Project Protocol for NIHR 13/43/55

Abstract:

The use of financial payments to encourage behaviours governments find useful is becoming common. The logic for these payments is that they may encourage small changes in behaviour which have potentially large benefits to the individual and society (e.g. Higgins et al., 2012; Promberger, Dolan, & Marteau, 2012). Policy based on traditional economics has focused on the direct behavioural effects of incentives and the provision of information. Recent insights from behavioural economics suggest that how cash transfers are labelled may affect how this money is spent. This is because people appear to allocate the cash transfer income to a relatively non-fungible mental account that is directly linked to the transfer label. An example of this type of cash transfer policy is the Winter Fuel Payment (WFP).

The WFP was initiated to combat fuel poverty and the related excess winter mortality and morbidity among older households in the UK. This winter morbidity is associated with cold indoor climates generally believed to be caused by insufficient heating of the home. The WFP provides households that include a member over the age of 60 years (in the qualifying week of a given year) with a lump sum annual payment in November, with the goal that it will be put towards increased energy use and lead to warmer indoor temperatures. Recent research (Beatty et al., 2011) suggests that recipients spend 41% of the transfer on fuel, much higher than the 3% expected increase if the payment were treated as cash.

Although the WFP has the objective of enhancing the health and well-being of the fuel poor, research has not yet evaluated this possibility. The proposed programme of work will treat the WFP as a natural experiment and employ a regression discontinuity design to estimate the potential causal effect of the WFP on household temperature, circulatory (e.g. blood pressure, coronary symptoms) and respiratory (e.g. lung function) health and the presence of infection (e.g. raised C-reactive protein levels.). Health variables which react quickly to cold and can gauge the presence of upper respiratory tract infections have been selected for this study. We also capitalize on the sharp eligibility criteria for the WFP to test whether the payment improves perceptions of physical health and mental health and well-being ratings.

To do this, we will utilize three large scale population health databases; the English Longitudinal Study of Ageing, the Health Survey for England, and the UK Biobank study. Each of these studies contain rich measures provided by participants sampled consistently throughout the year, making this data ideal for producing comparisons between those who turn 60 before (recipients) and after (nonrecipients/comparison group) the eligibility cut-off date for the WFP.

The proposed programme of research brings together an interdisciplinary team working in areas of behavioural economics, environmental economics, epidemiology and behavioural medicine who together will build an evidence base for assessing the potential health benefits of the WFP and whether these are located principally amongst those on low incomes. We will estimate the role of the WFP in making homes warmer and attenuating the 'Winter excess' in morbidity. In addition, we will gauge how these potential effects differ by income groups. This research will provide key insights into how the labelling of a key Government transfer may have health effects.

Aims and Objectives:

The aim of this grant is to progress and develop a research agenda on the health impact of the Winter Fuel Payment (WFP). We will provide insight into the extent to which the labelling of this Government cash transfer as targeting domestic energy expenditure has affected biological markers of healthy functioning, health perceptions, and measures of mental health and well-being. To do so, this research will capitalize on rich sources of secondary data including the English Longitudinal Study, the Health Survey for England and the UK Biobank study. These studies provide a wealth of measures covering the time period from the introduction of the WFP in the late 1990's to the present. We will employ a regression discontinuity design which takes advantage of the sharp eligibility criteria of the WFP combined with the presence of a sample of participants from each week of the year in the above datasets.

Our team have substantial experience in econometrics, analysis of large scale databases and the examination of biomarkers. Collectively we have extensive expertise in working on research problems that exist at the interface of psychology, economics, and medicine. Our team have employed the proposed regression discontinuity design to study the impact of the WFP on consumption and have gathered and coded much of the relevant data and conducted promising preliminary analyses. Furthermore, we have carefully selected the health outcomes utilized in this proposal based on their association with cold indoor temperatures.

Although there is some evidence that the WFP leads households to increase fuel expenditures, little is known about whether this translates into improvements in health outcomes. The goal of the current proposal is to shed light on this issue by addressing the following questions.

1. Does the WFP increase the household temperature in households eligible for the transfer?

2. Does the WFP improve recipient households' health outcomes (e.g., inflammation, blood pressure, mental and physical health ratings) and what is the magnitude of these effects?

3. Do the household temperature and health benefits of the WFP differ based on the social position of household members (e.g. income, social class)? Does the WFP appear to be effective in combatting fuel poverty?
4. Are these results robust to sensitivity and falsification tests? These include counterfactual tests examining false eligibility cut-off points (e.g if we simulate the WFP cut-off point existing at age 58 or 62), examining changes in health outcomes that are unlikely to be affected by indoor temperature (e.g. cancer diagnoses, hearing acuity), examining different functional forms to ensure findings are robust to nonlinearities and, testing for alternative explanations (e.g. to rule out the impact of bus passes we can examining whether the results are sensitive to travel mode).

