



# Alternative measures to BMI: Exploring income-related inequalities in adiposity in Great Britain



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## ABSTRACT

Socio-economic inequalities in adiposity are of particular interest themselves but also because they may be associated with inequalities in overall health status. Using cross-sectional representative data from Great Britain (1/2010–3/2012) for 13,138 adults (5652 males and 7486 females) over age 20, we aimed to explore the presence of income-related inequalities in alternative adiposity measures by gender and to identify the underlying factors contributing to these inequalities. For this reason, we employed concentration indexes and regression-based decomposition techniques. To control for non-homogeneity in body composition, we employed a variety of adiposity measures including body fat (absolute and percentage) and central adiposity (waist circumference) in addition to the conventional body mass index (BMI). The body fat measures allowed us to distinguish between the fat- and lean-mass components of BMI. We found that the absence of income-related obesity inequalities for males in the existing literature may be attributed to their focus on BMI-based measures. Pro-rich inequalities were evident for the fat-mass and central adiposity measures for males, while this was not the case for BMI. Irrespective of the adiposity measure applied, pro-rich inequalities were evident for females. The decomposition analysis showed that these inequalities were mainly attributable to subjective financial well-being measures (perceptions of financial strain and material deprivation) and education, with the relative contribution of the former being more evident in females. Our findings have important implications for the measurement of socio-economic inequalities in adiposity and indicate that central adiposity and body composition measures should be included health policy agendas. Psycho-social mechanisms, linked to subjective financial well-being, and education –rather than income itself–are more relevant for tackling inequalities.

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## 1. Introduction

The prevalence of obesity is an increasing worldwide concern (OECD, 2014). Obesity can be defined using different adiposity measures, such as the conventional Body Mass Index (BMI), body composition (for example, body fat, muscles), waist-circumference (WC) and body-shape measures (for example, the “A Body Shape Index” (ABSI)) (O’Neill, 2015). Recent evidence has shown that the United Kingdom (UK) not only has one of the highest obesity prevalence rates in Western Europe and the eighth highest among all OECD member countries (OECD, 2014) but is one of the countries with the highest obesity growth rates in the past three decades

(OECD, 2014). If the increasing obesity trends are not stemmed, there could be 11 million more obese adults in the UK by 2030 than in 2011 (Wang et al., 2011). Obesity is associated with increased mortality and morbidity risks (WHO, 2000) and places a significant burden on health care systems worldwide (Lehnert et al., 2013; OECD, 2014); the estimated proportion of health expenditures attributed to obesity in the United States (9%) and UK (5%) is among the highest worldwide (Allender and Rayner, 2007; Lehnert et al., 2013). It is no surprising therefore that obesity is considered a global public health concern and that a growing number of countries and the World Health Organization have established policies and strategies to reduce obesity levels (WHO, 2013). More specifically, UK governments have identified tackling obesity as a key priority (for example, Gilman, 2015; House of Commons Health Select Committee, 2015).

The existing literature on socio-economic determinants of adiposity showed negative associations between BMI (or BMI-

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based obesity measures) and education (Chou et al., 2004; Rashad, 2006), income (Chou et al., 2004; Lakdawalla and Philipson, 2009) and childhood socio-economic position (Baum and Ruhm, 2009). A review of several biomedical studies revealed that socio-economic position was, in general, negatively associated with adiposity measures; the findings were more evident in women and varied by the socio-economic measure employed (McLaren, 2007). However, most of these studies applied regression techniques to identify the existence of a “socio-economic gradient in adiposity”. They did not take into account the whole distribution of the socio-economic measures and, more generally, did not quantify the extent of socio-economic inequality in adiposity (Wagstaff et al., 1991; Zhang and Wang, 2004). The degree of socio-economic inequality depends on both the association of adiposity with the chosen socio-economic measure and the dispersion of the adiposity measure itself. This is important because similar associations can imply different inequalities, depending on the variability of the adiposity measures (O'Donnell et al., 2008). For example, for a given negative association between income and body weight, the degree of the inequality should be higher when the inequality in the distribution of the body weight measure itself is higher (i.e., the magnitude of the differences in body weight within the society).

