Long-run Health and Mortality Effects of Exposure to Universal Health Care at Birth

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Preliminary.

Abstract

In this paper we investigate to what extent the childhood healthcare environment influences later life health outcomes. We examine a fundamental re-organisation of the healthcare environment to universal healthcare in the United Kingdom, which occurred through the introduction of the National Health Service (NHS) in July 1948. Immediate large decreases in infant mortality ensued. They were focused on the neo-natal period and larger for individuals who prior to the NHS had a lower access to medical services. Using administrative data on mortality, we compare mortality outcomes above age 50 of individuals born in the immediate cohorts around the introduction of the National Health Service (NHS) in a regression discontinuity design. We additionally exploit geographical variation in the change in medical services upon the NHS introduction for identification. Our findings indicate that age-specific survival rates are systematically higher among lower class individuals whose post-natal care expanded through the NHS, with the magnitude of the effect increasing monotonically with age. We supplement these findings with analysis of hospital records, which reveal a similar decrease in hospitalisations for cardiovascular disease for lower class individuals. These long run impacts of birth exposure to universal healthcare coverage through the NHS are economically significant, representing a 14% reduction in mortality at age 58.

JEL classification: I12, I13, I14, J14

Keywords: Universal health care, early life intervention, life cycle impact, mortality, health

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"*The astonishing fact is that Bevan's vision has stood both the test of time and the test of change unimaginable in his day. At the centre of his vision was a National Health Service, and sixty years on his NHS – by surviving, growing and adapting to technological and demographic change – remains at the centre of the life of our nation as a uniquely British creation, and still a uniquely powerful engine of social justice.*"
(Gordon Brown, UK Prime Minister, 2008)

1 Introduction

In September 2015 the United Nations launched a new development agenda comprising 17 Sustainable Development Goals (SDGs). A central aspect in this agenda is Health, encompassed within SDG3 to "ensure healthy lives and promote well-being for all at all ages". Universal health coverage is understood as the key mechanism through which these health targets will be met (World Health Organization, 2016). However, even in developed countries there can be substantial inequality in healthcare provision. US data reveals that 3.8% (18.2%) of children (adults) do not have a "usual source of healthcare", and these proportions rise to 6.5% (30.6%) among children (adults) below the poverty line (Center for Disease Control and Prevention, 2015).

The benefits of expanding access to healthcare can be most readily seen in infant health. Analysing the expansion of Medicaid in the United States in the 80s, Currie and Gruber (1996a,b) find that increasing the availability of healthcare has large impacts on perinatal (stillbirths and deaths under 7 days) and neonatal (deaths within 28 days of birth) mortality rates. Several studies analyse whether birth exposure to Medicaid expansions in the 80's to 90's yield medium-run effects that reach into adolescence and early adulthood. They find reductions in mortality in both life phases, as well as improvements in educational attainment, tax receipts from beneficiaries of the program and lower welfare dependency (Currie, Decker, and Lin (2008); Brown, Kowalski, and Lurie (2015); Wherry and Meyer (2016)). These policy interventions can now be analysed for their impacts on outcomes in early adulthood, but evidence beyond this life stage is yet missing. The earliest date at which data on their long-run impacts that reach to retirement age can be obtained would be in the 2040s (for a survey of early childhood healthcare intervention studies, see Almond, Currie, and Duque (2017)).

To our knowledge, this is the first study investigating whether the positive effects of expanding access to healthcare at birth persist throughout the life course into older ages. We examine health outcomes of individuals 50 to 60 years after birth exposure to the introduction of a universal healthcare system, the National Health Service (NHS), introduced by the UK Government in July 1948. The inception of the NHS saw a fundamental re-organisation of the healthcare environment and involved a substantial increase in the provision of healthcare, in particular to individuals for whom healthcare had previously been unaffordable. Our analysis is possible due to the coincidence of two factors: first, the introduction of the NHS is a large-scale historical intervention that reaches back long enough to offer the opportunity to study health and mortality impacts at older ages of birth exposure to universal healthcare. Second, although rising rapidly during ages 50 to 60, major health shocks and death are events that occur with low probabilities. Recent innovations in the availability of large administrative datasets which hold information about individuals throughout their life course make it possible to address power problems which may inhibit the identification of such effects in small-sample survey data.

We identify the long-run health and mortality impacts of birth exposure to universal healthcare using two methods: First, as the NHS was introduced nationwide on a single date, we employ a Regression Discontinuity Design, where we allow for pre-existing trends in the outcomes to be different either side of the threshold (i.e. being born in a narrow window around the NHS introduction). Additionally, we exploit geographical variation in the expansion of medical services at birth (across counties), combining the RDD with a difference-in-differences design. We develop a simple model of medical services based on competition among (a changing number of) patients for access to medical services, which predicts that areas with a larger proportion of poorer individuals, for whom healthcare could be unaffordable, should see larger reductions in mortality after the expansion of access to healthcare. We focus on mortality and the onset of cardiovascular disease at older ages in the analysis of later-life health outcomes.[1] We use age-specific mortality rates using data from the Office of National Statistics Longitudinal Study,

[1]World-wide cardiovascular disease is the leading cause of death, in 2015 accounting for around 8.5 million deaths (World Health Organisation, 2017), and accounted for 11.5% of all deaths registered in England and Wales Office for National Statistics (2016).

a 1% sample of the population containing information on individuals linked between 5 successive censuses combined with administrative death records. For the analysis of health impacts we use the UK Biobank, a rich high-quality micro-dataset linked to administrative hospital records. We observe individuals' birth exposure to county-specific medical services through information on individual's location at birth recorded in both datasets.

Our findings indicate that survival rates are systematically higher among lower class individuals whose maternity care expanded through the NHS, with the magnitude of the effect increasing monotonically with age and becoming statistically significant from age 58 onwards. The increase in the beneficial impact of the NHS on survival rates in this population group represents a 14% reduction in mortality. In the parallel analysis of health records we find that the onset of cardiovascular disease amongst lower class individuals between age 52 and 63 is reduced by 7%. Both identification strategies proposed above yield the same qualitative result.

Our identification strategy is supported by additional evidence on the *immediate* impact of the NHS on infant health. While microdata dating back to the 1940s is not available, we have digitised detailed information on infant mortality at a low-level geographical disaggregation for this period. We find a decrease in infant mortality that was driven predominantly by improvements in neo-natal outcomes for individuals with lower socio-economic status. We also find that these improvements were larger in areas where a higher proportion of the population are of low socio-economic status.

Given this immediate increase in infant survival, which varies by social class and location of birth, later life changes in health and mortality may be the result of a combination of two factors: the long-run impacts of better childhood health outcomes, and selective survival at earlier ages. Our current estimates may underestimate the long-run impact of birth exposure to the NHS, if infants who would not have survived prior to the NHS were, say, inherently weaker or unhealthier than those who survived. Selective infant mortality may imply a lowering of overall population health for cohorts born (and surviving) after the NHS introduction, and may lower the average health and mortality of survivors in adulthood. Previous studies of early child interventions acknowledge this limitation, and derive bounds for their estimates of the long-run health premium under assumptions about the health distribution of

those who died. In future work, we intend to extend the analysis to examine the extent to which an individuals health environment during infancy influences later-life health outcomes, explicitly controlling for selective mortality effects. We will extend the model in Bozzoli, Deaton, and Quintana-Domeque (2009), and implement it in estimation to separately quantify i) the health premium of enhanced health outcomes in adulthood due to improved childhood conditions, and ii) the selective mortality effect ensuing from increases in infant survival.

Our work has important policy implications. Quantifying the long-run health dividend of NHS services around birth provides new evidence in the current discussion within the UK regarding the financial pressures and potential reform of the NHS. Similarly, they relate to the long-term consequences associated with expanding health care provision ensuing from the Patient and Affordable Care Act (2010) in the United States. Our findings will also be relevant to countries which today share features of the pre-NHS healthcare environment, and who are developing universal healthcare programs.[2] Finally, our results point to universal healthcare access at birth as a mediating factor that reduces future health inequalities.

The remainder of the paper is structured as follows. Section 2 briefly sets out the institutional environment around the NHS introduction and discusses the impact on infant mortality. Section 3 presents the empirical methodology and data used in the mortality and cardio-vascular disease onset analysis, and discusses the results. Section 4 concludes and outlines the pathway for our subsequent analysis.

2 Institutional Setting

The availability of adequate healthcare is fundamentally linked to population health. Following the 1942 Beveridge report, which highlighted the extent of social and health disparities within Britain, in July 1948 the UK Government introduced a National Health Service whereby comprehensive health services were provided free at the point of use, instead being centrally

[2]Maeda, Araujo, Cashin, Harris, Ikegami, and Reich (2014) present case studies on 11 countries which in recent years have adopted or are developing universal health coverage schemes.

funded through general taxation. Public demand for healthcare quickly exceeded predictions. The primary beneficiaries were individuals in the lower tail of the income distribution, who were able to access previously unaffordable health services.