Overview of research plan for design:

The WFP is a policy intervention that aims to reduce cold exposure and improve the health and wellbeing of elderly people in the UK. Policies in general and income transfers in particular are usually directed to benefit certain groups (i.e., they are not randomly assigned). These groups may have systematically different characteristics which also impact household decisions, independent of any effects of income transfers themselves. For example, a naïve multivariate regression analysis comparing health outcomes between recipients and non-recipients of income transfers may find that recipients are more likely to have positive health outcomes. However, claiming that income transfers generate these differences could be incorrect if recipients also differ in other attitudes or practices that would impact their decision-making around healthy behaviours, such as their frequency of exercise or quality of diet.

Similarly, evaluating the health effects of the WFP is challenging because those who receive the WFP are likely to differ from the remainder of the population on many non-policy factors. If the WFP was randomly assigned to a portion of households with a member aged over 60 then intervention and control groups would be similar with respect to confounders. Although the WFP is not randomly assigned, the policy can be treated as a natural experiment. This is because there are not likely to be other differences between households where the eldest member turns 60 right before (recipients) and right after (non-recipients)the WFP-qualifying week.

The health of these sub-sets of WFP recipient and non-recipient households will be compared using a technique known as regression discontinuity design (e.g. Lee & Lemieux, 2009). The structure of the WFP allows for identification of the causal impact of the labelled income support on household health without the concern that other unobservable and observable factors (attitudes toward risk, frequency of exercise, education, etc.) could be the main drivers.

The proposed program of work will draw on data from pre-existing large scale (N > 10,000) population representative health studies. Our principal estimation method will utilize the sharp eligibility criteria of the WFP and a plethora of control variables available to identify the causal impacts of the income support on health outcomes. The detail available in the English Longitudinal Study of Ageing (ELSA), Health Survey for England (HSfE), and UK Biobank datasets will allow us to assess whether the observable characteristics of households are statistically equivalent between those that receive the WFP and those that do not. If appreciable differences exist, we will be able to control for any differences in observable characteristics that may exist between WFP recipients and non-recipients.

Our team have extensive experience in working with large-scale population health datasets, developing sophisticated econometric models, and employing complex estimation strategies including regression discontinuity analysis. Daly has expertise in the area of behavioural medicine and behavioural economics. He has published several papers using the HSfE and ELSA databases including a recent paper in the area of thermoregulation and health. Moro has strong expertise in environmental economics and has developed two working papers which use a regression discontinuity design to examine the impact of the WFP on the energy consumption and efficiency of homes. Angelini works at the interface of labor and health economics and has broad experience including working on the design of a multidisciplinary population health survey (SHARE), and in integrating econometric modelling and analysis of large scale databases to address salient health and welfare issues. Sidman is an epidemiologist with expertise in the area of indoor environmental exposures and respiratory health and research and public health practice activities involving elderly populations.

Details research design:

1. Research design:

Ideally, to evaluate the effects of the WFP on morbidity one would run a randomised control trial, in which one group is assigned to the WFP (“treatment group”) while another one is not (“control group”). Differences between the two groups would be randomised and a simple comparison of mean outcomes could be interpreted causally. However, some non-experimental techniques, such as the Regression Discontinuity (RD) design, allow researchers to recover causal effects from the analysis of observational data.

The RD mimics a randomised experiment by exploiting features such as sharp eligibility criteria of programs. In our case, the WFP is transferred to households who have a member who is 60 or older at the beginning of the qualifying week. The placement of the qualifying week has changed over time, however during the years in our data the qualifying week came in September for most of the period.[1]

The RD method can be illustrated graphically. Figure 2 consists of two graphs, each showing the situation that might exist between a health outcome *h* (e.g., lung function, health perceptions) and *age* under different circumstances. The vertical line in the centre of each graph designates the cut-off point at age 60, above which household are assigned to the treatment (i.e., receive the WFP) and below which are not assigned to the treatment.

The top graph illustrates what one would expect in the absence of the WFP. The crucial aspect here is the smoothness of the relationship between the health outcome and age. Albeit very stylized, the top graph captures essential features. The relationship is downward sloping implying that

[1] Detailed description of the use of the RD design for programme evaluation can be found in Lee and Lemieux (2010), Jacob and Zhu (2012) and Angrist and Pischke (2008), among others.

h declines as age increases. The relationship is also continuous around the eligibility age of 60 years old. This implies that there is no substantial difference in health outcome for households who are just above and just below the cut-off point.

The bottom graph in the figure illustrates what might occur if the WFP has a positive impact on the health outcome *h*. In this case, there is a sharp upward jump in the relationship between health outcomes and age at the cut-off age. The aim of the RD analysis is to test for the presence of such jump/discontinuity around 60. Note the overall relationship between *h* and *age* is still negative, however it is discontinuous.

The assignment age employed by the WFP program is exogenous and the WFP effectively divides the population of households between a treatment group (i.e., households which oldest member is just above 60 years of age) and a control group (i.e., households which oldest member is just below 60 years of age). Near the cut-off age of 60, differences between these two types of households can be assumed to be random. The direction and magnitude of the jump is a direct measure of the causal effect of the WFP on health outcome *h* for households close to the cut-off point.