Excess adiposity is viewed, to a large extent, as a preventable condition (Ljungvall and Gerdtam, 2010). Given its association with several health conditions and its uneven distribution across socioeconomic groups, inequalities in adiposity are likely to be reflected in socio-economic inequalities in overall health status (Borg and Kristensen, 2000). Therefore, socio-economic inequalities in adiposity are of particular interest themselves, but also because they may be associated with inequalities in overall health status. However, studies that do quantify socio-economic inequalities in adiposity are limited and restricted to BMI-based obesity measures that are often self-reported. These studies suggest that inequalities in obesity favour the less disadvantaged females, while the evidence for males is mixed (Costa-Font et al., 2014; Costa-Font and Gil, 2008; Hajizadeh et al., 2014; Ljungvall and Gerdtam, 2010; Madden, 2013; Zhang and Wang, 2004). A few of these studies investigate the underlying factors that contribute to such inequalities; however, the evidence to date has not reached consensus (Costa-Font and Gil, 2008; Hajizadeh et al., 2014; Ljungvall and Gerdtam, 2010; Madden, 2013).

Employing nationally representative data from Great Britain, the aim of this paper is twofold: a) to explore the presence of income-related inequalities in a number of alternative adiposity measures by gender and b) to identify what factors contribute to these inequalities. Concentration indexes (CIs) were used to quantify income-related inequalities in adiposity. These are widely used inequality measures (Erreygers and Van Ourti, 2011) that capture the socio-economic dimension of health inequalities using information from the whole distribution of the socio-economic measure rather than just the extremes (Wagstaff et al., 1991). Given the advantages of the methodology, regression-based decomposition techniques were then implemented to explore the contribution of the variables underpinning the observed income-related adiposity inequalities. We particularly focused on the role of more intermediate mechanisms linked to psycho-social processes, such as subjective financial well-being (SFW), as opposed to the impact of “structural” factors (such as income and education) and health behaviours.

Measures of SFW have been shown to be associated with health as independent correlates and as mediators between income and health (Arber et al., 2014; Gunasekara et al., 2013). Income and SFW measures, although related, should be viewed as distinct measures, with the latter mainly capturing individual *perceptions* of financial condition and to lesser extent actual indebtedness/budget

problems (Arber et al., 2014; Zyphur et al., 2015). For example, people with similar levels of (low) income may make different judgements about adequacy of their income, potentially as a result of the role of expectations or social comparisons (Arber et al., 2014; Mirowsky and Ross, 1999; Zyphur et al., 2015). Measures of SFW have been found to be associated with adiposity (Averett and Smith, 2014; Conklin et al., 2013; Laaksonen et al., 2004) and weight gain (Loman et al., 2013). These associations can be theorized through two generally distinguishable mechanisms, following a similar framework to Arber et al. (2014). First, perceptions of financial strain, i.e. feeling unable to manage on their income, may involve stressful psychological processes that may result in people overeating and excess adiposity (Averett and Smith, 2014; Wardle et al., 2011). Second, SFW measures may be linked to adiposity through “perceived relative material deprivation” pathways, which reflect the extent to which individuals feel that their income is insufficient to participate in ways considered customary within the community (Conklin et al., 2013); this mechanism is related to the reference group theory and the role of social comparisons (Arber et al., 2014). However, the impact of SFW on socio-economic inequalities in adiposity remains unknown.

In this study, alternative measures of adiposity were used. In addition to the conventional BMI, we employed body fat and WC measures. Body mass index (and consequently BMI-related obesity measures) is a noisy adiposity measure because it does not distinguish fat from lean body mass (Schutz et al., 2002; Burkhauser and Cawley, 2008). In particular, disentangling fat-from lean-mass is important for obesity research because these two components have distinct health consequences (Burkhauser and Cawley, 2008). Recent evidence has shown that different adiposity measures may result in different levels of obesity (Burkhauser and Cawley, 2008; O'Neill, 2015), different effects on outcomes (Burkhauser and Cawley, 2008) and different socio-economic patterns (Ljungvall et al., 2015). It is important therefore to examine a range of adiposity measures to better identify potential intervention points for tackling inequalities in adiposity.

