per quality adjusted life year estimates for public health and healthcare expenditure, 2013/14

Outcome specification	Mortality elasticity associated with public health expenditure	Mortality elasticity associated with healthcare expenditure	Cost per QALY (£)		Health (QALY) gains associated with £1bn budget boost	
			public health	healthcare	public health	healthcare
	col 1	col 2	col 3	col 4	col 5	col 6
With public health spend only:						
backward selection	-0.115	n/a	£3,412	n/a	293,083	n/a
	[0.048]	n/a				
With public health and healthcare spend						
(a) backward selection	-0.081	-0.672	£4,845	£14,912	206,415	67,060
	[0.034]	[0.233]				
(b) forward selection	-0.144	-0.837	£2,725	£11,973	366,960	83,473
	[0.040]	[0.269]				

4. Discussion

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 is £13,500. Similarly, the total health gains associated with a spending boost in public health are about three and a half times as great as those associated with the same boost in healthcare expenditure. This finding – that public health offers a much better return than healthcare at the margin – is also reported by other (American) studies.[10 21] Our (marginal) cost per QALY estimate for the public health grant (£3,800) is about halfway between the median cost per QALY associated with public health interventions assessed by NICE between 2005 and 2010 (£1,053), and between 2011 and 2016 (£7,843).[8]

Our cost per QALY estimates for the public health grant can also be compared with the return on investment associated with the public health interventions revealed by a systematic search of the literature.[22] This reported that, across both local and national interventions, 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 (this is the figure used by HM Treasury to evaluate public sector programmes).[23] Thus our cost per QALY estimates are very much in line with the findings from other studies that have used very different data sets and very 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 healthcare 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 new investments in public health interventions need to cost less than £3,800 per QALY to be accommodated within current levels of funding.

Our results also suggest that NHS expenditure is very productive of health (about £13,500 per QALY) and that it is considerably more productive than: (a) the norm (£30,000 per QALY) used by NICE to judge whether new technologies are cost-effective; and (b) HM Treasury's value of a QALY (£60,000) when assessing public sector projects.[23] Our results also suggest that the inclusion of prevention expenditure in the health outcome equation does not materially affect the estimated cost per QALY associated with treatment expenditure. The cost per QALY for NHS expenditure reported here is similar to previous estimates where public health expenditure was excluded.[11 12 17]

Different levels of expenditure on local public health services may affect mortality both directly and indirectly. For example, a recent review estimated that approximately one in five hospital in-patients in the UK are using alcohol harmfully, and one in ten is alcohol-dependent.[24] These figures are ten and eight times higher respectively than the general population.[24] Reductions in local community-based alcohol misuse services might increase alcohol-related mortality rates. They might also increase non-alcohol related mortality as addicts, who would have been treated in the community, now require hospitalisation and, by occupying a bed, delay other patients' access to hospital services.

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) and we ignore the impact of other health-related expenditure (eg such as social care). Second, we ignore the impact of national public health programmes (eg for national immunisation and national screening programmes). These are the responsibility of the NHS Commissioning Board and are omitted because we do not have data for expenditure on national programmes by local area. Also, 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.

Moreover, 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. In a recent 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.[25] 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. Finally, there is always the possibility that we have omitted a relevant variable (eg one that affects both mortality and expenditure) from our regression specifications and such an omission might bias our results.

5. Conclusions

An increase in public health expenditure is more productive of health than a change in NHS healthcare expenditure, and hence the recent proposal to shift resources away from the latter and towards the former is an evidence-based one. However, NHS healthcare expenditure is also productive of health and the cost per QALY (£13,500) is less than one-quarter of the value of a QALY (£60,000) used by HM Treasury when evaluating public sector projects. These comparisons suggest that additional prevention and healthcare expenditure, whether funded through additional taxation, borrowing or reallocation from other spending departments, appear good value when compared with the Treasury's estimates of the consumption value of health. Our cost per QALY calculations reveal that public health expenditure appears to be about three to four times more productive at the margin than healthcare expenditure. 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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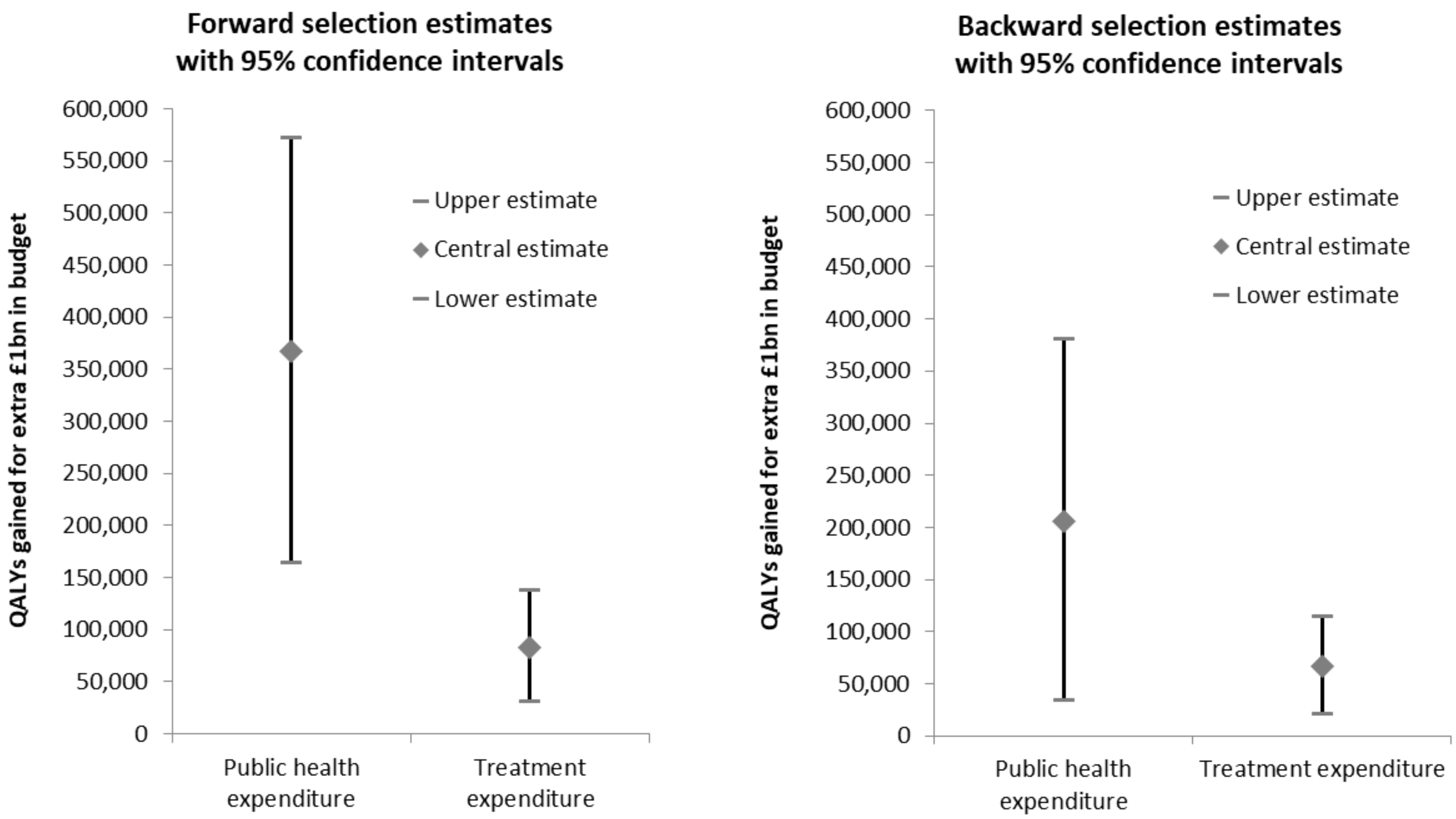
Figure 1 Total health gains associated with a £1bn budget boost for public health and NHS treatment expenditure, by method of selection of covariates