Formal description

Assignment to the treatment is determined exogenously by the age of the oldest member of the household in the arbitrary qualifying week. From this follows two important aspects. First, the entire selection into treatment is on the basis of the observable variable age and second, this selection rule is exogenous and cannot be manipulated by households. In other words, this ensures that households on the left-hand side of the cut-off represent a good counterfactual. A formal representation of the causal effect, denoted by ρ, of the WFP on the health outcome h can be given by the difference between the two conditional expectations around the cut-off age:

$$\rho = \lim_{\epsilon \to 0} \mathrm{E}(h|Age = 60 + \epsilon) - \mathrm{E}(h|Age = 60 - \epsilon)$$

The empirical specifications will then compare households who are immediately above and below the eligibility age of 60 under the identifying assumption that health outcome *h* would have been similar in the absence of WFP receipt.[2]

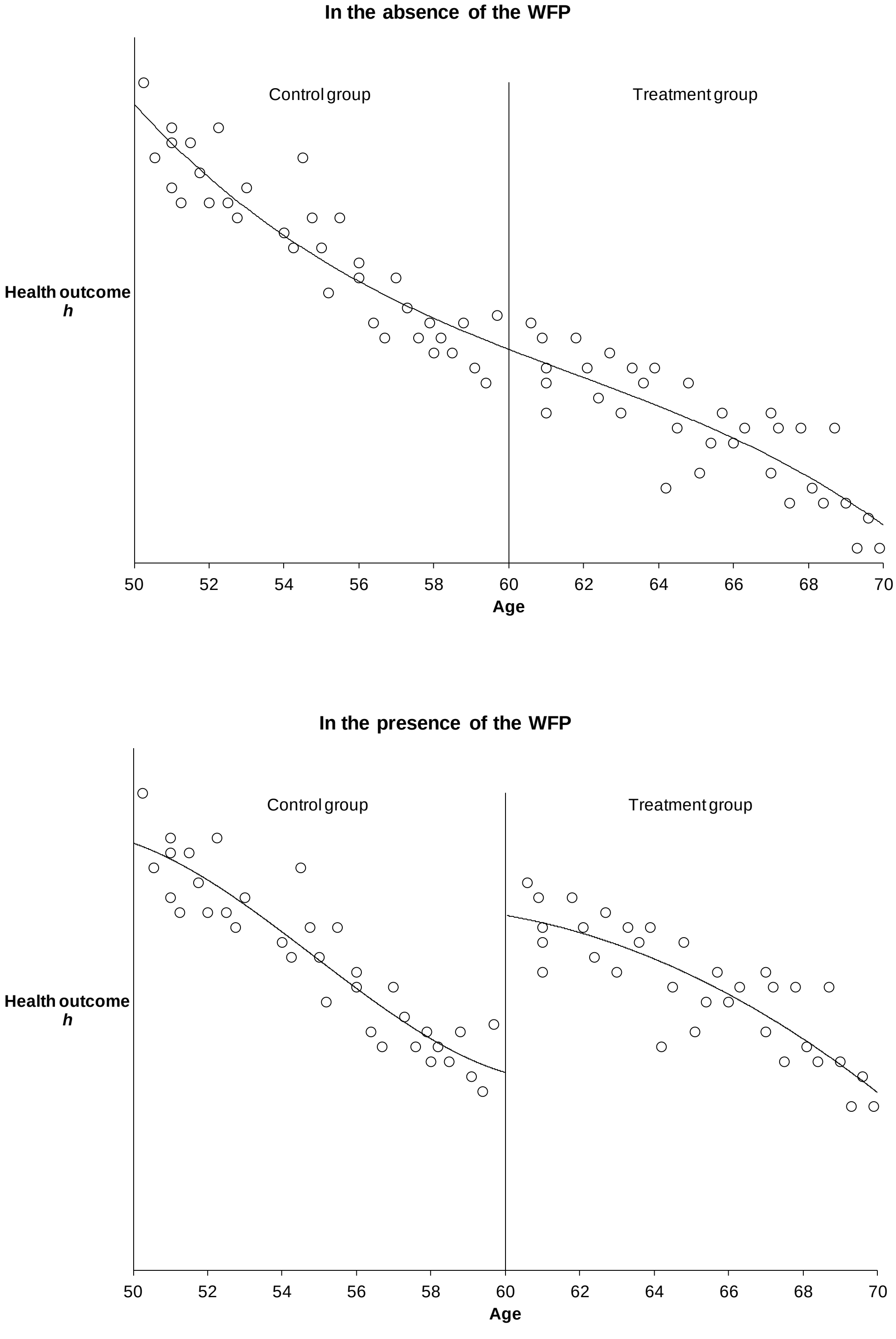
From this discussion follows that to ensure identification of the causal effect one must check that no other factors except being a recipient of WFP should be discontinuous around the age of 60. This seeks to rule out the possibility of jumps in other covariates that may affect health outcomes. The possibility that other confounding factors would jump around 60 is limited, however, for this proposal, there are a series of factors that comes to mind that are worth checking: housing types, income and job status changes, inter alia. We have conducted preliminary analyses using the last wave of the British Household Panel Survey and Understanding Society. We report RD graphs in Figure 3 showing the absence of a discontinuity for log of income and being employed. It follows from this that income and employment are not confounding factors because these baseline covariates have the same distribution just below and just above the cut-off.