Based on the existing literature we hypothesized that: income-related inequalities in adiposity will favour the rich; these inequalities will differ between alternative adiposity measures and by gender; and SFW measures will considerably contribute to the income-related inequalities in adiposity after accounting for demographic, socio-economic and lifestyle factors.

This study contributes to the literature in a number of ways. This is the first study, to our knowledge, that explores income-related inequalities in alternative adiposity measures employing CI techniques; conventional BMI-based measures, body composition (fat and lean-mass components of BMI; percentage body fat, BF%) and central adiposity measures (WC) are used. These adiposity measures are treated as continuous and discrete obesity indicators. Second, in contrast to many of the previous studies, we employ clinically obtained adiposity measures. It has been shown that reporting errors in body weight (or BMI) are non-classical (Cawley et al., 2015; O'Neill and Sweetman, 2013) and they systematically differ by socio-economic status (Ljungvall et al., 2015). Hence, socio-economic inequalities in BMI-based measures may be biased when self-reported measures are employed (Ljungvall et al., 2015; O'Neill and Sweetman, 2013). Previous attempts to correct for bias in self-reported BMI data using a priori information on reporting behaviour (Costa-Font et al., 2014) were criticized regarding the ability of their methods to fully eliminate reporting error (Cawley et al., 2015). Measured anthropometric data are therefore preferable (Cawley et al., 2015). Finally, this is the first attempt to quantify the contribution of SFW, after accounting for demographic, socio-economic and lifestyle factors, to income-related inequalities in adiposity.

## 2. Methods

### 2.1. Concentration index

Concentration indices (CIs) measure inequality in the distribution of health/ill-health across the distribution of the chosen socio-economic measures. CIs are derived from concentration curves that plot the fraction of the total sum of the health variable that is concentrated in a fraction of the population ranked by the socio-economic measure (Wagstaff et al., 1991). In this context, CIs can be defined as twice the area between the concentration curve and the line of equality (the 45-degree line). In a finite sample, the CI can be formally expressed as:

$$CI = \frac{2 \times cov(y_i, r_i)}{\mu} \quad (1)$$

where  $y_i$  is the adiposity measure for each individual ( $i$ ),  $\mu$  represents its mean value,  $r_i$  is the individual's fractional rank along the income distribution (our socio-economic measure) and  $cov(\cdot)$  denotes the covariance. This index ranges between  $-1$  and  $1$ , with negative (positive) values indicating that the health/ill-health variable is concentrated among the relatively poor (rich) and a zero value representing an equal distribution across income. In our analysis, it is assumed that a negative CI favours the rich ("pro-rich" inequality in adiposity).

However, the boundedness of the health variable has crucial implications for the properties and value judgements of the CIs (Erreygers and Van Ourti, 2011; Wagstaff, 2005; Erreygers, 2009). Wagstaff (2005) as well as Erreygers (2009) and Erreygers and Van Ourti (2011) have proposed two different normalizations that are both appropriate for bounded health variables. Since our adiposity measures were either discrete or linear bounded variables (bounded by the biologically feasible limits, while BF% is further bounded as a percentage), these normalizations should be applied to enable inequality comparisons across adiposity measures of different measurement scales (Erreygers and Van Ourti, 2011). Following Erreygers and Van Ourti (2011), Erreygers' normalization was adopted here because Wagstaff's index might result in higher socio-economic inequality when there is a *ceteris paribus*-decrease in relative differences in health status among individuals. Nevertheless, a sensitivity analysis employing Wagstaff's normalization produced similar inequality results (available upon request). The Erreygers' (2009) corrected concentration index (CCI) is calculated as:

$$CCI = \frac{4 \times \mu}{b - a} \times CI \quad (2)$$

where,  $a$  and  $b$  are the lower and higher bounds of the adiposity measure, respectively. Since significant differences in income-related inequalities in BMI-based measures have been observed by gender, our analysis was stratified by gender (following Costa-Font et al., 2014; Hajizadeh et al., 2014; Zhang and Wang, 2004).