Prior to the NHS, healthcare was mainly provided privately for a doctor's or hospital fee. Limited access to free healthcare was provided by voluntary hospitals who depended on private donations (and the agreement of such donors to sponsor a patient in need), or through hospitals operated by local authorities, based on the Poor law. Both institutions were suffering severe financing problems in the early 1940s. In addition, workers were partially covered through a highly fragmented network of ca. 6,000 Approved Societies, established under the National Insurance Act 1911 (Carpenter, 1984). Compulsory cover was provided to employed persons aged 16 to 70 with annual earnings below £420 (and all manual labourers).[3] Contributions amounted to seven (six) pence a week for men (women), of which the employer contributed 3 pence. These contributions were topped up with government subsidies of about two pence per worker. Workers' contributions were deducted from wages by the employer. Approved Societies were not-for-profit private organisations who could refuse to provide insurance coverage to workers. Workers who could not find an insurer paid into a private healthcare fund which was drawn down upon need.

In return to their contributions, workers were entitled to rudimentary medical care from doctors who received a fixed 'capitation fee' per patient.[4] The non-comprehensive scheme often did not cover drugs nor hospital treatment; most importantly, these schemes did not cover medical services to their dependants such as women or children. National Health Insurance provided these limited services to between a quarter and a third of the population between 1911 and 1948.

The NHS substantially increased access to healthcare, with a considerable focus on increasing ante- and post-natal care, midwifery and obstetric services. It was based on three main principles: i) that it meet the needs of everyone, i.e. universal provision, ii) that it be free at the point of delivery, and iii)

[3]Self-employed persons could insure voluntarily.

[4]Additional entitlements were: sickness pay of 10 shillings per week for 26 weeks and disability benefits of 5 shillings a week beyond the 26 weeks; maternity benefits of 30 shillings per child.

that it be based on clinical need, not ability to pay (see NHS Constitution). It was financed through general taxation.

On the supply side, local and voluntary hospitals were centralised into a single hospital service. Doctors became independent contractors that were paid fixed fees per treatment which were set by Executive Councils which decided on contracts and payments. As previously, local authorities administered family health services such as maternity and child welfare clinics, midwives, and other services. Hence, while the NHS resulted in a fundamental change in accessibility to patients, medical services supply remained under administration by several entities. More importantly, the re-organisation of the healthcare environment wrought by the introduction of the NHS was not immediately accompanied by large investments into the expansion of the healthcare infrastructure.[5]

As we will show in the next section, increased access to maternity healthcare and pediatric services had an immediate impact on infant mortality rates, which is particularly salient as compared to immediate mortality effects at older ages.[6]

2.1 The impact on infant mortality

Our analysis of the immediate impacts of birth exposure to the NHS is based on aggregate data on mortality in infancy, obtained from the Registrar General's statistical review of England and Wales and the Ministry of Health Annual Reports[7]. We digitised this historic datasource to illustrate the im-

[5]Abel-Smith and Titmuss (1956) find that capital expenditure on hospitals in the first five years of the NHS was approximately one third of the pre-war level of expenditure.

[6]An examination of annual (period) mortality rates from the Human Mortality Database reveals a decline in deaths within the first year of life of approximately 20% between pre and post-NHS cohorts. In contrast there is no evidence of a clear and systematic drop in the mortality of older individuals (aged 50 and older) around or following the introduction of the NHS in 1948. This is consistent with US evidence of the increase in health insurance coverage at age 65 through Medicare eligibility, although Card, Dobkin, and Maestas (2008) find a reduction in health inequalities, but only a small impact on self-reported health and no impact on mortality rates.

[7]Both these series are held in the archives of the Wellcome Library. The data contain detailed mortality rates at different ages. However, these are period rather than cohort mortality rates. For example, death rates under age 1 in 1948 may contain deaths from babies born in 1947. Thus, we only consider mortality rates during the first year of life as under age 5 mortality rates in 1948 would contain a large fraction of children born prior to the NHS introduction.

mediate impact of the NHS introduction in 1948 on infant mortality. We mainly use nationally aggregated data for England and Wales to present our results, and complement this with data aggregated to the regional level.

Table 1: Mean mortality rate in infancy by time of death, 1940 to 1947

Period of death	Mortality rate (per 1000 total births)	Percent of mortality under 1 year	
		period	cumulative
Stillbirths	27.33	.3865	.3865
Under 1 day	35.76	.1193	.5058
Under 1 week	44.46	.1234	.6292
Under 1 month	50.93	.0917	.7209
Under 3 months	58.49	.1066	.8275
Under 1 year	70.72	.1725	1.000

Notes: The table shows cumulative deaths per 1,000 total births, including stillbirths in England and Wales.
Source: Registrar General's Annual report 1940-1955, The Wellcome Library.

First, we identify critical pre- and postnatal periods up to the end of the first year of life with high mortality rates in the period 1940 to 1947, the year before the NHS was introduced (see Table 1). For this purpose, we construct deaths per 1000 total births, thus including prenatal deaths. On average, we find that stillbirth[8] was the largest driver of early life mortality with 27 deaths per 1,000 total births, or about 39% of the total deaths recorded during pregnancy and up to the end of the first year of life. The first day also carried a high death rate of about 7 per 1,000 total births (approximately an additional 12%). By the end of the first week, these amounted to 44 deaths per 1,000 total births (accounting for 63% of total deaths within one year). 72% of total infant deaths occurred within the neonatal period[9].

A closer look at the critical neonatal period, (see Table 2), shows that about 18 deaths per 1,000 live births occur in the first week of life, and death rates in the first 4 weeks of life are 24 per 1,000. The neonatal mortality rate is almost as high as prenatal mortality and accounts for 54% deaths within one year of birth. After these first 4 weeks, mortality drops significantly to under 8 per 1,000 live deaths per 3 month period.

Overall the data show that the pre-NHS period was characterised by very high mortality rates in infancy. Death rates amounted to 71 per 1,000 total births

[8]Stillbirths are defined as births after 28 or more weeks completed gestation which did not, at any time, breathe or show signs of life

[9]The neonatal period is defined as the period between birth and one month. Neonatal mortality rates are calculated as the number of deaths per 1,000 live births

Table 2: Mean neonatal mortality by week of death, 1940 to 1947

Period of death	Mortality rate (per 1,000 live births)	Percent of infant mortality rate
In week 1	17.61	0.3958
In week 2	3.01	0.0677
In week 3	2.05	0.0460
In week 4	1.55	0.0347
Total	24.26	0.5454

Notes: The table shows deaths per 1,000 live births, and mortality rates in percent of the infant mortality rate (defined as deaths from birth to under 1 year per 1,000 live births).
Source: Registrar General's Annual report 1940-1955, The Wellcome Library.

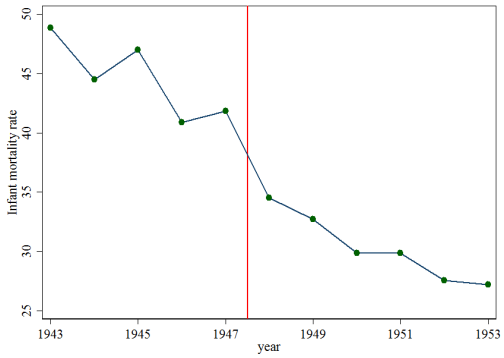
up to the end of the first year of life, and infant mortality rates amounted to 45 deaths (per 1,000 live births)[10]. Bringing these figures into context: infant mortality rates in the pre-NHS period were as high as modern day infant mortality rates in Sudan, Zambia or Turkmenistan, while neonatal mortality was as high as it is on average in South-East Asia in 2015.[11] In 2014, less than 9 deaths per 1,000 total births were recorded in England and Wales with an infant mortality rate of 3.6 per 1,000 live births.

Figure 1 shows infant mortality rates for cohorts born around the NHS introduction. There is a sharp reduction of approximately 17% between 1947 and 1948, coinciding with the introduction of the NHS.

[10]Infant mortality rates describe mortality within the first year of life, thus excluding stillbirths, and are calculated as deaths within the first year of life as a proportion of live births.

[11]2015 Estimates Developed by the UN Inter-agency Group for Child Mortality Estimation (UNICEF, WHO, World Bank, UN DESA Population Division) at childmortality.org. Projected data are from the United Nations Population Division's World Population Prospects; and may in some cases not be consistent with data before the current year.

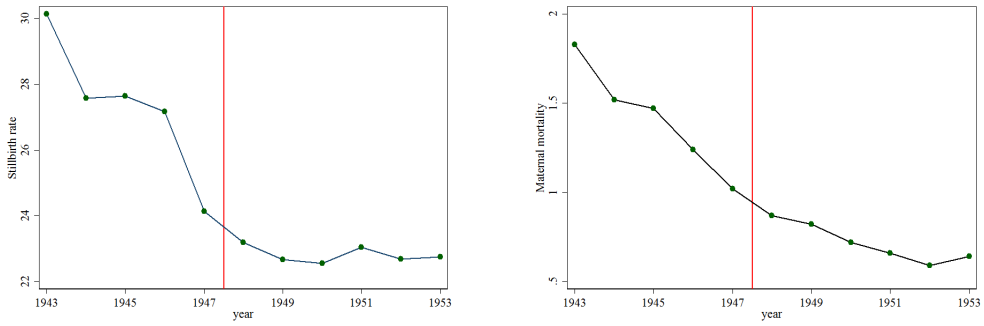
Figure 1: Infant mortality by time of death



Notes: The graph shows deaths per 1,000 live births in England and Wales.
Source: Registrar General's Annual report 1940-1955, The Wellcome Library.