Investigation of mechanisms

If a causal effect of the WFP on health and well-being is identified, analysis on the potential mechanisms can be performed using similar RD design on different outcomes. Improved health and well-being if found must be a direct consequence of behavioural changes stimulated and facilitated by the cash transfer. For instance, RD will be applied to see whether this may be attributable to a statistically significant jump in indoor temperatures.

[2] Details on the statistical analysis can be found in section 12.

Figure 2. Stylized graphical representation of the RD design

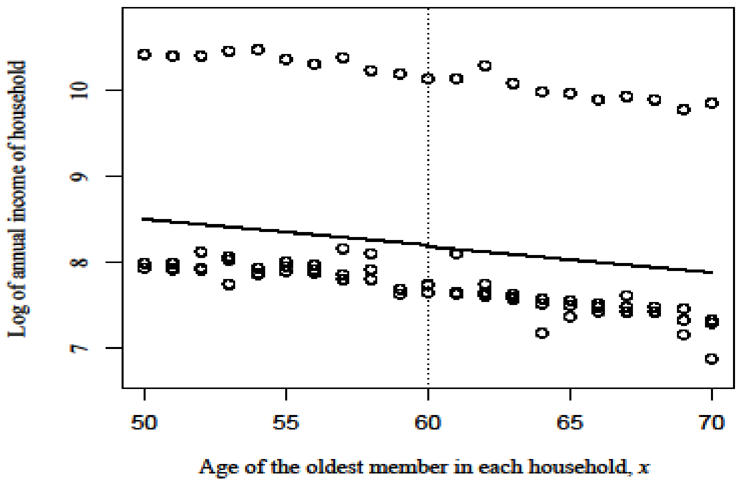


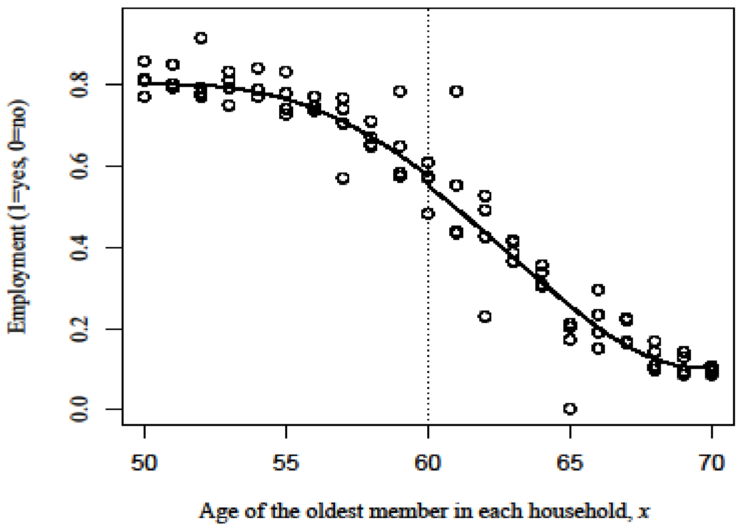
Note: Each dot represents the average of the health outcome corresponding with each age group. The vertical line delimits the cut-off point at age 60 above which households receive the WFP.

2. Study population

The WFP policy is implemented across the UK. Households receiving the WFP are those with one or more members over the age of 60 years (as of each year's qualifying week), and individuals within these households will serve as our study's 'intervention group'. The proposed statistical methodology, known as regression discontinuity design and fully described in Section 12 (Statistical analysis), relies on comparing the intervention group to a 'control group' of individuals of similar ages. Data from three existing population-based health studies will be used to test the study research questions in representative samples of the UK population. Specifically, we propose to use the Health Survey for England (HSfE), the English Longitudinal Study of Ageing (ELSA), and the UK Biobank in the current research. ELSA and the HSfE recruited participants from England, while UK Biobank includes additional coverage of Scotland and Wales. In order to conduct the appropriate regression discontinuity analyses (see section 12 'Statistical analysis') our studies will include only data collected on participants aged 50 – 70 years (10 years either side of the age 60 eligibility cut-off for the WFP, though a series of bandwidths will be tested: 4, 6, 8 years either side of the WFP cut-off).