### 2.2. Decomposition of concentration indices

Concentration indexes can be decomposed to explore and quantify the impact of the factors underpinning the observed income-related inequalities in adiposity. Decomposition of the CI is based on a regression analysis of the association between adiposity measures and a set of  $k$  explanatory variables ( $X$ ). The contribution of each of these variables reflects both its association with the adiposity measure and its degree of income-related inequality (Doorslaer et al., 2004).

The CCIs for continuous adiposity measures and discrete obesity indicators were decomposed. Following common practices in the literature (Costa-Font and Gil, 2008; Doorslaer et al., 2004; Ljungvall and Gerdtham, 2010), equivalised net household income was also included in the decomposition analysis to separate the contribution of income inequality from that attributed to other covariates. In this context, the contribution of income itself can be interpreted as a measure of income-related inequality in adiposity after removing the effect of other variables that may be correlated with both income and adiposity. Details on the decomposition analysis can be found in the supplementary appendix [-Insert a link to the supplementary material about here-].

## 3. Data

The data came from Understanding Society: the UK Household Longitudinal Study (UKHLS), a longitudinal, nationally representative study in the UK (Knies, 2014; University of Essex (2015)). For this paper, we employed the General Population Sample (GPS), a random sample of the general UK population. As part of wave 2 (1/2010-3/2012), health measures (including adiposity) were collected by a nurse approximately 5 months after the initial wave 2 data collection. Of the 36,963 people who participated in wave 2 (GPS), 26,699 were eligible for the nurse visit (ages 16 and older, not living in Northern Ireland, and interviewed in English), and of those, 15,632 participated. The UKHLS has been approved by the University of Essex Ethics Committee and the nurse data collection by the National Research Ethics Service.

### 3.1. Variables

#### 3.1.1. Adiposity measures

Height was measured using a stadiometer (McFall, 2014). Body weight ( $W$ ) and BF% were measured by a floor body fat monitor/scale (Tanita BF 522) that imputes BF% by the bioelectrical impedance analysis (McFall, 2014). BMI was calculated as the weight (kilograms) over the square of height (meters). WC was measured twice, or three times if the two original measurements differed by more than 3 cm. The mean of the valid measurements (the two closest, if there were three) was used (McFall, 2014). Fat-free mass (FFM) and total body fat (TBF) were calculated as:  $TBF = W \times BF\%/100$ ,  $FFM = W - TBF$  (Burkhauser and Cawley, 2008). Moreover, TBF and FFM indexes (TBF $_i$  and FFM $_i$ ) were calculated as:  $TBF_i = TBF/height^2$ ,  $FFM_i = FFM/height^2$  (Schutz et al., 2002); these indexes decomposed BMI into fat- and lean-mass (BMI is their combined total).

Discrete obesity measures were also calculated. Obesity based on BMI was defined as BMI  $\geq 30$  ("Obesity-BMI"), while abdominal obesity was defined as having a WC greater than 102 cm and 88 cm for males and females, respectively (WHO, 2000). Following the American Council on Exercise guidelines (Cotton, 2003), males (females) with %BF  $\geq 25$  (BF%  $\geq 32$ ) were classified as obese ("Obesity ACE-BF%"). However, given the lack of consensus about BF% thresholds (Snitker, 2010) and because the "ACE-BF%" thresholds may result in high obesity rates (Burkhauser and Cawley, 2008), we also applied BF% ranges that linked BMI-obesity thresholds to BF%, accounting for age variations in body density (Gallagher et al., 2000). The corresponding charts ("Obese Gallanger-BF%") are presented in Table A2 in the supplementary appendix [-Insert a link to supplementary material about here -].

#### 3.1.2. Household income

Net (after taxes) equivalised monthly household income, as a continuous variable, was used as the ranking variable in the CCI; this provided a finer ranking than can be obtained from categorical

measures, such as education or occupational class (O'Donnell et al., 2008). Income from all sources was collected from each household member and, if missing, was imputed. This variable is included as a derived variable in the dataset; Knies (2014) provides details on the income imputation methods. Income data were collected over the 1/2010–3/2012 period, when the consumer price index was fairly stable (Office for National Statistics, 2016); therefore, inflation is unlikely to affect our results. Our income variable was equivalised (using the modified OECD scale) to adjust for household size and composition and was log transformed.