Figure 1 Total health gains associated with a £1bn budget boost for public health and NHS treatment expenditure, by method of selection of covariates



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

Appendices

Appendix A1

Is public health expenditure solely preventative?

One rudimentary guide to the volume of preventative expenditure by CCGs is provided by the programme budgeting data set for 2013/14. This 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'.[1] 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.

Appendix A2

On the use of the market forces factor (MFF) as an instrument for public health expenditure

The local input price index (MFF), which will reflect characteristics of the local (health) economy, may 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. 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.

Appendix A3

Estimation strategy with the inclusion of healthcare expenditure

Initially the health outcome equation (equation 1) is estimated using the strategy described in section 2.2 with public health as the sole health expenditure variable. We then re-estimate equation 1 – using the same 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 that stripped out actual expenditure on these components and, for 2013-14, each CCG was given an uplift of 2.3% on these 2012 baselines.[2]

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 cost component of the total allocation. The DFT variable is available from the Department of Health's website at https://www.networks.nhs.uk/nhsnetworks/health-investment-network/news/2012-13-programme-budgeting-data-is-nowavailable (accessed 09 January 2019), and the MFF and prescribing cost 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).

A recent study provided no explicit arguments in support of these instruments for healthcare expenditure but this omission is easily remedied.[3] First, our measure of mortality and the prescribing cost 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 and these might 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. 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 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.

Appendix A4

Extended presentation of results

With the public health grant as the only expenditure variable

Estimation of the health outcome equation (equation 1) with public health as the sole expenditure variable generates the result shown in column 1 of table A1. The corresponding first-stage result is in column 1 of table A2. Application of the backward selection process generates the more parsimonious specification shown in column 2 of table A1. 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 pvalue<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.

Table A1 Derivation of preferred specification for public health expenditure, second-stage results, 2013/14

VARIABLES	(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 SA_1	(6) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model instrument PH spend weighted IV second stage new derivation revised2 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 A2 First-stage regression results for derivation of preferred specification for public health expenditure, 2013/14

VARIABLES	(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 SA_1	(6) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS new derivation revised2 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

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 A3. 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 A4.

Some authors have expressed concern about the inclusion of weak instruments,[4] and hence we re-estimate the 'full' specification without the two insignificant MFF instruments (see column 2 of table A3). 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 is significant when added as a control to the second-stage, we found that the 'permanently sick' variable squared 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 A3 Derivation of preferred specification for public health expenditure with healthcare expenditure, backward selection, 2013/14

VARIABLES	(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 five instruments	(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 three instruments	(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 three instruments	(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 revised	(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 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

Table A4 First-stage regression results for derivation of preferred specification for public health expenditure with healthcare expenditure, backward selection, 2013/14

VARIABLES	(1) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification five instruments	(2) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification five instruments	(3) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification three instruments	(4) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification three instruments	(5) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification three instruments	(6) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification three instruments	(7) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification revised	(8) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification revised	(9) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification revised	(10) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification 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

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 A5 for the second-stage and table A6 for the first-stage results). Column 1 of table A5 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 A3. 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 A5) 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 A5 Derivation of preferred specification for public health expenditure with healthcare expenditure, forward selection, 2013/14

VARIABLES	(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 five instruments	(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 three instruments	(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 three instruments	(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 three instruments	(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 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

Table A6 First-stage regression results for derivation of preferred specification for public health expenditure with healthcare expenditure, forward selection, 2013/14

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	All causes	All causes	All causes	All causes	All causes	All causes	All causes	All causes	All causes	All causes
	2013/14 PH spend	2013/14 PB spend	2013/14 PH spend	2013/14 PB spend	2013/14 PH spend	2013/14 PB spend	2013/14 PH spend	2013/14 PB spend	2013/14 PH spend	2013/14 PB spend
	SYLLR 2013/14/15	SYLLR 2013/14/15	SYLLR 2013/14/15	SYLLR 2013/14/15	SYLLR 2013/14/15	SYLLR 2013/14/15	SYLLR 2013/14/15	SYLLR 2013/14/15	SYLLR 2013/14/15	SYLLR 2013/14/15
	outcome model	outcome model	outcome model	outcome model	outcome model	outcome model	outcome model	outcome model	outcome model	outcome model
	first-stage	first-stage	first-stage	first-stage	first-stage	first-stage	first-stage	first-stage	first-stage	first-stage
	weighted	weighted	weighted	weighted	weighted	weighted	weighted	weighted	weighted	weighted
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
	forward selection	forward selection	forward selection	forward selection	forward selection	forward selection	forward selection	forward selection	forward selection	forward selection
	round 1	round 1	round 1	round 1	round 2	round 2	round 3	round 3	round 4	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

References for appendices

1. NHS England (2015). 2013-14 CCG Programme Budgeting Benchmarking Tool. Available from https://www.england.nhs.uk/prog-budgeting/ [accessed 08 January, 2019].