Figure 3. Preliminary RD analysis showing no discontinuity of log of income and employment status around 60 years of age (data from the BHPS and Understanding Society)





To briefly describe the population-based studies from which our data will be drawn:

HSfE: The HSfE provides repeated cross-sectional random samples that are nationally representative of persons living in private households in England. We will use data from all fifteen available waves conducted since the WFP came into effect in 1998, each of which recruited approximately 8,500 to 23,000 individuals. Boost samples of participants from populous minority ethnic groups in 1999 and 2004 will help ensure that our study sample captures the ethnic diversity of UK populations.

ELSA: In 2002, ~12,000 individuals aged ≥50 years who had previously participated in the HfSE were recruited for the multi-disciplinary and longitudinal ELSA study. Data are collected every 2 years. The original ELSA cohort was supplemented with refresher samples of HSE respondents during ELSA waves 3 and 4. Five waves of data are currently available, through 2011, with data from wave six (2012/2013) forthcoming. ELSA's longitudinal design allows us to maximize sample size because additional participants will "age-in" to become eligible at each wave.

UK Biobank study: Residents registered with NHS and living within 25 miles of one of 21 study assessment centres throughout England, Scotland, and Wales were invited to enrol in the UK Biobank study. Between March 2006 and July 2010, >500,000 participants aged 40-69 years were recruited into the study's pilot and main cohorts and participated in baseline surveys, physical measurements, and biological sample collection. While UK Biobank does not include data on all our health outcome variables of interest, it will provide a large sample size and statistical power to detect associations should they exist for outcomes on which UK Biobank data are available (see Section 9 'Proposed outcome measures'). In our analyses, UK Biobank-identified participants will be restricted to those living in private homes in order to match the home type studied in the HSE and ELSA; UK Biobank participants living in sheltered accommodations, care homes, or mobile and temporary structures (i.e., caravans) will be excluded.

Inclusion criteria for our main analyses are as follows:

i) **Aged 50 to 70 years**, which provides a maximum age band of 10 years around the WFP-eligibility age of 60 years and helps ensure that intervention and control groups are more likely to be similar in age and age-associated characteristics; statistical analyses will also investigate narrower age bands by further restricting the study population by age (e.g., 5 year age band by studying 55 to 64 year old participants, 2 year age band using 58 to 61 year olds).

ii) **Oldest member of household only**, to maintain similarities between intervention and control groups and to reduce exposure misclassification by avoiding situations where participants <60 years old actually live in households with persons ≥60 years of age (and thus are not personally eligible for

WFP but live in a WFP-receiving household). This restriction is only possible with HSE and ELSA data. UK Biobank does not include detailed data on household membership; however based on number of household members and relationships between participants and other household members, sensitivity analyses will be run on UK Biobank data restricted to single-person households or household groupings for which we can accurately infer household WFP status (e.g., participants living only with children or grandchildren can reasonable be assumed to be the oldest household member). Other sensitivity analyses utilizing HSE and ELSA data will investigate whether WFP effects are detectable on younger members (<60 years) of WFP-recipient households.

iii) **Winter data collection visits**, initially defined as November through March; results based on physiological and physical functioning outcome data collected during non-winter visits will be compared to the main winter-visit analyses in sensitivity and falsification analyses since acute effects of the WFP are expected to be restricted to, or strongest in, the winter months.

Additional sensitivity and falsification analyses which are not based on study eligibility criteria are described in Section 12.

3. Socioeconomic position and inequalities

Impact of WFP across socioeconomic groups

The RD analysis, implemented with the statistical techniques described in section 12 will recover the average causal effect of the WFP on health outcomes (and indoor temperatures). However the WFP is likely to have different effects across income groups. From a policy perspective, the WFP can be seen as a measure to combat fuel poverty. In England, households are considered to be fuel poor if they have to spend more than 10% of their household income (including benefits and income supports) on fuel to keep their home in a satisfactory condition and cover other normal fuel costs.

The largest category of fuel poor, which makes up over one-third of all fuel poor households in the UK, is households with a single occupant over 60 years of age, while the third largest category is households with a couple over age 60 which happen to be recipients of the WFP. This calls for separate analysis in which the RD analysis will be run on different income quartiles, single households only and a combination of the two (the size and richness of the Biobank data will allow for this type of analysis without loss of power). Each analysis will provide the causal effect of the WFP for each category considered allowing for fruitful comparative analysis.

A robustness check will be run by using the large sample of single households from the Biobank dataset to establish more clearly the mechanisms and the behavioural changes at play. We are particularly interested in how the effect of the WFP may vary across socioeconomic groups (e.g. as a function of income).

Our preliminary ‘naïve’ multivariate regression analyses have provided suggestive evidence that there is an increase in household temperature when those aged 58-59 are compared to those aged 61-62 and that this is most pronounced amongst those from lower social class backgrounds. Specifically, we utilized household temperature data from 6,214 individuals from the HSfE to show that those aged 61-62 live in warmer households than those aged 58-59 ($B = .14$, $SE = .057$; $t = 2.46$, $p < .05$) and that this difference is robust to the inclusion of observed covariates (e.g. gender, social class, year of study, month of study).