### 3.1.3. Subjective financial well-being measures

Two SFW measures were included: a) subjective measures of current financial situation (living comfortably/doing alright, just getting by and facing difficulties), capturing individual perceptions of financial strain and b) a measure of perceived material deprivation (Arber et al., 2014). The latter is based on nine binary variables that ask one household member if the household can afford holidays, social meals/drinks, pair of shoes for everyone, house maintenance, content insurance, regular savings ( $\geq \text{£}10/\text{month}$ ), furniture replacement, electrical goods repair/replacement and adequate heating. We used a three category variable for being unable to afford: no items, 1–2 items and 3 + items.

### 3.1.4. Other covariates

The explanatory variables used in the decomposition analysis (Eqs. (3) and (4)) are thought to be associated with adiposity (according to the theoretical framework of Chou et al., 2004) and, are likely to influence its socio-economic gradient. Similar variables were included in previous studies on socio-economic inequalities in obesity (Costa-Font and Gil, 2008; Hajizadeh et al., 2014; Ljungvall and Gerdtam, 2010).

Demographic characteristics were age (quadratic polynomial) and ethnicity (white, non-white). Educational attainment (university degree, post-secondary, a-level, o-level or basic/no-qualifications) was included because higher schooling may improve health production efficacy and health knowledge (Chou et al., 2004; Costa-Font and Gil, 2008). We controlled for marital status (married/cohabitated) since being married may be associated with changes in eating habits and making less effort to be physically attractive (Ljungvall and Gerdtam, 2010). In addition, we included health-related lifestyle indicators: a) physical activity, proxied by sports activities (three or more times per week, at least monthly, less frequently/not at all) and walking (binary variable for walking five or more days per week), because it may result in a body fat loss (Rashad, 2006); b) smoking status, given previous evidence of the negative association between smoking and adiposity through lower appetite and increased metabolism (Chou et al., 2004; Rashad, 2006); and c) an indicator for consuming five or more fruits/vegetables per day. Regional dummies (nine regions of England, Wales and Scotland) and a variable to capture variations in time between the main survey and nurse visits were also incorporated. Descriptive statistics are presented in Table A1 in the supplementary appendix [-Insert a link to the supplementary material about here-]. As can be seen, mean BMI did not differ by gender, while both TBFi and BF% were higher in females than in males. As expected, males had a higher mean WC and FFMi than females. The prevalence of obesity, regardless of the measure applied, was higher in females.

### 3.2. Sample selection

We restricted our analysis to individuals over the age of 20 to eliminate any puberty-related body-size growth (Rogol et al., 2002); this resulted in a potential sample of 14,959 adults.

Moreover, 1297 cases had missing information on any of the adiposity measures, 71 lacked data on SFW, and 130 had missing data on the remaining covariates. To avoid income reporting problems associated with outliers, the lowest/highest 1% of the income distribution was excluded (278 cases). Thus, our final sample consisted of 13,138 observations. Comparisons between the raw means of the potential and analysis sample showed no substantial differences, suggesting that the impact of item missingness might be limited. Sample weights were used to account for survey non-response and attrition, making the sample representative of the population (McFall, 2014).