2. DH (2018). Personal communication, 07 November.

3. Andrews, M. et al., 2017. Inference in the presence of redundant moment conditions and the impact of government health expenditure on health outcomes in England. Econometric Reviews, 36(1–3), pp.23–41. Available at: https://www.tandfonline.com/doi/full/10.1080/07474938.2016.1114205 [Accessed July 24, 2017].

4. Small, D.S. (2007). Sensitivity analysis for instrumental variables regression with overidentifying restrictions. Journal of the American Statistical Association **102**(479), 1049-1058.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5-6
Objectives	3	State specific objectives, including any prespecified hypotheses	5-6
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	6-7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	10-11
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	10-11
Bias	9	Describe any efforts to address potential sources of bias	7-9
Study size	10	Explain how the study size was arrived at	10
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-9
		(*b*) Describe any methods used to examine subgroups and interactions	None
		(*c*) Explain how missing data were addressed	10
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n/a
		(*e*) Describe any sensitivity analyses	11-14
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Table 2
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	10
Outcome data	15*	Report numbers of outcome events or summary measures	10-11

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-14 & Table 2
		(*b*) Report category boundaries when continuous variables were categorized	n/a
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11-14
Discussion			
Key results	18	Summarise key results with reference to study objectives	14-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-16
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Is an ounce of prevention worth a pound of cure? A cross-sectional study 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? A cross-sectional study of the impact of English public health grant on mortality and morbidity

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All (SM, JL and KC) authors contributed to the concept and design of this paper. SM led on the analysis and drafting, and the final paper was edited and approved by all three authors. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting these criteria have been omitted. SM is the paper's guarantor.

Transparency declaration

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

Details of ethical approval

Ethical approval was not required because neither human participants nor animals were involved in the study.

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Statement of independence of researchers from funders

Although funded by the DHSC, the Department had no influence on the study design, the way in which the research was undertaken, or the results.

Patient and public involvement statement

Neither patients nor the public were involved in the design, or conduct, or reporting, or dissemination of our research.

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Data sharing statement

All of the raw data are in the public domain. The healthcare expenditure data are available in the 2013-14 CCG Programme Budgeting Benchmarking Tool. This is available from https://www.england.nhs.uk/prog-budgeting/ [accessed 14 July, 2020]. The socio-economic variables have been constructed from the 2011 Population Census. These are available from the Office for National Statistics at https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/2011censuskeystatisticsforlocalauthoritiesinenglandandwales [accessed 14 July, 2020]. The public health expenditure data are available from 'Local authority revenue expenditure and financing England: 2013 to 2014 individual local authority data – outturn' which is available from https://www.gov.uk/government/statistics/local-authority-revenue-expenditure-and-financing-england-2013-to-2014-individual-local-authority-data-outturn [accessed 14 July, 2020]'. The instruments for public health expenditure are available in 'Exposition Book Public Health Allocations 2013-14 and 2014-15: Technical Guide' and this is available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/213324/Public-Health-Weighted-Capitation-FormulaTechnical-Guide-v0.13.pdf [accessed 14 July, 2020]. The DFT variable for healthcare expenditure is available from the Department of Health's website at https://www.networks.nhs.uk/nhsnetworks/health-investment-network/news/2012-13-programme-budgeting-data-is-now-available [accessed 14 July, 2020], and the MFF and prescribing cost 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 14 July, 2020].

Similarities between the present paper and the paper available at https://www.york.ac.uk/media/che/documents/papers/researchpapers/CHERP166_Impact_Public_Health_Mortality_Morbidity.pdf.

The initial version of the submitted paper was re-written for a much wider audience with most of the more technical material moved to appendices. The revised version of the submitted paper has also benefitted from important changes prompted by the reviewers' comments on the initial submission.

Word count

The text consists of 5,035 words. There are three tables in this document. There are also two figures each in a separate file.

Is an ounce of prevention worth a pound of cure?
A cross-sectional study of the impact of English public health grant on mortality and morbidity

Abstract

Objectives

The UK government is proposing to cease cutting the local authority public health grant by re-allocating part of the treatment budget to preventative activity. This study examines whether this proposal is evidenced-based and, in particular, whether these resources are best re-allocated to prevention, or whether this expenditure would generate more health gains if used for treatment.

Methods

Instrumental variable regression methods are applied to English local authority data on mortality, healthcare and public health expenditure to estimate the responsiveness of mortality to variations in healthcare and public health expenditure in 2013/14. Using a well-established method, these mortality results are converted to a quality-adjusted life year (QALY) basis, and this facilitates the estimation of the cost per QALY for both National Health Service (NHS) healthcare and local public health expenditure.

Results

Saving lives and improving the quality of life requires resources. Our estimates suggest that each additional quality-adjusted life year (QALY) costs about £3,800 from the local public health budget, and that each additional QALY from the NHS budget costs about £13,500. These estimates can be used to calculate the number of QALYs generated by a budget boost. If we err on the side of caution and use the most conservative estimates that we have, then an additional £1bn spent on public health will generate 206,398 QALYs (95% CI 36,591 to 376,205 QALYs), and an additional £1bn spent on healthcare will generate 67,060 QALYs (95% CI 21,487 to 112,633 QALYs).

Conclusions

Additional public health expenditure is very productive of health and is more productive than additional NHS expenditure. However, both types of expenditure are more productive of health than the norms used by NICE (£20,000 to £30,000 per QALY) to judge whether new therapeutic technologies are suitable for adoption by the NHS.

Strengths and limitations of this study

- Cross-sectional analysis of the impact of public health and healthcare expenditure on mortality.
- The endogenous nature of expenditure is accommodated via the use of instrumental variable methods.
- The analysis includes controls for the need for healthcare expenditure.
- The estimated mortality effects are converted into quality-adjusted life year effects.
- There may be other healthcare need factors beyond those included in this study.

Is an ounce of prevention worth a pound of cure?
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1. Introduction

The UK's NHS spends about 5% of its annual budget on preventative activity with most of the remainder on treatment.[1] However, most observers agree that prevention is better than cure and two recent government publications emphasise the importance of prevention if the government's target gains in life expectancy by 2035 are to be realised.[2 3 4] The government's 2019 Spending Review announced that cuts to the public health grant will cease and that a real-terms increase from 2019/20 to 2020/21 will be achieved by a reprioritisation within the Department of Health's budget.[5 6] Although there is some debate about whether the increased funding will even compensate for increased costs,[7] this re-prioritisation raises the issue of whether these resources are best re-allocated to prevention, or whether this expenditure would generate more health gains if used for treatment.