In contrast, although stillbirth rates declined substantially during the pre-NHS period, there is no evidence of a discontinuous change in antenatal mortality in 1948, measured though stillbirth rates per 1,000 total births around 1948 (see Figure 2a). Similar to stillbirth, we find no effect of the NHS introduction on maternal mortality per 1,000 total births (see Figure 2b).

Figure 2: Stillbirths and Maternal Mortality per 1,000 total births



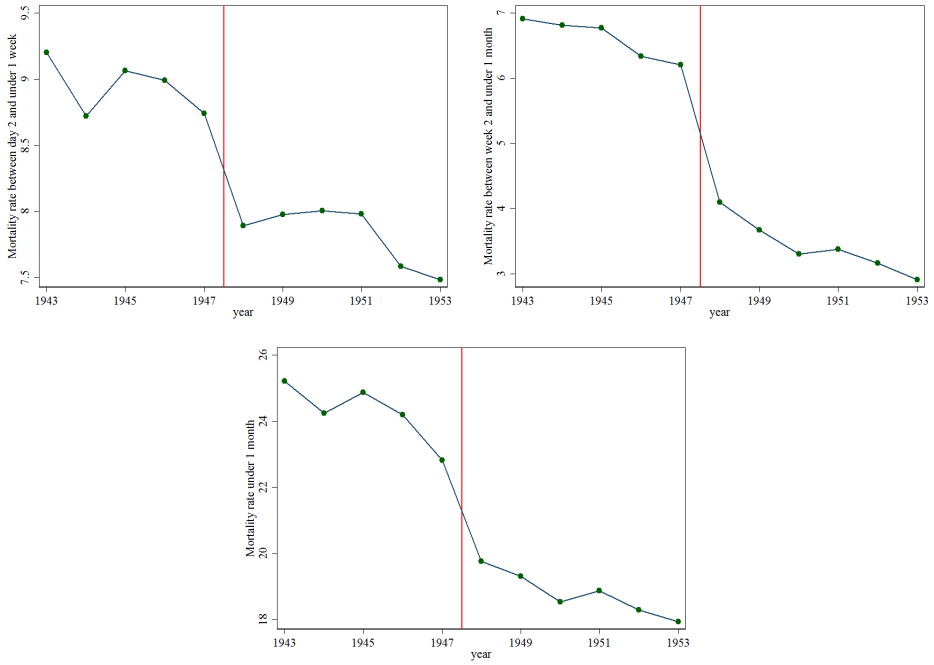
(a) Stillbirth (b) Maternal Mortality

Notes: The graph shows rates per 1,000 total births in England and Wales.
Source: Registrar General's Annual report 1940-1955, The Wellcome Library.

Figures 1 and 2 suggest that the decrease in infant mortality was driven by post-natal rather than ante-natal conditions. Examining neonatal mortality in detail, we find no NHS effects in the first 30 minutes or 24 hours of life, that would be suggestive of improved delivery methods through better health care access. However, we do find a significant reduction of 11% in deaths

occurring between 1 day and 1 week of birth, and a one-third decrease in mortality between the second and the fourth week (see Figure 3). Overall, this amounts to a reduction in neonatal mortality of around 13%.

Figure 3: Neonatal mortality, by period of death



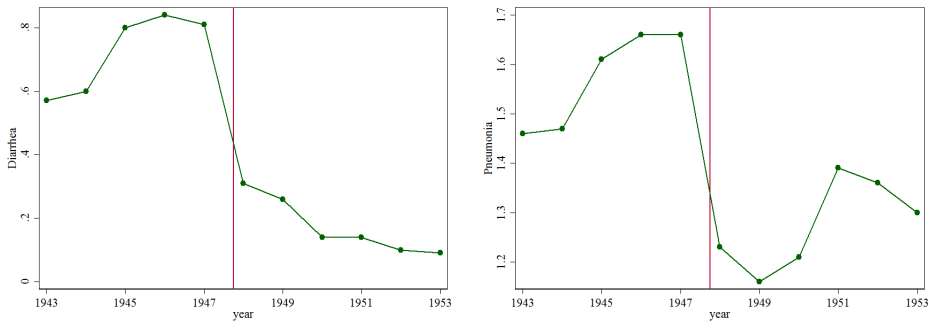
Notes: The graph shows deaths per 1,000 live births in England and Wales.
Source: Registrar General's Annual report 1940-1955, The Wellcome Library.

The Ministry of Health Annual reports also contain information on neonatal mortality according to certified cause.[12] Figure 4 shows large declines in two cause of death categories: a decline of approximately 0.35 deaths per 1,000 due to diarrhea (ca. 50% decrease); and a decline of 0.4 deaths per 1,000 due to pneumonia (roughly a 25% fall). Therefore these two causes alone contribute to approximately one third of the reduction in neonatal mortality. Both declining death causes, pneumonia and diarrhea, relate to conditions developed after birth, and both are particularly dangerous in the neonatal period where we observe the largest NHS-related decrease in infant mortality. As both pneumonia and diarrhea could be successfully treated during the 1940s, but require timely intervention, this suggests that the NHS resulted in more timely treatment or access to treatment when a critical health shock

[12]Eight specific death causes common to this period, are listed: Asphyxia and Atelectasis, Bronchitis, Congenital Malformations, Diarrhea, Immaturity, Infective Parasitic Disease, Pneumonia and Other.

manifests.

Figure 4: Neonatal mortality by cause of death



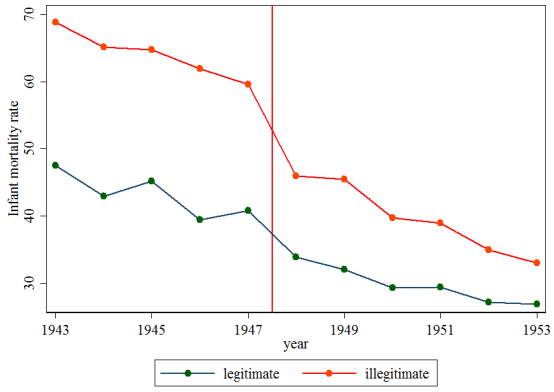
(a) Diarrhea (b) Pneumonia

Notes: The graphs show the neonatal (within 28 days) death rate per 1,000 related births by cause of death over the period 1943-1953).
Source: Ministry of Health Annual Reports, The Wellcome Library.

Our conjecture is that these early life impacts of NHS exposure around birth differ by pre-NHS access to health care. More precisely, we expect stronger reduction in mortality rates among children of lower social class whose mothers would not have had health insurance before the NHS was introduced. Unfortunately mortality statistics are not available by maternal (or childrens') social class or other relevant socio-demographic metrics such as education or income. As auxiliary evidence, we therefore use the available distinction of mortality rates by the legitimacy of the child.[13] Figure 5 confirms our hypothesis, illustrating particularly large mortality declines among illegitimate children relative to legitimate children and a consequent narrowing of the (large) mortality gap between illegitimate and legitimate children. Overall, the mortality gap about halves.

[13]Wright (1973) finds that illegitimate births in Britain are highly concentrated among mothers of lower social class.

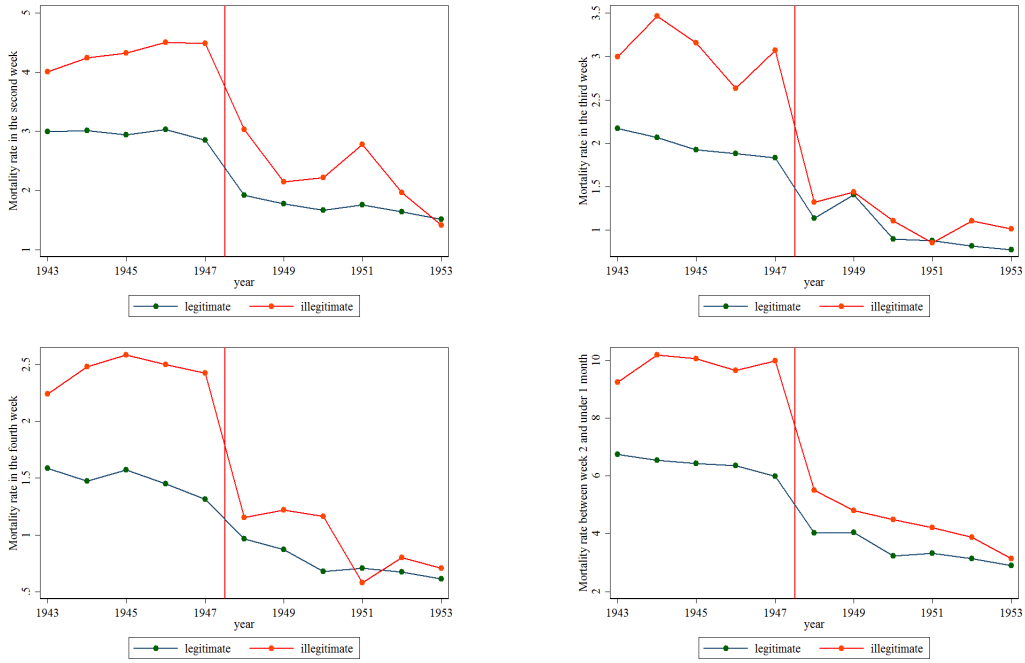
Figure 5: Infant mortality by legitimacy



Notes: The graph shows infant mortality in England and Wales by legitimacy of child.
Source: Registrar General's Annual report 1940-1955, The Wellcome Library.