Crucially, this difference was found to interact with social class ($B = .121$, $SE = .041$; $t = 2.91$, $p < .0005$) so that the increase in temperature around the age of WFP eligibility is most pronounced amongst those from lower social classes (e.g for social class V: $B = .547$, $SE = .208$; $t = 2.64$, $p < .01$). Thus, our preliminary analyses suggest that there is an increase in household temperature from the time before to after the introduction of the WFP that is most pronounced amongst those from low social classes. This project will allow a more sophisticated, causally sensitive test of this suggestion to be conducted and to test whether health changes also follow from the WFP.

4. Planned interventions

The WFP is a policy intervention that aims to reduce cold exposure and improve the health and well-being of older people in the UK. The WFP takes the form of a cash transfer to UK households that include a member over the age of 60 years. The payment was introduced in the late 1990's and is provided in the form of a lump sum payment in November of each year and the Government make a £2 billion to £3 billion spend on the WFP each year. Once a household is in receipt of the payment, it continues to be paid until the Department of Work and Pensions (DWP) is notified of a change in circumstance that makes the household no longer eligible for the payment.

Recent research (Beatty et al., 2011) suggests that recipients spend 41% of the transfer on fuel. We propose to treat the allocation of the WFP as a natural experiment and capitalise on the sharp eligibility criteria for the WFP (i.e. oldest household member is 60 in a given week of the qualifying year) to evaluate its influence on a range of health and well-being metrics. Households receiving the WFP are those with one or more members over the age of 60 years (as of each year's qualifying week), and individuals within these households will serve as our study's 'intervention group'. Thus, the eligibility criteria of the WFP effectively divide the population of households between a treatment group (i.e., households which oldest member is just above 60 years of age) and a control group (i.e., households which oldest member is just below 60 years of age). Near the cut-off age of 60, differences between these two types of households can be assumed to be random.

5. Give a brief explanation of the methods proposed: Not applicable

This section refers to methods for ensuring compliance and dealing with loss-to-follow-up. These are not relevant for the current proposal which draws solely on pre-existing large-scale population representative datasets.

6. Proposed outcome measures:

Circulatory, respiratory, and mental health conditions are most strongly associated with low indoor temperatures. Health outcomes within these domains have been selected from among the biomarker and physical functioning data collected during nurse visits of HSfE and ELSA or during health centre assessments carried out as part of the UK Biobank study, and from participant-reported responses drawn from survey components of these studies. Table 1 summarizes the outcomes data available from each parent study.

For primary outcomes, we have selected objective health measurements that have been shown to respond acutely to direct cold exposure or to capture the occurrence of short-term cold-related conditions such as upper respiratory tract infections. Specifically, we will examine systolic and diastolic blood pressure, the inflammatory biomarkers C-reactive protein and fibrinogen, and lung function (forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), and peak expiratory flow (PEF)). These indicators of cardiovascular and respiratory health and infection have each demonstrated robust associations with cold indoor or outdoor temperatures and related conditions (e.g., Woodhouse et al., 1993; Schneider et al., 2008; Hampel et al., 2010; Donaldson et al., 1999). These physiological and functional measurements would also be expected to respond quickly to changes in exposures, such as to indoor temperature during the months before and after household receipt of the WFP. For instance, the inflammatory marker C-reactive protein has been shown to correlate strongly with the severity of acute influenza infection symptoms which are frequently experiences in cold environments (Harran et al., 2012). Psychometrically valid instruments in the psychosocial modules of HSfE and ELSA, specifically the Centre for Epidemiological Studies Depression Scale (CES-D) and the General Health Questionnaire (GHQ-12), will be utilized to gauge whether WFP influences mental health and well-being.

Table 1. Summary of proposed outcome measures and parent study sources. Check marks (x) indicate when data on specified variables are available from one or more study waves.

	Outcomes	HSE	ELSA	UK Biobank
Blood pressure (systolic; diastolic)	1º	x	x	x
C-reactive protein	1º	x	x	
Fibrinogen	1º	x	x	
Lung function (FEV1; PEF; FVC)	1º	x	x	x
Mental health/well-being (CES-D)	1º		x	
Mental health/well-being (GHQ-12)	1º	x	x	
Self-assessed general health	2º	x	x	x
Self-reported respiratory symptoms	2º	x	x	x
Self-reported angina symptoms	2º	x	x	x
Indoor home temperature	2º	x	x	

The secondary health outcome measures of self-reported general health and participant-reported respiratory and angina symptoms will be used to capture the influence of the WFP on health perceptions.

Since the mechanisms by which WFP is hypothesized to affect health include increases in indoor air temperatures, we will also test the impact of the WFP on household temperature using data collected from HSE and ELSA participants' homes. This will allow us to estimate the magnitude of change in household temperature induced by the WFP and whether this change differs as a function of household income or social position. In addition to providing large sample sizes of elderly individuals and extensive health outcomes data, the HSE, ELSA, and UK Biobank studies include detailed information about participants' existing chronic health conditions, medication use, income, wealth, sociodemographics, and household accommodations (e.g., rent vs. own, heating type). These variables can be used to adjust and/or stratify analyses by health or social vulnerability or home status.