There is considerable evidence that specific individual preventative interventions generate substantial health benefits. For example, a study of the cost per quality adjusted life year (QALY) associated with public health interventions assessed by the National Institute for Health and Care Excellence (NICE) over two five-year periods reported that the median cost per QALY was £1,053 between 2005 and 2010, and £7,843 between 2011 and 2016.[8] Both of these cost per QALY figures are far below the £30,000 threshold that NICE uses for the approval of new therapeutic treatments within the NHS.[9]

Studies of individual public health interventions are useful but, if budgets are re-allocated, we need to know the health gains associated with the increased spending on public health across *all* types of investments and the health losses associated with reduced spending on treatment (again, across *all* programmes that are likely to be curtailed). In other words, we need to know the health effects at the margin of changes in the totality of the public health and healthcare budgets.

There is some American evidence on the effect of public health expenditure on mortality but the relevance of this for the UK is limited because the US healthcare system is very different and these studies do not simultaneously account for the impact of treatment expenditure.[10]

There is considerable evidence about the marginal productivity of English NHS healthcare (treatment) expenditure.[11 12] However, we want to investigate the marginal productivity of preventative expenditure while simultaneously controlling for treatment expenditure, and the inclusion of prevention expenditure in the health outcome specification may affect the estimated marginal productivity of treatment expenditure.

Here we exploit the availability of a funding formula for the public health grant. This determines how much of the total national budget is allocated to each local authority. Some components of this formula are conditionally exogenous, i.e., they are not related to health outcomes after controlling for the need for healthcare, except through their influence on the level of expenditure, and this makes it possible to identify the causal effect of changes in expenditure on mortality.

At the time of this study, the most recent mortality data available at a local level was for 2013/2014/2015 combined, and hence we relate expenditure in 2013/14 to a measure of mortality for these three years. Moreover, by converting healthcare (treatment) expenditure as reported by Clinical Commissioning Groups (CCGs) to a local authority geography, we are also able to estimate a health 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.

2. Methods

2.1 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 achieved 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 organized 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 including inpatient care, outpatient and community care, and pharmaceutical prescriptions. We use their reported expenditure from the programme budgeting dataset as a measure of local healthcare expenditure.[13] Primary care, specialised commissioning and *national* public health programmes were administered centrally. £2,203m was made available for these nationally funded 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).[14]

Responsibility for *local* public health was delegated to local government with each 'unitary' or upper tier local authority receiving a fixed annual budget, ring-fenced for public health activities. Here, our focus is on the impact of the local public health grant because we do not have data for expenditure on national programmes by local area. In 2013/14 local authorities spent 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.[15]

We sometimes refer to public health expenditure as 'preventative' and CCG 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 services) and some expenditure by CCGs will be preventative (eg on medication for blood pressure and blood cholesterol). This issue is discussed further in the online appendix (see section A1). Strictly speaking, we are comparing the productivity of the public health grant with CCG healthcare expenditure but we believe that it is reasonable to think of this as a comparison of the marginal productivity of preventative and treatment expenditure.

2.2 Estimation strategy

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

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

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.[16 17] 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.

Even after controlling for observable need for health expenditure, estimating the impact of health expenditure on mortality is challenging for two reasons and these are illustrated in the top half of Figure 1: first, there might be some reverse causation with historical mortality influencing the current level of expenditure; and second, there might be some unobserved factor that is driving both expenditure and mortality. Our estimation approach involves finding variables (known as 'instruments') that are good predictors of expenditure but which have no direct impact on either mortality or unobserved factors.
These instruments are used to predict the level of expenditure that is not influenced by either historical mortality or unobserved factors. Having severed the link with unobserved factors and mortality, the *predicted* level of expenditure can then be used in a regression model to examine the causal impact of expenditure on mortality (bottom half of Figure 1).

Insert Figure 1 near here

We use the resource allocation formula for the public health grant to local authorities as a source of instruments for public health expenditure. This formula 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:
local budget per person= (national budget per person) x (local age index) x
(local additional needs index) x (local input price index) x (local DFT Index) (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.[16] The DFT index 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.[18]

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. We use these variables as instruments to predict expenditure, and then estimate the relationship between this predicted level of expenditure and health outcomes. The MFF and DFT are valid instruments if they are not related to health outcomes (except through their influence on expenditure) or an unobserved confounder.[16 17]

The local input price index (MFF), which will reflect characteristics of the local (health) economy, could be correlated with unmeasured determinants of mortality (i.e., an unobserved confounder). 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 (see online appendix A2 for further discussion of this instrument). 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; (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.[17] 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 (backward selection). 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. Further details of this estimation process and the instruments for healthcare expenditure are in the online appendix A3. As a sensitivity analysis, we repeat our estimation strategy using forward selection to identify relevant controls when we have both public health and healthcare expenditure in the health outcome equation.

2.3 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 is not available 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. 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). 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.

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)	152	1.0667	0.5362	0.5392	6.6247
Market Forces Factor (public health)	152	1.0122	0.0790	0.9151	1.2076
Distance from target (healthcare: total)	152	1.0055	0.0515	0.9282	1.2250
Age index (healthcare: prescribing)	152	0.9776	0.1283	0.6422	1.3007
Market Forces Factor (healthcare: HCHS)	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

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. Further details about the data can be found elsewhere.[19] All specifications are estimated using the *ivreg2* command in *Stata*.[20]

2.4 Patient and public involvement

Neither patients nor the public were involved in the design, or conduct, or reporting, or dissemination of our research.

3. Results

3.1 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. Application of the backward selection process generates the more parsimonious specification shown in column 2 of table 2. 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. Details of the intermediate estimations associated with this backward selection process are in the online appendix A4 (see table A1 for the second-stage and table A2 for the first-stage results).

3.2 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 3 of table 2. This specification includes five instruments (two for public health expenditure and three for healthcare expenditure). Application of the backward selection process generates the more parsimonious result shown in column 4 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). Details of the intermediate estimations associated with the backward selection process are in the online appendix A4 (see table A3 for the second-stage and table A4 for the first-stage results).

3.3 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 results are also reported using forward selection (see table 2, columns 5 and 6). Column 5 shows the result with the inclusion of the most significant single control ('permanently sick') with the same five instruments from the 'full' specification in column 3. Further re-estimation, with the inclusion of additional significant controls, generates the result shown in column 6. No further additional significant controls could be found and, as the result in column 6 is both in line with both our theoretical priors and passes the appropriate statistical tests, this is our preferred specification using forward selection. Details of the intermediate estimations associated with the forward selection process are in the online appendix (see tables A5 and A6 in appendix A4).