In Figure 6, we again focus on the neonatal period. The narrowing of the mortality gap by legitimacy status is particularly pronounced, indeed it is practically eliminated in the second, third and fourth week after birth.

Figure 6: Infant mortality by time of death and legitimacy

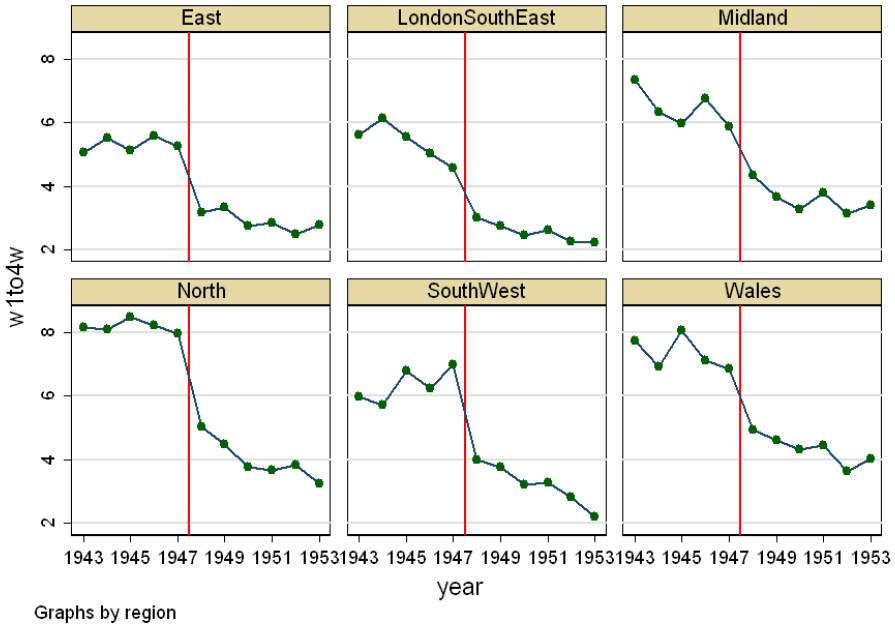


Notes: The graph shows infant mortality in England and Wales in the neonatal period.
Source: Registrar General's Annual report 1940-1955, The Wellcome Library.

We examine geographical differences in the impact of the NHS, finding similar effects at the regional level. Figure 7 illustrates regional differences in

not only the levels of the neonatal mortality rate, but also in the magnitude of the decline between 1947 and 1948. In the North, and South West regions, areas traditionally with a relatively high proportion of the population in lower socio-economic groups, neo-natal mortality both before and after the NHS introduction is higher than in London and the East regions, areas traditionally with a relatively low proportion of the population in lower socio-economic groups. However, the decline in neo-natal mortality around the NHS introduction is higher in areas with a higher proportion of low social class individuals.

Figure 7: Neonatal mortality by time of death and region



Notes: The graph shows neonatal mortality in England and Wales.
Source: Registrar General's Annual report 1940-1955, The Wellcome Library.

In summary, we find no evidence that would suggest improved mortality before or around birth. Rather, neonatal mortality decreases strongly. This has important effects on cumulative mortality under 4 weeks, leading to a reduction in infant mortality rates by about 17% between 1947 and 1948. While we find throughout that female mortality in infancy is significantly lower in all considered time periods, we find no differential NHS effect by gender (not shown). The strong declines in infant mortality are particularly evident for illegitimate children and in areas with a high proportion of lower class individuals.

3 Empirical analysis of long-run impacts of birth exposure to the NHS

In Figure 1 we demonstrated an immediate and discontinuous drop in infant mortality by ca. 20% among birth cohorts who benefitted from health care coverage through the introduction of the NHS at birth, relative to those born just before its introduction. We now seek to identify the impact of birth exposure to universal health care over the life course in two dimensions - health and mortality.

We proceed as follows: In section 3.1, we describe the empirical method and identification strategy used in both parts of the analysis. Section 3.2 describes the data used to establish the impact of birth exposure to the NHS on mortality beyond age 50, and presents the results. Section 3.3 does the same for the onset of cardiovascular disease, a key driver of mortality during this life period.

3.1 Empirical method

As the NHS was implemented nationally in July 1948 there is a clearly defined threshold, and the analysis therefore proceeds using a regression discontinuity approach. We define birth exposure to universal health care exploiting the timing of the scheme's introduction combined with date of birth information. We allow for pre-existing trends in mortality at either side of the threshold. Our analysis considers cohorts born within a narrow window of maximally 4 years either side of the threshold, the introduction of the NHS in July 1948. In the following, we describe two identification strategies that we use to identify the causal impact of birth access to universal healthcare on later life mortality and health.

Given the differential access to healthcare before universal coverage was provided by the NHS, as described in Section 2, we do not expect a discontinuity in available maternity care for each individual born after the introduction of the NHS. Instead, we apply a fuzzy design. The probability of an increase in pre- and postnatal care is larger for individuals born by mothers of lower social class than for those whose mothers could afford to purchase private

maternity care. In consequence, we do not expect an overall reduction in later life mortality and the onset of disease among cohorts who were exposed to the NHS at birth. Rather, we expect any treatment effect to be concentrated among individuals who absent of the treatment would have had limited availability of healthcare around birth, i.e. that mothers of lower social class, and their children, have disproportionately benefited from the introduction of universal health care.

Hence, we first estimate the following model:

$$y_{ica} = \alpha + \beta C_c + \gamma_1 T_c + \gamma_2 T_c LC_{ic} + \delta LC_{ic} + X'_{ic}\eta + \mu_g + \epsilon_{ic} \qquad (1)$$

where y_{ica} denotes the mortality or health outcome of interest of individual i born into cohort c at age a. C_c is the cohort trend, X_{ic} denotes a set of socio-demographic characteristics. μ_g capture fixed effects for county of birth, reflecting potential differences in childhood environments and healthcare infrastructure as well as other relevant geographical differences that are constant over time. T_c denotes the time and cohort discontinuity that we exploit for identification, and $T_c LC_{ic}$ captures the differential increase in healthcare access that the introduction of the NHS afforded to newborns whose mothers were of lower social class. We estimate linear probability models and report robust standard errors throughout.

In our second approach, we posit that the introduction of the NHS represents an expansion in medical services for lower class individuals, the magnitude of which varies by county of birth. This geographical variation in the availability of medical services refines our identification strategy. To show this we construct a simple, stylised model of medical services before and after the introduction of the NHS. Our model incorporates three core principles of the NHS, i.e. i) equalisation of access to medical services, ii) medical services are free at the point of delivery, and iii) access is based on clinical need, not ability to pay (NHS Constitution, 2011). We derive two assumptions from these principles. First, we assume equal access to (and quantity of) medical services per patient once universal healthcare coverage was rolled out. Secondly, we assume that medical services are consumed free of charge.[14] We further assume that capacity remains fixed at pre-NHS levels in the short

[14]We do not model the taxes raised to finance the NHS, as these will not affect consumption of medical services at the margin.

run.

Our model has two sources of heterogeneity: first, individuals differ in access to medical services m_i prior to the existence of the NHS. Second, individuals live in different counties g. The population composition differs by area, such that the fraction of individuals with access to medical care prior to the NHS, I_g, varies across counties. For simplicity, we abstract from other sources of heterogeneity at the county level, and assume a fixed population and that pre-NHS, per patient medical services are equal across counties (for those who have access to them), and normalise these to 1.