## 4. Results

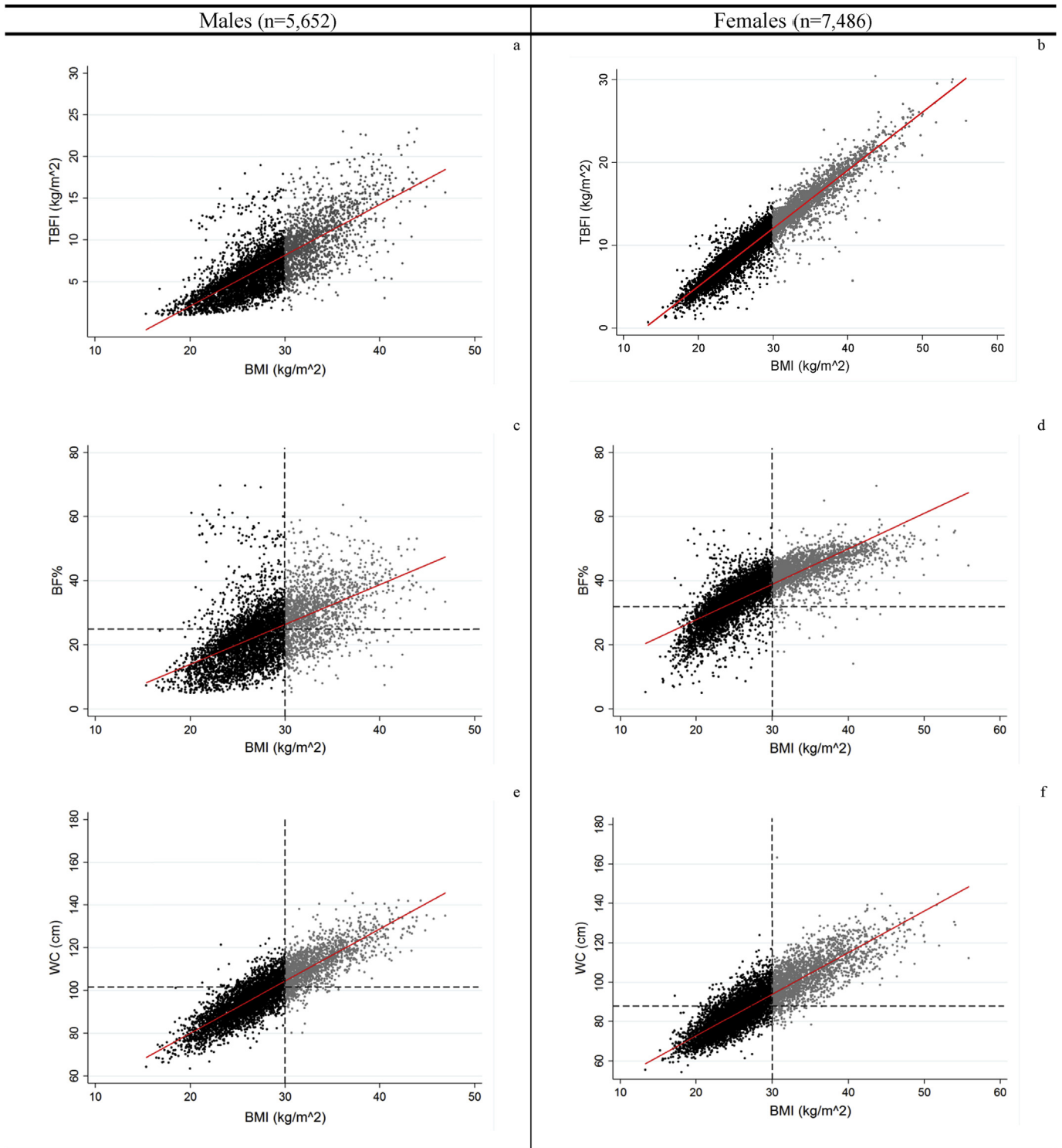
### 4.1. Differences between adiposity measures

Fig. 1 presents preliminary evidence comparing the adiposity measures. A stronger positive association of BMI with TBFi and BF% (less dispersed scatter plots) was found in females (Fig. 1b and 1d) than in males (Fig. 1a and 1c). These differences might be attributed to higher fat-mass in females (steeper fitted lines) compared to males with a similar BMI (Burkhauser and Cawley, 2008; O'Neill, 2015). Inconsistently classified observations -for the discrete obesity measures-are located in the upper left and lower right squares of each graph (Fig. 1c–f). These classification disparities differed by gender (Fig. 1c and 1d); for example, unlike males, almost none of the females who were classified as BMI-obese (grey dots), were below the “Obesity ACE-BF%” threshold (horizontal line). This may reflect previous evidence of the higher “false positive rates” of BMI-based obesity measures in males versus females (Burkhauser and Cawley, 2008; O'Neill, 2015). Classification disparities between abdominal and BMI-obesity differed less by gender (Fig. 1e and 1f).