The estimation of a mortality equation that includes both public health and healthcare expenditure generates 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 (£65bn for healthcare and £2.5bn for public health in 2013/14). The coefficient on public health expenditure from column 2 of table 2 implies that a 1% increase in such expenditure (=£25.107m) in 2013/14 is associated with a 0.115% decline in mortality. With 446,560 deaths in England in 2013, the coefficient on public health expenditure implies that an additional £25.107m of expenditure would avert 514 deaths (=0.115% of 446,560) and that the cost per death averted would be £48,894. Similar calculations can be made for the other outcome elasticities reported in table 2 and summarised in columns 1 and 2 of table 3. The resulting cost per death averted estimates are shown in columns 3 and 4 of table 3. The estimates reveal that the healthcare cost of a death averted is between three times (backward selection) and four times (forward selection) the size of the public health cost.

Although interesting, the cost per death averted estimates are of limited relevance because a large proportion of CCG expenditure is not directed towards saving life but to improving the quality of life. To capture the full health effects associated with a change in expenditure, we require a measure that incorporates both survival and quality of life effects, i.e., we require a measure of the number of quality-adjusted life-years (QALYs).

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

VARIABLES	(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 derived specification	(3) All causes **2013/14 PH & PB spend** SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage full specification **backward selection**	(4) All causes **2013/14 PH & PB spend** SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage derived specification **backward selection**	(5) All causes **2013/14 PH & PB spend** SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage initial specification **forward selection**	(6) All causes **2013/14 PH & PB spend** SYLLR 2013/14/15 outcome model instrument PH&PB spend weighted IV second stage derived specification **forward selection**
Public health spend per person	-0.084**	-0.115**	-0.024	-0.081**	-0.006	-0.144***
	[0.041]	[0.048]	[0.037]	[0.034]	[0.025]	[0.040]
Healthcare spend per person			-0.551	-0.672***	-1.012***	-0.837***
			[0.413]	[0.233]	[0.244]	[0.269]
IMD 2010	0.203***	-0.505***	0.253***	0.221***		
	[0.075]	[0.157]	[0.062]	[0.063]		
Proportion of all residents born outside the EU	-0.016		-0.043*	-0.084***		-0.070***
	[0.018]		[0.024]	[0.019]		[0.019]
Proportion of population in white ethnic group	0.246***		0.226***			
	[0.060]		[0.051]			
Proportion of population providing unpaid care	-0.439***	-0.231**	-0.399***	-0.479***		-0.547***
	[0.167]	[0.091]	[0.144]	[0.096]		[0.122]
Proportion of population aged 16-74 with no qualifications	-0.034		-0.111			
	[0.112]		[0.105]			
Proportion of households without a car	-0.062		-0.033			
	[0.072]		[0.087]			
Proportion of households that are owner occupied	0.129*		0.090			
	[0.071]		[0.075]			
Proportion of households that are one pensioner households	-0.082		-0.023			
	[0.084]		[0.079]			
Lone parent households with dependent children	0.056		-0.048			
	[0.060]		[0.082]			
Proportion of population aged 16-74 that are permanently sick	0.315***	0.475***	0.237***	1.187***	0.554***	0.601***
	[0.070]	[0.068]	[0.068]	[0.331]	[0.031]	[0.051]

Proportion of those aged 16-74 that are long-term unemployed	0.039		0.085			0.156***
	[0.057]		[0.060]			[0.040]
Proportion of those aged 16-74 working agriculture	-0.015		-0.007			
	[0.010]		[0.013]			
Proportion of those aged 16-74 in professional occupations	-0.201***	-0.205***	-0.259***	-0.194***		
	[0.077]	[0.049]	[0.072]	[0.045]		
IMD 2010, squared		0.092***				
		[0.028]				
Proportion of population aged 16-74 permanently sick, squared				0.138***		
				[0.052]		
Constant	5.532***	7.936***	8.714***	11.286***	15.008***	13.666***
	[0.649]	[0.402]	[2.852]	[1.409]	[1.756]	[1.762]
Observations	151	151	150	150	150	150
Endogeneity test statistic	11.369	10.579	5.928	17.683	6.137	22.853
Endogeneity p-value	0.001	0.001	0.052	0.000	0.046	0.000
Hansen-Sargan test statistic	14.750		20.849	1.667	23.78	1.465
Hansen-Sargan p-value	0.000		0.000	0.197	0.000	0.226
Kleibergen-Paap LM test statistic	26.821	32.762	9.027	16.034	24.002	18.331
Kleibergen-Paap p-value	0.000	0.000	0.060	0.000	0.000	0.000
Kleibergen-Paap F statistic	69.320	120.521	2.323	8.979	7.220	11.627
Pesaran-Taylor reset statistic	10.116	2.456	1.405	0.175	0.073	0.466
Pesaran-Taylor p-value	0.001	0.117	0.236	0.676	0.788	0.495
SW_PH F-statistic	n/a	n/a	70.796	70.796	100.608	57.002
SW_PH p-value	n/a	n/a	0.000	0.000	0.000	0.000
SW_PB F-statistic	n/a	n/a	13.469	13.469	9.052	17.375
SW_PB p-value	n/a	n/a	0.000	0.000	0.000	0.000

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

Unfortunately, direct estimates of the QALY effects of public health expenditure are not available. However, previous work has used the estimated mortality effects of changes in NHS healthcare expenditure to calculate the QALY effects[12] . We can apply the same approach to estimate the QALY effects of public health expenditure if we assume that the distribution of mortality benefits across disease areas for public health expenditure is similar to that for CCG expenditure.

Previous work estimated that, in 2012/13, a 1% change in total healthcare expenditure generates 65,773 QALYs across all disease areas and this result implies an all-cause mortality elasticity 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).[12] Therefore, a 1% increase in public health expenditure (£25.107m), which reduces all-cause mortality by 0.115% is 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 local public health expenditure of £3,412 (column 5, table 3).

Similar calculations can be made for the two other public health elasticities (-0.081 and -0.144) reported in table 2 and the implied cost per QALY estimates are £4,845 and £2,725 respectively (see column 5 of table 3). Using the same method, we can also use convert the all-cause healthcare elasticities in column 2 of table 2 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 (see column 6 of table 3).