In consequence, medical services of individual i in county g are:

$$m_{ig} = \begin{cases} 0 & if \quad i = NI, \\ 1 & if \quad i = I \quad \forall g \end{cases} \tag{2}$$

Previously covered individuals I enjoy one unit of medical services, while those previously uninsured (denoted as NI) obtain no medical services. Initial county-level capacity M_g then varies with the number of previously covered individuals living in the geographical area previous to the NHS, and amounts to $M_g = I_g$.[15]

In the short-run the capacity of medical services is fixed. The introduction of universal healthcare coverage therefore leads to increased demand for a fixed resource, as newly eligible patients compete with pre-existing patients for a fixed level of medical services M_g. The gain in medical services for previously uncovered individuals NI varies with the ratio of new to old patients in each county g. Hence, the increase in medical services (from initially zero) for each previously uncovered individual is:

$$\Delta(m_{NI,g}) = I_g \tag{3}$$

This implies cross-county variation in per capita medical services provision. To illustrate: County A has a large fraction of pre-existing patients, therefore the NHS introduction does not add many new patients, so that $m_{NI,g}$ is high and close to 1. In contrast, County B has a small fraction of pre-existing patients and therefore a large fraction of the population gain access

[15]Since we abstract from population size, we normalise $NI_g + I_g = 1$.

to medical service for the first time with the NHS introduction. As the supply of medical services is fixed at the pre-NHS level, and there are now more users, per capita medical services in County B will be lower than in County A. Overall, the (per capita) level of medical services in a county increases with the proportion of pre-existing patients, I_g, after the introduction of the NHS.

This simple model has several implications for our empirical strategy: first, the geographical variation in the number of new patients, and in the amount of medical services available to new patients may explain the regional variation in the magnitude of infant mortality rate reductions that we presented in section 2. We assume that infant mortality is declining in the level of medical services, but with decreasing returns, and specify infant mortality as a function $Inf_{ig} = -\gamma \ln(m_{ig})$ of medical services. The reduction in infant mortality for individuals who gain access to medical care is then described by:

$$\Delta Inf_{NI,g} = -\gamma \ln(I_g) \tag{4}$$

and post-1948 county-level infant mortality is the sum of infant mortality of the previously insured I and newly insured NI, weighted by their population proportions:[16]

$$\Delta Inf_g = -\gamma(I_g \cdot \ln(1 - I_g) + (1 - I_g) \cdot \ln(I_g)) \tag{5}$$

As access to medical services increases for previously uncovered individuals after the introduction of the NHS, their infant mortality will decline. County-level infant mortality depends on the local proportion of individuals with previous access to medical services, and is u-shaped.[17]

More importantly, our model informs our analysis of long-run effects. If the amount of medical services provided per person varies with the county-level proportion of previously covered individuals, then we can exploit such

[16]Note that in our model, medical services for previously covered individuals decrease in the short-run due to the above mentioned competition effect.

[17]We will shortly complete the digitisation of historical infant mortality data by county-level which will allow us to test these predictions. We will use county-level social class composition data to proxy for the proportion of previously covered individuals in a county, I_g, which drives the level of medical services available after the birth of the NHS. Social class proxies for healthcare coverage status prior to the NHS, as low income individuals had no previous access to healthcare while individuals of higher social class could pay for healthcare privately.

county-level variation in addition to temporal variation in our identification strategy. The higher I_g, the lower NI_g, the proportion of new patients competing over the fixed resource, and the higher are medical services enjoyed by newly eligible individuals, $m_{NI,g}$. Hence, we expect larger NHS birth exposure effects in areas with a high proportion of previously insured. In the model, we assumed homogeneity of counties in terms of population and pre-existing levels of medical services in our model. When we take the model to the data, the county fixed effects will sweep up these pre-existing differences (and any other relevant county-level differences that are constant over time). To link individual health and mortality outcomes around ages 50 to 60 with information on social class composition at birth, we use the individual-level information on county of birth information contained in both microdatasets.

We estimate the following second model:

$$y_{ica} = \alpha + \beta C_c + \gamma_1 T_c + \gamma_2 T_c LC_{ic} + \gamma_3 T_c HIGHarea_g + \gamma_4 T_c LC_{ic} HIGHarea_g + \gamma_5 LC_{ic} HIGHarea_g + \delta LC_{ic} + \zeta HIGHarea_g + X'_{ic}\eta + \epsilon_{ic} \quad (6)$$

where $HIGHarea_g$ denotes whether the individual was born in an area with a high proportion of previously insured. We interact this variable with our Treatment indicator T_c, the social class of the individual LC_{ic}, and include a full set of interactions to saturate the model. Our parameters of interest are γ_1 to γ_4, while γ_5 allows for health externalities in areas with a high proportion of previously insured individuals that may benefit individuals with such access, e.g through vaccination externalities or charitable giving to provide more free health services for the poor.

3.2 Empirical analysis: long-run impacts on mortality

The analysis in this section is based on microdata from the ONS Longitudinal Study, an approximate 1% sample of the population of England and Wales. The study contains census records of individuals born on four specific days of the year, the LS members, which are linked between five successive censuses (1971 to 2011). The census data is also linked to key event records

from administrative data, such as birth, death, and emigration records.[18] New LS members enter the sample through birth or immigration, whereas attrition occurs only through emigration or death. Approximately 500,000 LS members are enumerated in any given census year, and the LS currently holds information on around 1 million sample members collected over the 40 years since its inception.

Since the first available census dates from 1971, we conduct our analysis conditional on an individual's survival up to 1971. The data contains a rich set of socio-economic characteristics collected at each census wave, supplemented with geographical information on place of birth,[19] as well as information on the time, cause and place of death where appropriate. The resultant dataset allows us to follow individuals through a large part of their life-cycle to analyse mortality patterns.

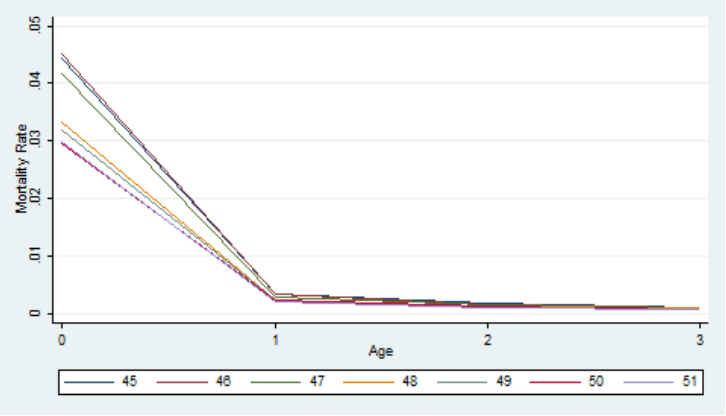
County-level social class composition data, used to estimate model 2, is contained in the Great Britain Historical Database (Southall, Aucott, and Dorling, 2004). The Database presents county-level statistics of social class composition aggregated from the 1951 census, based on the county proportion of males above age 15 in 5 social classes.[20] We use county-level social class composition data to proxy for the proportion of previously covered individuals in a county, I_g, which drives the level of medical services available after the birth of the NHS. Social class proxies for healthcare coverage status prior to the NHS, as low income individuals had no previous access to healthcare while individuals of higher social class could pay for healthcare privately. We construct county-level population proportions in high (consisting of those in Professional and Intermediate occupations) and middle class (Skilled and Party Skilled Occupations), and create dummy variables

[18]The linkage with these event records are periodically updated. Currently the study holds information for deaths occurring until December 2013. This will be updated with additional death records for up to the end of 2015 by the end of 2017.

[19]Place of birth information is derived from the information in identifying codes within NHS records, which contains a geographic identifier of a person's place of birth. For individuals born prior to 5th July 1948 the NHS identifier is comprised of their National Registration number, which is similarly coded with a geographic identifier of natality for those born after September 1939. For individuals born prior to September 1939 place of enumeration on the National Registration day is recorded.

[20]To our knowledge, data from the 1951 census is the closest available date to 1948 that records this information at the county level. It is not accessible as a microdataset. More aggregated data at the level of government office regions is available for the pre-NHS census from 1931, and we find little difference in social class composition between the 1931 and 1951 census.

Figure 8: Cohort mortality rates up to age 3



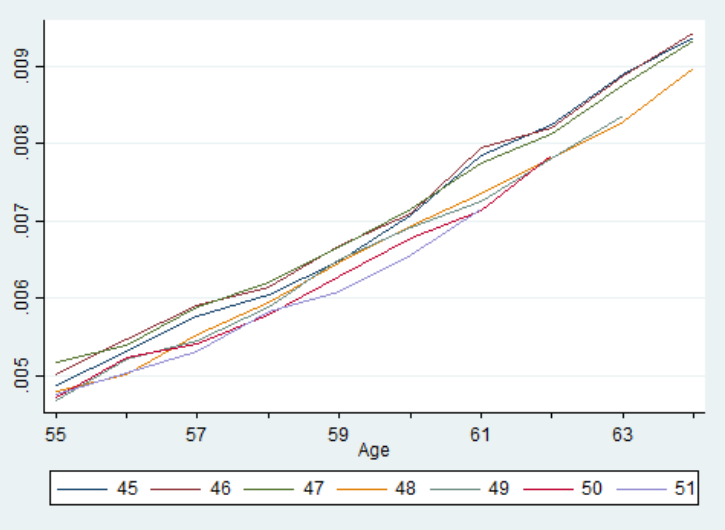
Notes: The graph shows mortality rates for cohorts born between 1944 and 1952 from birth to age 3. Source: Human Mortality Database.

for counties in which the proportion of inhabitants of high (middle) social classes in the upper tertile.