7. Assessment and follow up

This section refers to intervention studies and assessment of their potential harms. Please see the discussion of *bandwidth* in section 12 which covers the assessment period in RD.

11. Proposed sample size:

Here we provide power calculations based on the English Longitudinal Study of Ageing (ELSA) sample. The Health Survey for England and UK Biobank samples contain several times more individuals and will allow for an even more precise test of the study questions. We include calculations from ELSA as these represent the smallest identifiable effects in the databases we will utilize.

Considering that our analysis will be restricted to observations taken during winter months, November to March, we have provided evidence that we have the statistical power to statistically detect changes in the outcome variables. Nurses' visit data from ~2,500 household-visits and interview data from ~4,500 household-visits are available for winter-only analyses, approximately evenly split between households in which the oldest individual was aged 60 to 64 years (WFP recipient households) and those in which the oldest occupant was aged 55 to 59 years (WFP non-recipient households). Data from summer household-visits (~3,100 nurses' visits; ~5,600 interviews) are available for use with winter-collected data to statistically compare WFP-health associations between seasons. Table 2 below reports detectable effect sizes for a selection of health outcomes based on winter-collected ELSA data, assuming two-sided tests, type 1 error of 0.05, and 90% or 80% power:

Table 2. Detectable effect sizes for example health outcomes

Health outcome	Mean (SD) or % (WFP non-recipients, 55-59 yrs)	Detectable effect size (% change)	
		90% power	80% power
Fibrinogen (mg/dl)	3.21 (0.64)	0.09 (2.8%)	0.08 (2.5%)
C-reactive protein (mg/l)	3.43 (6.19)	0.86 (25.1%)	0.75 (21.9%)
Systolic blood pressure (mmHg)	130 (17)	3 (2.3%)	2 (1.5%)
Diastolic blood pressure (mmHg)	78 (11)	<2 (<2.6%)	<2 (<2.6%)
Self-reported general health – excellent/very good/good	77%	4 (5.2%)	<4 (<5.2%)

These detectable effect sizes are similar in magnitude to those effects observed in prior studies of cold temperatures (e.g., decrease of 1.3 mmHg blood pressure per 1 ºC increase (Woodhouse et al., 1993); temperature effects of ≤24 mmHg systolic and ≤13 mmHg diastolic blood pressure (Bull & Morton, 1975); 25% decrease in C-reactive protein with 5 ºC increase in 4 weeks' moving temperature average (Halonen et al., 2010); 1.3% decrease in fibrinogen per 10 ºC increase (acute temperature effect, whereas cumulative temperature effects appear stronger for inflammatory markers (Halonen et al., 2010; Schneider et al., 2008). Additionally, changes in mean levels of these magnitudes would be of public health significance. Policies such as the WFP are examples of population approaches to disease prevention, in which an entire population group is targeted instead of only high-risk individuals. When health risks are progressive with increasing risk factor levels, as is the case with blood pressure, fibrinogen, and C-reactive protein, even modest decreases in risk factors in an overall population can prevent substantial morbidity or mortality (e.g., estimated 14%, 9%, and 7% reductions in stroke, coronary heart disease, and all-cause mortality, respectively, with 5 mmHg reduction in population systolic blood pressure (Chobanian et al.,, 2003)).

These preliminary calculations provide us confidence that the proposed analysis is sound and statistically meaningful.

12. Statistical analysis

One way of estimating the causal effect of the WFP on the health outcome *h* (see Figure 1), would be to run two separate regressions: one for the left-had side of the cut-off and one for the right-hand side. A more direct way, and one that is typically used in the literature, is to run a pooled regression on both sides of the cut-off. This has the advantage of obtaining the standard errors of the potential causal effects directly.

From an empirical point of view, the challenge is to choose a correct functional form of the relationship between health outcome and age. If the functional form is not correctly specified, the estimated effects will be biased. In the worst case scenario, incorrect functional forms may confound discontinuity for nonlinearities. For this reason, a battery of different functional forms is typically used to check sensitivity of the results.

Formally, we will estimate variation of the following:

$$h_i = \alpha + \rho(WFP) + f(normalised\ age_i) + \varepsilon_i\ , \quad (1)$$

where: WFP takes the value of 1 if individual *i* is a member of a household who is assigned the cash transfer and 0 otherwise; $normalised\ age_i$ is the age for individual *i*, centered at the cut-off point of 60. The assignment variable is typically normalised to ensure that the coefficient ρ on the WFP can still be interpreted as the causal effect even in the presence of polynomials in (normalised) age, which are included in the model and represented by the function $f(x_i)$.

Models such as (1) although allowing for a variety of functional forms, effectively impose identical relationship on both sides of the cut-off point. One may argue that an intervention such as the WFP may modify the slope of the health-age relationship. To allow for different functional forms on either side of the age 60, the regression model in (1) can include interaction terms between WFP, (normalised) age and its polynomials.