Another way to look at the impact of changes in expenditure is to calculate the total health gains/losses associated with any such change. For example, two leading health charities recently estimated that (local) public health funding would have to increase by £1bn in 2020/21 for real expenditure per person to be restored to its 2015/16 level.[21] We can use our cost per QALY estimates to calculate the total health gains associated with such a budget boost. If the £1bn is allocated to public health then the total health gain will be 206,398 QALYs (=£1bn/£4,845). This calculation uses the most conservative of the two elasticities for health outcomes (-0.081) associated with public health expenditure. Alternatively, if the additional £1bn is allocated to healthcare then the total health gain will be 67,060 QALYs

(=£1bn/£14,912). This calculation uses the most conservative of the two elasticities for health outcomes (-0.672) associated with healthcare expenditure.

Similar health gain calculations can be made using the (less conservative) elasticities obtained using the forward selection process. The health gain estimates for public health and NHS treatment expenditure, and for forward and backward selection, are shown in columns 7 and 8 of table 3. These health gain estimates, together with 95% confidence intervals, are illustrated graphically in figure 2

Insert figure 2 near here.

Using the point and standard error estimates associated with the mortality elasticities in table 3, we undertook a simulation study of the difference between the public health and CCG QALY gains associated with the budget boost described in columns 7 and 8 of table 3. We made one million pairs of draws from the two distributions. We found that the public health QALY gain was greater than the CCG QALY gain in just over 94% of the draws from the backward selection estimates, and that this proportion increased to over 99% when the forward selection estimates were used. We conclude that the marginal public health QALY effect is greater than the CCG healthcare effect.

Table 3 Mortality elasticities and cost per quality adjusted life year estimates for public health and healthcare expenditure, 2013/14

Outcome specification	Mortality elasticity associated with public health expenditure	Mortality elasticity associated with healthcare expenditure	Cost per death averted (£)		Cost per QALY (£)		Health (QALY) gains associated with £1bn budget boost	
			public health	healthcare	public health	healthcare	public health	healthcare
	col 1	col 2	col 3	col 4	col 5	col 6	col 7	col 8
With public health spend only:								
backward selection	-0.115	n/a	£48,894	n/a	£3,412	n/a	293,083	n/a
	[0.048]	n/a						
With public health and healthcare spend:								
(a) backward selection	-0.081	-0.672	£69,414	£213,780	£4,845	£14,912	206,398	67,060
	[0.034]	[0.233]						
(b) forward selection	-0.144	-0.837	£39,047	£171,631	£2,725	£11,973	366,973	83,512
	[0.040]	[0.269]						

4. Discussion

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 is £13,500. Similarly, the total health gains associated with a spending boost in public health are about three and a half times as great as those associated with the same boost in healthcare expenditure. This finding – that public health offers a much better return than healthcare at the margin – is also reported by other (American) studies.[10 22] Our (marginal) cost per QALY estimate for the public health grant (£3,800) is about halfway between the median cost per QALY associated with public health interventions assessed by NICE between 2005 and 2010 (£1,053), and between 2011 and 2016 (£7,843).[8]

Our cost per QALY estimates for the public health grant can also be compared with the return on investment associated with the public health interventions revealed by a systematic search of the literature.[23] This reported that, across both local and national interventions, 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 (this is the figure used by HM Treasury to evaluate public sector programmes).[24] Thus our cost per QALY estimates are very much in line with the findings from other studies that have used very different data sets and very 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 healthcare 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 new investments in public health interventions need to cost less than £3,800 per QALY to be accommodated within current levels of funding.

Our results also suggest that NHS expenditure is very productive of health (about £13,500 per QALY) and that it is considerably more productive than: (a) the norm (£30,000 per QALY) used by NICE to judge whether new technologies are cost-effective; and (b) HM Treasury's value of a QALY (£60,000) when assessing public sector projects.[24] Our results also suggest that the inclusion of prevention expenditure in the health outcome equation does not materially affect the estimated cost per QALY associated with treatment expenditure. The cost per QALY for NHS expenditure reported here is similar to previous estimates where public health expenditure was excluded.[11 12 17]

Different levels of expenditure on local public health services may affect mortality both directly and indirectly. For example, a recent review estimated that approximately one in five hospital in-patients in the UK are using alcohol harmfully, and one in ten is alcohol-dependent.[25] These figures are ten and eight times higher respectively than the general population.[25] Reductions in local community-based alcohol misuse services might increase alcohol-related mortality rates. They might also increase non-alcohol related mortality as addicts, who would have been treated in the community, now require hospitalisation and, by occupying a bed, delay other patients' access to hospital services.

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) and we ignore the impact of other health-related expenditure (eg such as social care). Second, we ignore the impact of national public health programmes (eg for national immunisation and national screening programmes). These are the responsibility of the NHS Commissioning Board and are omitted because we do not have data for expenditure on national programmes by local area. Also, 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.

Moreover, 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. In a recent 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.[26] 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 local authority have been reasonably stable over a period of time, and that any lagged of effect of current expenditure on future mortality is offset by the impact of previous expenditure on current mortality. These are 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.

The final limitation that must be mentioned is that there is always the possibility that we have omitted a relevant variable (eg one that affects both mortality and expenditure) from our regression specifications and such an omission might affect our results.

5. Conclusions

An increase in public health expenditure is more productive of health than a change in NHS healthcare expenditure, and hence the recent proposal to shift resources away from the latter and towards the former is an evidence-based one. However, NHS healthcare expenditure is also productive of health and the cost per QALY (£13,500) is less than one-quarter of the value of a QALY (£60,000) used by HM Treasury when evaluating public sector projects. These comparisons suggest that additional prevention and healthcare expenditure, whether funded through additional taxation, borrowing or reallocation from other spending departments, appear good value when compared with the Treasury's estimates of the consumption value of health. Our cost per QALY calculations reveal that public health expenditure appears to be about three to four times more productive at the margin than healthcare expenditure. 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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Figure 1 Causal paths diagram

Figure 2 Total health gains associated with a £1bn budget boost for public health and NHS treatment expenditure, by method of selection of covariates