We consider a narrow window of cohorts born prior (1944-1947) and after (1948-1950) the introduction of the NHS in 1948. We focus our analysis on mortality from age 52 onwards, since mortality rates were high in infancy but very low between ages 3 to around 52, see Figures 8 and 9.[21] Above age 52, a time where critical health shocks begin to manifest, we see the mortality rates begin to 'fan out' indicating mortality differentials by cohort. In Figure 9 we show descriptive evidence that that there is a widening mortality gap between pre- and post-NHS cohorts.

[21] Our results do not change if we start at age 50. We choose age 52 for comparability, as it is the earliest possible age in the analysis of health outcomes.

Figure 9: Cohort mortality rates from age 55 to 65



Notes: The graph shows mortality rates for cohorts born between 1944 and 1952 from age 55 to age 65. Source: Human Mortality Database.

Our outcome variables are age-specific mortality rates up to age 62, the maximum age for which we observe all study cohorts in the data.[22]

Summary statistics of the resulting sample are presented in Table 3. 2.58% of the sample died by age 50[23], with the mortality rate increasing with each year of age. By age 62, 8.19% of individuals first observed in 1971 have died. When first observed in the 1971 census, individuals have a mean age of around 23 years, 49.1% are female; 22.8% are of low, 56.9% of middle, and 10.3% of higher social class. We do not observe the social class of the mother at the time of her child's birth, but instead use the individual's social class in early adulthood, as reported in 1971, the earliest available census year.[24]

[22]Death records are currently available up to the end of 2013, but updated on an annual basis, thus allowing us to extend the age range considered in the analysis in a few months. The oldest cohort we consider is born in 1944, and thus 69 in 2013, the cutoff year for the death registers. The youngest cohort we consider is born in 1950 and thus 63 in 2013. We exclude 2013 as some death records are updated with delay, and consider deaths up to age 62. While death registers consider all death of individuals in the sample, the earliest we observe an individual is in the 1971 census, so we only consider deaths after age 31, the lowest age at which we observe all cohorts.

[23]All death rates based on ONS Longitudinal Data are defined conditional on surviving to age 31.

[24]This classification is based on the Office of National Statistics 7-category social class code which assigns categories according to occupation/employment duties. We define classes I-II (Professional, Intermediate) as "High Social Class", III-IV as middle class (Skilled nonmanual, Skilled Manual) and classes V-VII (Partly Skilled, Unskilled, Armed Forces) as "Low Social Class". Since class is always missing for non-working women, we

Table 3: Descriptive statistics, ONS Longitudinal Study

Variable	Mean	Std. Dev.
Died by age ...		
50	0.0258	0.1587
51	0.0291	0.1681
52	0.0321	0.1762
53	0.0355	0.1849
54	0.0392	0.1942
55	0.0433	0.2036
56	0.0477	0.2132
57	0.0530	0.2241
58	0.0584	0.2345
59	0.0634	0.2436
60	0.0694	0.2541
61	0.0749	0.2632
62	0.0819	0.2742
Female	.4914	.4999
Low Social Class	.2276	.4193
Mid Social Class	.5690	.4952
Observations	*44,107*	

Source: ONS Longitudinal Study

Although a degree of intergenerational social mobility is to be expected, it is probable that social class in early adulthood is highly correlated with social class at birth. Additionally, we control for parental origin.

Table 4 shows the estimation results for the probability of death by ages 52 to 62 using a linear probability model and the empirical specification from equation 1.[25] As expected, we do not find evidence of an overall impact of at birth exposure to NHS maternity care at any of these ages and the mortality rates of lower class individuals are systematically higher at all ages. For individuals in their early fifties, we also do not find evidence of an impact of at birth exposure to NHS maternity care among individuals from lower social class. However, the initially statistically insignificant parameter estimate $\hat{\gamma_2}$ increases in each additional year of age, from 0.0044 percentage points at age 52 to 0.0138 percentage points at age 62. By age 58, mortality rates are statistically significantly and pronounced among lower class individuals whose maternity care expanded through the NHS. They remain statistically

use her household's social class, and fill in missing data using individual and household social class information from 1981.

[25]We re-estimated these using a probit model with similar results.

significant throughout age 62. The beneficial impact of the NHS on mortality rates in this population group at successive ages is monotonic and large. It represents a 14.39% (12.71%) reduction in mortality at age 58 (62). These represent large long run impacts which manifest 50 to 60 years after birth exposure.

In Table 5 we present the analysis using the empirical specification described in equation 6, where we include the social class composition in county of birth to proxy geographical variation in medical services available during infancy. Consistent with our expectation we observe larger NHS birth exposure effects specifically for low class individuals born in areas with a larger high social class population composition, evidenced in the triple interaction coefficient. As in the simple specification, the magnitude and significance of the effect increases with age. Relative to the lower class mean mortality rate in high class areas, by age 62 the reduction in mortality is 24.17%.

3.3 Empirical analysis: long-run impacts on health

We now proceed to the analysis of health impacts, using a rich, high-quality micro-dataset, the UK Biobank. The data comprises a sample of approximately 500,000 individuals. It contains detailed self-reported health information, as well as objective measures recorded by a healthcare professional. The data was collected between 2006 and 2010, and therefore provides a snapshot of individual health around age 60 for those born in the 1940s. It is linked to all hospital spells occurring between 1997 and 2016, generating a 19-year panel of health trajectories at older ages which we use to estimate impacts on health and morbidity.

Again, we consider a narrow window of cohorts around the introduction of the NHS in 1948, i.e. cohorts born between 1945 and 1951.[26] We focus our analysis on cardiovascular disease for three reasons: first, it has relatively high onset rates in the age range that we consider (ages 52 and 63). Second, we expect childhood environments to matter if at all, most in terms of cardiovascular disease. Third, cardiovascular disease is the leading cause of death worldwide (World Health Organisation, 2017), and is the second

[26]For comparability with the ONS Longitudinal Study data, we exclude data from Scotland.

Table 4: Estimates of mortality rates by ages 52 to 62 (simple difference)

	52	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**
$T_c * LC_{ic}$	-0.0044	-0.0061	-0.0079	-0.0065	-0.0046	-0.0066	-0.0113*	-0.0099	-0.0135**	-0.0152**	-0.0138**
	(0.0041)	(0.0049)	(0.0053)	(0.0050)	(0.0049)	(0.0059)	(0.0063)	(0.0067)	(0.0066)	(0.0069)	(0.00658)
T_c	0.0041	0.0050	0.0078**	0.0067**	0.0045	0.0052	0.0052	0.0060	0.0083*	0.0083*	0.0086*
	(0.0031)	(0.0031)	(0.0033)	(0.0033)	(0.0034)	(0.0041)	(0.0039)	(0.0040)	(0.0043)	(0.0044)	(0.0046)
LC_{ic}	0.0169***	0.0194***	0.0223***	0.0249***	0.0248***	0.0269***	0.0316***	0.0317***	0.0351***	0.0392***	0.0411***
	(0.0031)	(0.0034)	(0.0042)	(0.0039)	(0.0041)	(0.0045)	(0.0051)	(0.0059)	(0.0056)	(0.0064)	(0.0062)
Constant	0.0212***	0.0232***	0.0237***	0.0266***	0.0310***	0.0345***	0.0385***	0.0414***	0.0443***	0.0481***	0.0532***
	(0.0024)	(0.0024)	(0.0025)	(0.0022)	(0.0024)	(0.0028)	(0.0026)	(0.0028)	(0.0030)	(0.0031)	(0.0033)
Observations	44,108	44,108	44,108	44,108	44,108	44,108	44,108	44,108	44,108	44,108	44,108
Lower-class mean mortality rate											
	0.0435	0.0481	0.0534	0.0602	0.0655	0.0715	0.0785	0.0843	0.0915	0.0994	0.1086
Lower-class mortality reduction in percent (relative to mean)											
	-10.11	-12.68	-14.79	-10.80	-7.02	-9.23	-14.39	-11.74	-14.75	-15.29	-12.71

Notes: The table shows estimates of equation 1. All specifications control for additional characteristics determined at birth (gender, birth location, and parental origin) and include cohort trends. Robust standard errors are reported in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Source: ONS Longitudinal Study