### 4.2. Income-related inequalities in adiposity

Table 1 presents the income-related inequality indexes for the continuous and discrete adiposity measures by gender. For females, the CCIs for BMI, TBFi, BF% and WC were statistically significant and negative, indicating greater adiposity among those with lower income (“pro-rich” inequality in adiposity), regardless of the adiposity measure; the CCIs ranged between  $-0.18$  (for BF%) and  $-0.025$  (for WC). Except for BMI, similar income-related inequalities in TBFi, BF% and WC were observed for males compared with females (pairwise tests of gender differences:  $p$ -values $>0.10$ ). Unlike females, income-related inequalities in BMI were not statistically significant for males ( $p$ -value $>0.10$ ); the corresponding CCI was 3.7 times lower than in females (test of CCI equality by gender,  $p$ -value $<0.01$ ). These gender differences may reflect the observed gender disparities in income-related inequalities in BMI components. Although income-related inequalities in TBFi did not significantly differ by gender, there was a greater concentration of females but not males with a higher muscle mass (FFMi) among those with a low income. Table A3 in the supplementary appendix [-Insert a link to the supplementary material about here-] depicts the pairwise tests of the mean equality of the CCIs.

Similar patterns were observed for obesity measures, though the degree of pro-rich inequalities was considerably higher for both men and women. The presence of similar income-related inequalities in both BF%-based obesity measures (pairwise equality tests for CCIs are presented in Table A4 in the supplementary appendix; [-Insert a link to the supplementary material about here-]), suggesting that our results did not differ based on the BF% threshold chosen.



Abbreviations: BF%, percentage body fat; BMI, body mass index; TBFI, total body fat index; WC, waist circumference. Notes: Grey (black) dots represent obese (non-obese) regarding BMI. Horizontal dashed lines represent “Obesity ACE-BF%” and abdominal obesity thresholds, while vertical dashed lines the “BMI-obesity” threshold.

**Fig. 1.** Scatter plots of BMI versus TBFI, BF% and WC by gender.

### 4.3. Decomposition results

#### 4.3.1. Continuous adiposity measures

Table 2 presents the decomposition analysis results of the continuous adiposity measures by gender. The table shows the

income-related CI for each of the adiposity covariates (second column) as well as, separately by adiposity measure, the beta coefficients ( $\delta_k$ ) and each variable's contributions (absolute and percentage contributions) towards the total income-related inequality in adiposity (Eq. (4) in the Supplementary Appendix; [-Insert a link

**Table 1**  
Income-related corrected concentration indices (CCIs) for alternative adiposity measures.

	Males (n = 5652)		Females (n = 7486)	
	CCI	Standard error <sup>a</sup>	CCI	Standard error <sup>a</sup>
<b>Continuous adiposity measures</b>				
BMI	−0.006	0.005	−0.022***	0.004
BMI components				
TBFi	−0.017***	0.006	−0.024***	0.005
FFMi	0.006*	0.003	−0.009***	0.002
BF%	−0.016***	0.006	−0.018***	0.004
WC	−0.013**	0.006	−0.025***	0.004
<b>Discrete adiposity measures</b>				
Obesity-BMI (≥30)	−0.020	0.016	−0.091***	0.013
Obesity ACE-BF%	−0.057***	0.018	−0.055***	0.015
Obesity Gallagher-BF%	−0.043***	0.014	−0.056***	0.015
Abdominal obesity	−0.062***	0.016	−0.093***	0.016

\*\*\*P < 0.01; \*\*P < 0.05; \*P < 0.10.

<sup>a</sup> Bootstrapped standard errors (500 replications).

to the supplementary material about here-]). Although absolute body-fat measures (TBFi) provide a direct way to distinguish between fat and fat-free mass in BMI, the corresponding relative indicators (such as BF%) are generally preferred because they account for body weight and thus allow for effective comparisons among people of different body sizes (Schutz et al., 2002); people with similar absolute measures of body fat may differ in muscle mass, which may imply distinct mortality risks (Heitmann et al., 2000). Therefore, the decomposition results of the BF% measures are presented, although they are comparable to those of TBFi.