Figure 1 Causal paths diagram

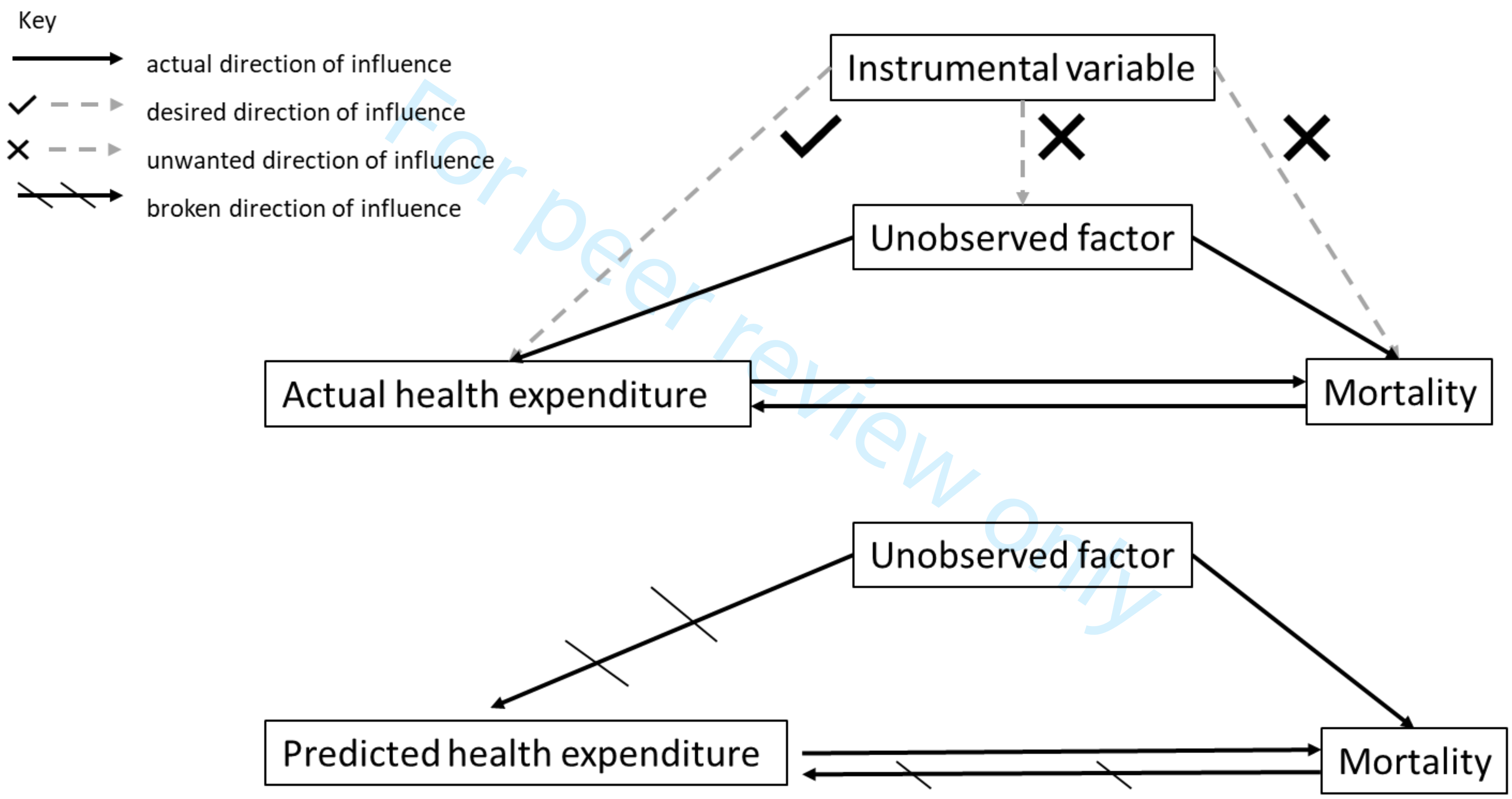
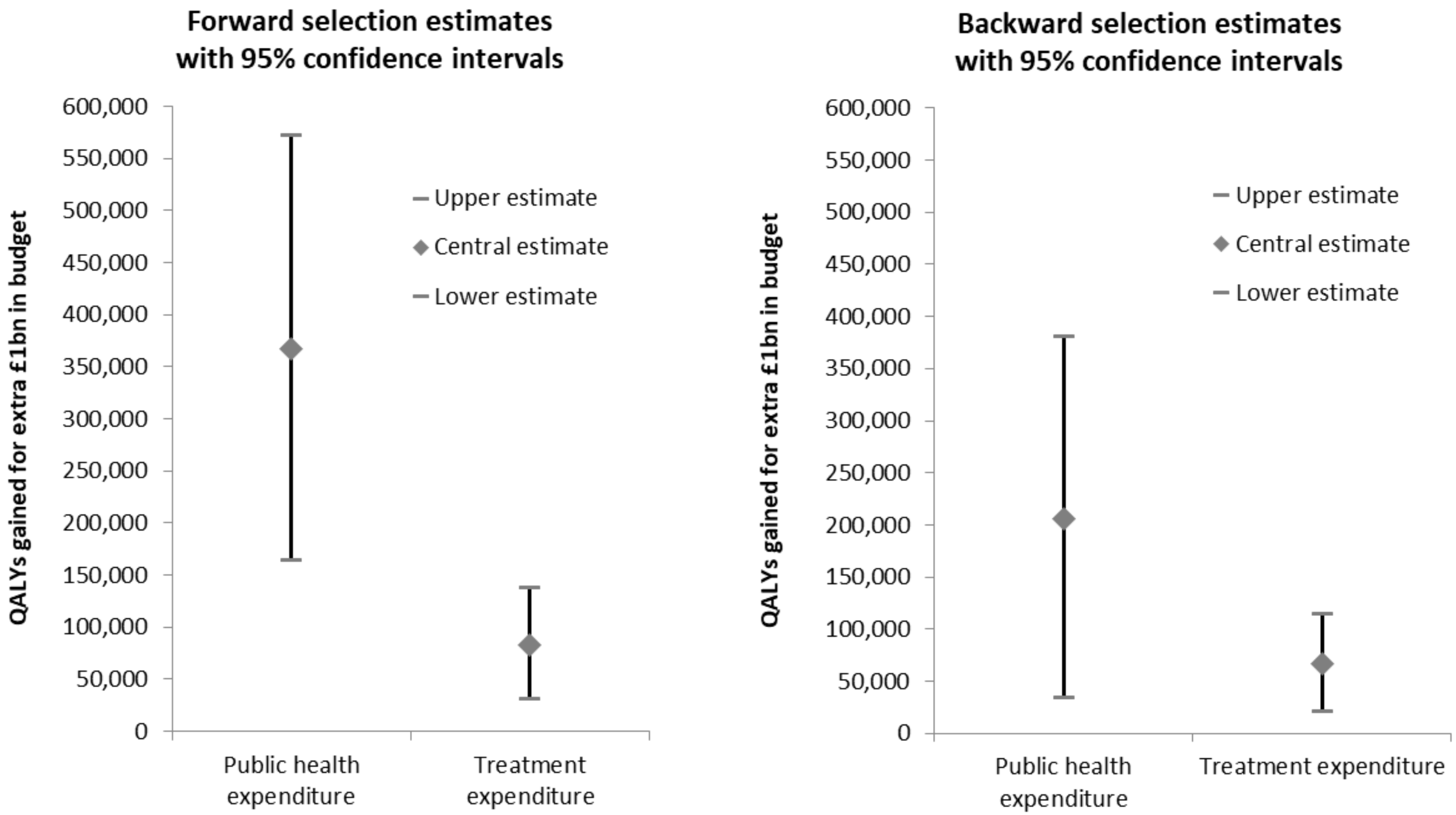