Table 5: Estimates of mortality rates by ages 52 to 62

	52	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**
$T_c * LC_{ic}$* HIGHarea	-0.0150	-0.0122	-0.0056	-0.0032	-0.0070	-0.0125	-0.0230*	-0.0202*	-0.0245*	-0.0202	-0.0276*
	(0.0128)	(0.0123)	(0.0129)	(0.0127)	(0.0114)	(0.0120)	(0.0121)	(0.0119)	(0.0129)	(0.0137)	(0.0144)
$T_c * LC_{ic}$	-0.0024	-0.0045	-0.0074	-0.0064	-0.0039	-0.0051	-0.0082	-0.0072	-0.0101	-0.0123	-0.0099
	(0.0044)	(0.0054)	(0.0059)	(0.0056)	(0.0056)	(0.0068)	(0.0072)	(0.0077)	(0.0075)	(0.0080)	(0.0074)
T_c* HIGHarea	-0.0073**	-0.0078**	-0.0081**	-0.0100***	-0.0108**	-0.0113**	-0.0093**	-0.0087*	-0.0072*	-0.0050	-0.0054
	(0.0031)	(0.0033)	(0.0036)	(0.0038)	(0.0051)	(0.0046)	(0.0045)	(0.0044)	(0.0042)	(0.0041)	(0.0046)
T_c	0.0055	0.0065*	0.0094**	0.0087**	0.0066*	0.0074*	0.0070*	0.0076*	0.0098**	0.0093**	0.0096**
	(0.0034)	(0.0034)	(0.0036)	(0.0035)	(0.0035)	(0.0043)	(0.0041)	(0.0042)	(0.0044)	(0.0045)	(0.0046)
LC_{ic}	0.0143***	0.0173***	0.0206***	0.0233***	0.0229***	0.0245***	0.0281***	0.0287***	0.0317***	0.0356***	0.0366***
	(0.0034)	(0.0039)	(0.0048)	(0.0044)	(0.0047)	(0.0051)	(0.0058)	(0.0066)	(0.0064)	(0.0074)	(0.0069)
HIGHarea	0.0020	0.0016	-0.0005	0.0011	0.0011	0.0005	-0.0000	0.0002	-0.0013	-0.0034	-0.0040
	(0.0022)	(0.0023)	(0.0024)	(0.0031)	(0.0039)	(0.0038)	(0.0043)	(0.0044)	(0.0044)	(0.0042)	(0.0045)
LC_{ic}* HIGHarea	0.0178**	0.0138*	0.0106	0.0107	0.0126	0.0155*	0.0226**	0.0198*	0.0221**	0.0227*	0.0291**
	(0.0082)	(0.0078)	(0.0086)	(0.0089)	(0.0080)	(0.0091)	(0.0104)	(0.0112)	(0.0106)	(0.0121)	(0.0131)
Constant	0.0208***	0.0228***	0.0238***	0.0264***	0.0307***	0.0344***	0.0385***	0.0413***	0.0445***	0.0487***	0.0539***
	(0.0027)	(0.0026)	(0.0027)	(0.0023)	(0.0024)	(0.0029)	(0.0027)	(0.0030)	(0.0032)	(0.0032)	(0.0032)
Observations	44,108	44,108	44,108	44,108	44,108	44,108	44,108	44,108	44,108	44,108	44,108
Lower-class mean mortality rate											
All areas	0.0435	0.0481	0.0534	0.0602	0.0655	0.0715	0.0785	0.0843	0.0915	0.0994	0.1086
in HIGHarea	0.0496	0.0516	0.0555	0.0640	0.0685	0.0738	0.0822	0.0875	0.0940	0.1038	0.1142
in LOWarea	0.0424	0.0475	0.0530	0.0595	0.0649	0.0711	0.0778	0.0837	0.0910	0.0986	0.1076
HIGH area lower-class mortality reduction in percent (relative to mean mortality rate)											
	-30.24	-23.64	-10.13	-4.94	-10.28	-16.94	-27.98	-23.09	-26.06	-19.46	-24.17

*Notes: The table shows estimates of equation 6. All specifications control for additional characteristics determined at birth (gender, birth location, and parental origin) and include cohort trends. Robust standard errors are reported in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.*
Source: ONS Longitudinal Study

largest cause of death in England accounting for 22% of deaths by age 75 (Department of Health, 2014).[27]

To minimise measurement error from self-reported outcomes, we use the linked hospital spell data to compute age-specific onset rates. Hospital spells are linked from 1997, and are currently updated to 2016 (with partial records for 2014 and 2015), so we observe hospital spells for all cohorts between ages 52 and 63. The data records the date of onset, and primary and secondary diagnosis, classified using the 9th and 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-9 and ICD-10). The same classification is used for main causes of death, which will allow us to link disease onset to mortality caused by cardiovascular disease. We use primary diagnosis codes and aggregate across all types of cardiovascular disease, e.g. ischaemic heart disease, hypertensive heart diseases etc. For each individual, we compute the age of first onset between ages 52 and 63 (if any onset occurs). We then construct onset rates between ages 52 and 63, and more detailed onset rates between ages 52 to under 54, 54 to under 56, 56 to under 58, 58 to under 60, and 60 to 63.

Table 6: Descriptive statistics, UK Biobank

Variable	Mean	Std. Dev.
Onset between ages...		
52 and 63	0.1031	0.3041
52 and under 54	0.0165	0.1273
54 and under 56	0.0176	0.1315
56 and under 58	0.0180	0.1330
58 and under 60	0.0190	0.1366
60 and under 63	0.0320	0.1760
Lower social class	0.3556	0.4787
Female	0.5443	0.4980
Single	0.1917	0.3937
Observations	*127,063*	

Notes: Source: UK Biobank

As with the mortality analysis, we expect treatment effects to be concen-

[27]The largest cause of death is cancer which accounts for 42% of deaths up to age 75. However, as cancer onset results from gene mutations, we expect that its onset is driven less by childhood environment and to a larger extent by genetic disposition and lifestyles in adulthood such as drinking, smoking, exercise and nutrition.

trated among individuals of lower class. As in the ONS Longitudinal Study, we do not observe the social class of the mother at the time of her child's birth. Instead we use the individual's school leaving age and the age at which they start working as indicators of social class. An individual is considered of lower class if they leave school before age 16, have no qualifications or if they start working before age 17.[28] Additional covariates are gender, and living alone. We control for county-level fixed effects to capture time-consistent differences in local health infrastructure and other relevant cross-county differences.[29]

Summary statistics for our estimation sample are shown in Table 6. Our estimation sample contains more than 127,000 individuals. The onset rate of cardiovascular disease increases with age, from 1.65% at age 52 to 3.20% at age 62. Between ages 52 and 63 the average onset rate of cardiovascular disease for individuals in our sample amounts to 10.31%.

Table 7 shows the estimation results for the probability of onset of cardiovascular disease between age 52 and age 63 using a linear probability model and the empirical specification from equation 1. As with the results for overall mortality we find the parameter estimate $\hat{\gamma}_2$ increases in magnitude and statistical significance with age. The overall reduction in the onset of cardiovascular disease between ages 52 and 63 is 0.0089 percentage points for individuals from lower social class. This represents a reduction of 7.57% relative to the mean for this population group. We can see that this is driven by onsets that occur after age 60, which is when the disease burden substantially increases. There is a 0.006 percentage point decline in the onset of cardiovascular disease between the ages of 60 and 63 for lower class individuals. This effect is large and represents a 18.75% reduction in onset relative to the mean for this age group.

Table 8 presents the analysis for the onset of cardiovascular disease using the empirical specification described in equation 6. The overall decline in onset for lower class individuals remains large and significant. However, in contrast to the analogous results for mortality presented in Table 5, we do not observe additional reductions in the onset of cardiovascular disease for

[28] The minimum school leaving age for these cohorts was age 15.

[29] We also control for current location of residence to control for contemporaneous cross-county variation, e.g. in medical service provision.

Table 7: Estimates of onset of cardiovascular disease between ages 52 to 63

	Onset between ages ...					
	52 to under 63	52 to under 54	54 to under 56	56 to under 58	58 to under 60	60 to 63
$T_c LC_{ic}$	-0.0078*	0.0006	-0.0027	-0.0002	0.0005	-0.0060**
	(0.0039)	(0.0017)	(0.0017)	(0.0018)	(0.0018)	(0.0022)
T_c	0.0053	0.0010	0.0033*	-0.0005	0.0012	0.0003
	(0.0035)	(0.0014)	(0.0015)	(0.0015)	(0.0016)	(0.0020)
LC_{ic}	0.0311***	0.0057***	0.0069***	0.0059***	0.0047***	0.0080***
	(0.0025)	(0.0011)	(0.0011)	(0.0011)	(0.0011)	(0.0015)
Observations	127,063	127,063	127,063	127,063	127,063	127,063
Lower-class mean onset rate						
	0.1031	0.0164	0.0176	0.0180	0.0190	0.0320
Lower-class onset reduction in percent (relative to mean)						
	-7.57	3.66	-15.34	-1.11	2.63	-18.75

Notes: The table shows estimates of equation (1). All specifications control for gender, birth location, home location, living alone. We include cohort trends. Robust standard errors are reported in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Source: UK Biobank