It follows from this, that there are two important choices to be made in the RD design framework when it comes to the estimation: the selection of the *bandwidth* (i.e., how many age cells on either side of the cut-off to include in the regression analysis) around the age of 60 years old and the order of polynomials. With respect to the latter, we have already discussed the opportunity to employ a variety of functional forms. However, the literature suggests also some strategies to select the optimal order of polynomials based on goodness of fit tests as suggested by Lee and Card (2008). In terms of specification choice procedure, the idea is to add a higher order term to the polynomial until the age cell dummies are no longer jointly significant. [3]

With regard to the size of the bandwidth, note that as the bandwidth becomes larger, say 15 years on either side of the cut-off points, more data is considered, however households at either end of the spectrum are less likely to have similar (observed and unobserved) characteristics, which would result in a violation of one of the RD assumptions. Narrower bandwidths, on the other hand, may reduce the precision of the regression model. In order to search for the optimal bandwidth, we will employ and compare two methods: the cross validation method -- as described in Ludwig and Miller (2007) -- and the more parsimonious and alternative procedure suggested by Imbens and Kalyanaraman (2012).

As with polynomials, it is good practice to show how and if the results are sensitive to changes of bandwidth. Thus, even after identifying the optimal bandwidth, we will show how ρ behaves when using a spectrum of bandwidth (e.g., 10, 8, 6).

Further sensitivity analysis and robustness checks

It should be mentioned that this research design would not work if other policies would take place around the same period, because the effect of the WFP would then be confounded. We have contacted Income Maximization Officers to learn about other benefits that households may become eligible for due exclusively to turning 60 years of age. The only other benefit identified is free local bus service. As a sensitivity analysis, we can remove households who take the bus to work as a way of confirming that our results are due to the WFP and not to this additional bus benefit.

We propose to additionally run counterfactual analyses on health outcomes not associated with indoor temperatures, including the outcomes of cancer diagnosis and acuity of sight and hearing, and compare the results with those hypothesized to be impacted by indoor temperature and the WFP. In addition, we will include falsification tests where we simulate the WFP cut-off point existing at alternative ages (e.g. 55, 65) and test whether discontinuity is observed in health outcomes.

Our models will include year fixed effects to control for any variation that occurs at annual level. In addition, a more in-depth year-by-year analysis (using year-by-year regressions or interaction terms) will reveal interesting insights into the effects of the WFP over time. Annual energy prices will be considered and interacted directly with the treatment dummy (controlling for years fixed effects) in order to gauge whether the influence of the WFP on our outcome variables has declines as the price of fuel has increased.

Finally, although the uptake of the WFP is very high (90% of the eligible households do receive the payment, Beatty et al. 2011) a small difference still remains between eligibility for the WFP and receipt of the payment. This is a classic case of measurement error which is proven to bias the coefficient downward. Therefore we would slightly underestimate the true effect of the WFP on health outcomes. To estimate and account for the measurement error captured by the difference between eligibility and receipt of the WFP we will conduct analyses using the English Longitudinal Study of Ageing where receipt of the WFP is observed using the below question. By examining the impact of the WFP on our outcome measures separately using eligibility and receipt information we will be able

[3] Another commonly used method to model selection is the Akaike Information Criterion procedure (Akaike, 1974).

to precisely estimate the influence of this measurement error on our estimates generated using other datasets that do not contain this information.

Did [you / or your husband / wife / partner]] receive a Winter Fuel Payment in the last year (that is since [^date a year ago])?

Inclusion of covariates

If the RD is valid and therefore the local randomization around the age of 60 holds, then including covariates will provide more precise estimate of the causal effect. (Lee and Lemieux, 2010). Covariates that will be considered will include gender, employment status, income, job status, and types of housing. A full list of potential confounders for each dataset that will be utilized is detailed in Table 1. It is important to stress that covariates will be used to test the validity of the RD design and therefore check whether the results are robust. We will study whether the covariates are continuous and smooth around the cut-off. If the regression discontinuity design is valid -- and therefore the local randomization around the age of 60 holds -- then including covariates should not change the size of the coefficient substantially but should provide more precise estimate of the treatment effect. On the contrary, a substantial difference of estimates across models would invite even more caution in the causal interpretation of the effect of the WFP. Also, covariates will be used to study whether the effects of the WFP on health varies across groups.

There are no subsidies that we are aware of that were introduced each and every year for which we have survey data and which need to be controlled for. Some households will be eligible for the Cold Weather Payment which is paid (currently 25 pounds) for a period of seven consecutive cold days (i.e., temperatures below zero) to those receiving certain welfare payments. We will not be able to control directly the impact of the Cold Weather Payment (CWP) as there is no information on receipt of this payment in any of the datasets we will utilize. Government expenditure on the Cold Weather Payment is very small when compared with the WFP and therefore we believe does not represent a threat to the identification of the effect of WFP.