Figure 2 Total health gains associated with a £1bn budget boost for public health and NHS treatment expenditure, by method of selection of covariates



Is an ounce of prevention worth a pound of cure?
A cross-sectional study of the impact of the
English public health grant on mortality and morbidity

Appendices

Appendix A1

Is public health expenditure solely preventative?

One rudimentary guide to the volume of preventative expenditure by CCGs is provided by the programme budgeting data set for 2013/14. This 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'.[1] 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.

Appendix A2

On the use of the market forces factor (MFF) as an instrument for public health expenditure

The local input price index (MFF), which will reflect characteristics of the local (health) economy, may 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. 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.

Appendix A3

Estimation strategy with the inclusion of healthcare expenditure

Initially the health outcome equation (equation 1) is estimated using the strategy described in section 2.2 with public health as the sole health expenditure variable. We then re-estimate equation 1 – using the same 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 that stripped out actual expenditure on these components and, for 2013-14, each CCG was given an uplift of 2.3% on these 2012 baselines.[2]

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 cost component of the total allocation. The DFT variable is available from the Department of Health's website at https://www.networks.nhs.uk/nhsnetworks/health-investment-network/news/2012-13-programme-budgeting-data-is-nowavailable (accessed 22 July 2020), and the MFF and prescribing cost 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 22 July 2020).

A recent study provided no explicit arguments in support of these instruments for healthcare expenditure but this omission is easily remedied.[3] First, our measure of mortality and the prescribing cost 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 and these might 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. 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 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.

Appendix A4

Extended presentation of results

With the public health grant as the only expenditure variable

Estimation of the health outcome equation (equation 1) with public health as the sole expenditure variable generates the result shown in column 1 of table A1. The corresponding first-stage result is in column 1 of table A2. Application of the backward selection process generates the more parsimonious specification shown in column 2 of table A1. 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 pvalue<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.

Table A1 Derivation of preferred specification for public health expenditure, second-stage results, 2013/14

VARIABLES	(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 SA_1	(6) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model instrument PH spend weighted IV second stage new derivation revised2 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 A2 First-stage regression results for derivation of preferred specification for public health expenditure, 2013/14

VARIABLES	(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 SA_1	(6) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS new derivation revised2 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

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 A3. 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 A4.

Some authors have expressed concern about the inclusion of weak instruments,[4] and hence we re-estimate the 'full' specification without the two insignificant MFF instruments (see column 2 of table A3). 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 is significant when added as a control to the second-stage, we found that the 'permanently sick' variable squared 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 A3 Derivation of preferred specification for public health expenditure with healthcare expenditure, backward selection, 2013/14

VARIABLES	(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 five instruments	(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 three instruments	(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 three instruments	(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 revised	(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 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

Table A4 First-stage regression results for derivation of preferred specification for public health expenditure with healthcare expenditure, backward selection, 2013/14

VARIABLES	(1) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification five instruments	(2) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification five instruments	(3) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification three instruments	(4) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection full specification three instruments	(5) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification three instruments	(6) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification three instruments	(7) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification revised	(8) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification revised	(9) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification revised	(10) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS backward selection derived specification 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

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 A5 for the second-stage and table A6 for the first-stage results). Column 1 of table A5 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 A3. 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 of table A5) 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 A5 Derivation of preferred specification for public health expenditure with healthcare expenditure, forward selection, 2013/14

VARIABLES	(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 five instruments	(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 three instruments	(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 three instruments	(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 three instruments	(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 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

Table A6 First-stage regression results for derivation of preferred specification for public health expenditure with healthcare expenditure, forward selection, 2013/14

VARIABLES	(1) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 1 five instruments	(2) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 1 five instruments	(3) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 1 three instruments	(4) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 1 three instruments	(5) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 2 three instruments	(6) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 2 three instruments	(7) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 3 three instruments	(8) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 3 three instruments	(9) All causes 2013/14 PH spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 4 three instruments	(10) All causes 2013/14 PB spend SYLLR 2013/14/15 outcome model first-stage weighted OLS forward selection round 4 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

References for appendices

1. NHS England (2015). 2013-14 CCG Programme Budgeting Benchmarking Tool. Available from https://www.england.nhs.uk/prog-budgeting/ [accessed 22 July, 2020].

2. DH (2018). Personal communication, 07 November.

3. Andrews, M., Elamin, O, Hall, A. R., Kyriakoulis, K. and M Sutton (2017). Inference in the presence of redundant moment conditions and the impact of government health expenditure on health outcomes in England. Econometric Reviews, 36(1–3), pp.23–41. Available from https://www.tandfonline.com/doi/full/10.1080/07474938.2016.1114205 [accessed 22 July, 2020].

4. Small, D.S. (2007). Sensitivity analysis for instrumental variables regression with overidentifying restrictions. Journal of the American Statistical Association **102**(479), 1049-1058.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5-6
Objectives	3	State specific objectives, including any prespecified hypotheses	5-6
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	6-7
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	10-11
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	10-11
Bias	9	Describe any efforts to address potential sources of bias	7-9
Study size	10	Explain how the study size was arrived at	10
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-9
		(*b*) Describe any methods used to examine subgroups and interactions	None
		(*c*) Explain how missing data were addressed	10
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n/a
		(*e*) Describe any sensitivity analyses	11-14
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Table 2
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	10
Outcome data	15*	Report numbers of outcome events or summary measures	10-11

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-14 & Table 2
		(*b*) Report category boundaries when continuous variables were categorized	n/a
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11-14
Discussion			
Key results	18	Summarise key results with reference to study objectives	14-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-16
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.