Table 8: Estimates of onset of cardiovascular disease between ages 52 to 63

	Onset between ages ...					
	52 to under 63	52 to under 54	54 to under 56	56 to under 58	58 to under 60	60 to 63
$T_c * LC_{ic}*$ HIGHarea	0.0075	0.0050	0.0093*	-0.0095*	-0.0021	0.0048
	(0.0089)	(0.0039)	(0.0039)	(0.0039)	(0.0042)	(0.0050)
$T_c * LC_{ic}$	-0.0104*	-0.0008	-0.0053*	0.0019	0.0012	-0.0075**
	(0.0047)	(0.0020)	(0.0021)	(0.0021)	(0.0021)	(0.0027)
T_c* HIGHarea	-0.0066	-0.0023	-0.0034*	0.0003	0.0016	-0.0028
	(0.0040)	(0.0016)	(0.0017)	(0.0017)	(0.0018)	(0.0023)
$LC_{ic}*$ HIGHarea	0.0035	0.0010	-0.0046	0.0061*	0.0036	-0.0026
	(0.0057)	(0.0024)	(0.0024)	(0.0026)	(0.0026)	(0.0033)
T_c	0.0077*	0.0019	0.0045**	-0.0006	0.0006	0.0014
	(0.0038)	(0.0016)	(0.0016)	(0.0017)	(0.0017)	(0.0023)
LC_{ic}	0.0305***	0.0055***	0.0082***	0.0044**	0.0037**	0.0088***
	(0.0030)	(0.0013)	(0.0013)	(0.0013)	(0.0013)	(0.0018)
HIGHarea	-0.0059	-0.0129***	-0.0146***	0.0120	-0.0206***	0.0301
	(0.0553)	(0.0035)	(0.0036)	(0.0334)	(0.0039)	(0.0453)
Observations	127,063	127,063	127,063	127,063	127,063	127,063
Lower-class mean onset rate						
All areas	0.1031	0.0164	0.0176	0.0180	0.0190	0.0320
in HIGHarea	0.090	0.0137	0.0147	0.0152	0.0175	0.0289
in LOWarea	0.110	0.0178	0.0190	0.0194	0.0197	0.0335

Notes: The table shows estimates of equation (1). All specifications control for gender, birth location, home location, living alone. We include cohort trends. Robust standard errors are reported in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Source: UK Biobank

low class individuals born in areas with a larger high social class population composition.

4 Conclusion

In this preliminary analysis we have demonstrated that in addition to the large immediate effect of birth exposure to universal health care on infant mortality (a 17% reduction), we find evidence of long-term effects on health and mortality that manifest 50 to 60 years later. This effect is concentrated among people who were likely to have had low socio-economic status at birth, for whom the introduction of the NHS would have provided a salient increase in the access to healthcare services.

Our results are consistent with Grossman (1972) who models health as a stock that depreciates with age and increases in health investments. Around age 50, depreciation accelerates stochastically via the onset of stochastic health shocks such as cardiovascular disease, stroke, cancer and other conditions.[30] While many of these conditions can be treated, most are hard to reverse. Hence, a better health stock at age 50 (or a lower probability of experiencing such a shock) will positively affect health in subsequent years. This way, small (and statistically insignificant) positive treatment effects at ages 50, 51 and so forth accumulate over time, yielding lower disease onset rates and hence stronger survival gains when individuals approach their sixties. In our analysis, we find a 14% reduction in mortality at age 58 for lower class individuals. These mortality reductions become larger for those individuals born in areas where the NHS introduction is likely to have resulted in increased medical services per capita. We find similar decreases in the onset of cardiovascular disease for low class individuals, although there is no evidence of geographical variation according to social class composition.

Overall, our empirical results point to long-run health and mortality premia from birth exposure to universal healthcare. The long-run effect manifests about 60 years after the intervention, at a time of life characterised by increasing onset rates of disease and rising mortality. However, our current

[30] Smith (2004) finds that the onset of major conditions approximately doubles with each decade of age, with an onset rate of 12.9% in the 51-61 age group as compared to 7.2% in the 41-50 age group.

estimates may underestimate the long-run impact of birth exposure to the NHS, if infants who would not have survived prior to the NHS were, say, inherently weaker or unhealthier than those who survived. Selective infant mortality may imply a lowering of overall population health for cohorts born (and surviving) after the NHS introduction, and may lower the average health and mortality of survivors in adulthood. We outline our future research intentions below, where we propose a strategy that will allow us to separate selective mortality effects from long-run health and mortality premia of universal healthcare coverage at birth.

5 Outlook

5.1 The role of selective mortality in infancy

Our current estimates may underestimate the long-run impact of birth exposure to the NHS, if infants who would not have survived prior to the NHS were, say, inherently weaker or unhealthier than those who survived. Selective infant mortality may imply a lowering of overall population health for cohorts born (and surviving) after the NHS introduction, and may lower the average health and mortality of survivors in adulthood. Given that we find a substantial reduction in infant mortality of 17% following the introduction of the NHS, such selection may significantly bias our estimates.

The tension between selective infant (or fetal) mortality and the impact of early life interventions on later outcomes has been recognised by several authors in the literature. Currie and Gruber (1996a) use information on infant mortality rates to provide bounds for the magnitude of the bias from selective mortality. Almond (2006) and Bozzoli et al. (2009) develop models that take into account the impact of selection effects on the health of survivors. Both authors either lack the necessary data or have to make strong assumptions to determine the magnitude of bias from selective mortality. Bozzoli et al. (2009) conclude that selection effects may dominate for high levels of infant mortality.

To account for this in estimation, we adapt the Bozzoli et al. (2009) model to separately identify i) the "health premium" of enhanced health outcomes

in adulthood due to improved childhood conditions, and ii) the "selective mortality" effect ensuing from increases in infant survival. We combine their model with our simple medical services model to reduce the number of parameters that need to be calibrated. We sketch this model in the following.

Bozzoli et al. (2009) find a strong inverse relationship between postneonatal (one month to one year) mortality and the mean height of those children as adults. The authors interpret infant mortality as an indicator of early childhood disease and nutritional environment, and develop a model that separates the long-run scarring effect of such early childhood conditions on health in adulthood from the impact of infant mortality on the probability to survive to adulthood. Simulations using the model predict that an increase in infant mortality may lead to a selection effect that may increase the average height of survivors, and may dominate the long-run scarring effect. In a pseudo cohort panel of birth-cohort data for 12 countries, they show that postneonatal mortality in the year of birth accounts for more than 60 percent of the variation in adult height.

The model assumes that individuals are born with an innate level of (adult) health which follows a distribution $F(h_{it})$. Individuals born with health h_{it} less than or equal to a threshold value z die in infancy. A change in the childhood environment acts as a shock v_t which moves the threshold value z. Infant mortality can thus be expressed as:

$$Inf_t = F(z + v_t) \tag{7}$$

Thus, the probability of surviving depends on the threshold value z and the childhood shock v_t.

This truncates the distribution of health for survivors which is:

$$\tilde{h}_{it} = \frac{\int_{F^{-1}(Inf_t)}^{\inf} h_i dF(h)}{1 - Inf_t} + \theta v_t \tag{8}$$

The first term captures the above described selection in the health status of survivors. The last term θv_t captures the long run scarring effect of the shock which moves the distribution of health to the left.

Bozzoli et al. (2009) then assume that $F(.)$ is a normal distribution with mean μ and variance σ^2. Substituting in equation 7, integrating and con-

verting to a standard normal distribution gives:

$$\frac{\tilde{h}_{it} - \mu}{\sigma} = \frac{\phi\Phi^{-1}(Inf_t)}{1 - Inf_t} - \theta\left(\Phi^{-1}(Inf_t) - \frac{z - \mu}{\sigma}\right) \tag{9}$$

where ϕ and Φ are standard normal density and distribution functions. The equation expresses the z-score of h_{it} in terms of mortality rate Inf_t, survival cutoff z (expressed in standard deviations from the mean) and the stunting parameter θ. Taking their model to the data, the authors make assumptions about the parameters of the normal distribution, μ and σ, and the threshold value z. They then estimate θ using data on Inf_t and the height of survivors (their indicator of adult health).

We apply this model to our setting with *decreasing* infant mortality which may result in negative selection of survivors and a positive long-run health premium θ. In contrast to Bozzoli et al. (2009) who do not observe what may have caused the shock in childhood disease environments, and have no information on v_t, we use the medical services model described in section 3.1 to put additional structure on the childhood environment shock. We posit that the childhood shock is a function $g(m_{gt})$ of county-level medical services.

In consequence, the health of survivors can be expressed as

$$\tilde{h}_{igt} = \frac{\int_{F^{-1}(Inf_{gt})}^{\inf} h_i dF(h)}{1 - Inf_{gt}} + \theta g(m_{gt}) \tag{10}$$

This implies that data on county-level infant mortality rates Inf_{gt}, medical services m_{gt} and indicators of health (or later life mortality) $\tilde{h_{igt}}$ of survivors, combined with assumptions about the normal distribution parameters μ and σ[31], will be sufficient to estimate the health premium that ensues from birth exposure to universal healthcare coverage. We will additionally use information on the differential infant mortality rates of population groups who had access to medical services before the NHS introduction, and those that newly gained access upon the introduction of the NHS in our estimation.

[31]Bozzoli et al. (2009) fix these parameters according to the height distribution of Danes between 1976 and 1980 when infant mortality rates were close to zero. We will use a similar approach.

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