For BF% in males (Table 2, Panel A), education and perceived financial strain played a greater role than the other covariates in contributing to the income-related inequality (similar contributions of 40% and 37%, respectively); their predominant role reflected their strong associations with both BF% and household income (Table 2). The measures of perceived material deprivation had a weaker contribution (p-value>0.05). Similarly, education and perceived financial strain exerted the greatest contribution to income-related inequality in WC, with the former being the major contributor. Household income itself did not exert a significant contribution. This suggests that the observed income-related inequalities in adiposity were mainly driven by the association between income and the other covariates that might be associated with adiposity.

Health behaviours made a smaller contribution to the income-related inequalities in adiposity, with sports participation being the most relevant. On the other hand, smoking exerted a larger negative percentage contribution as a result of being both negatively associated with BF% and WC as well as being concentrated among those with a lower income. For example, if smoking had been evenly distributed over income and/or had not been associated with BF%, the income-related inequality in BF% would have been about 13% larger (more negative). The contributions of the remaining variables were less pronounced and varied among the adiposity measures.

For completeness, the decomposition results for BMI were estimated for males (Table A5 in the supplementary appendix; [-Insert a link to the supplementary material about here-]), although the corresponding CCI was not statistically significant (Table 1). These results confirmed the dominant contribution of SFW measures and education on the “pro-rich” inequalities in adiposity for males, regardless of the adiposity measure employed.

For women, the SFW measures made the largest contribution to the income-related inequalities in BMI, BF% and WC (Table 2, Panel B), ranging between 70% and 80% (about 22% from perceived financial strain and 48–58% from “material deprivation”).

Education contributed in a similar way but to a smaller extent (around 51%–59%). Health behaviours played less of a role, with their percentage contributions being in the same direction as the corresponding results for males (Table 2, Panel A).

#### 4.3.2. Obesity measures

In general, the decomposition results for the obesity measures (Table 3) were similar to those of the continuous adiposity measures (Table 2). However, some variations in the variables' percentage contributions to the inequalities were observed. For males (Table 3, panel A), SFW measures had the largest contribution followed by education for obesity-BF% measures. Similar primary contributing factors were identified in the decomposition results of “Obesity-BMI” (Table A5 in the supplementary appendix; [-Insert a link to supplementary material about here-]). However, these results should be interpreted with caution because their CCI (Table 1) was not statistically significant. Limited differences were observed for abdominal obesity (Table 3, panel A) and the corresponding results of WC for males (Table 2, panel A).

The decomposition results for the obesity measures for women (Table 3, Panel B) were comparable to the corresponding continuous adiposity measures (Table 2, Panel B). For example, SFW was the major contributor (combined contribution: 59%–82%) followed by educational attainment.

## 5. Discussion and conclusions

Employing nationally representative data from Great Britain, we explored the presence of income-related inequalities in multiple adiposity measures using CIs and decomposition techniques. Capitalizing on the richness of the data, we went beyond the conventional BMI measures to also use body composition and central adiposity measures. In accordance with previous evidence (Burkhauser and Cawley, 2008; Ljungvall et al., 2015), we found notable disparities between those classified as obese using BMI and the alternative adiposity measures. These disparities followed distinct patterns by gender, potentially reflecting differences in body composition, i.e., muscle- and fat-mass (Burkhauser and Cawley, 2008; Kyle et al., 2003). For BMI we found no statistically significant income-related inequalities in males, while pro-rich inequalities were observed in females. These gender differences did not hold for the alternative adiposity measures. After distinguishing between fat- and lean-mass in BMI, pro-rich inequalities in the fat-mass component (TBFi) in both genders became evident. In support of this finding, pro-rich inequalities were also observed for BF% and WC. Similar inequality patterns,

**Table 2**  
Decomposition of income-related inequalities in continuous adiposity measures.

Panel A: Males (n = 5652)											
	CI		BF%			WC					
	$\hat{\delta}_k$	Contribution <sup>a</sup>	Absolute	Aggregated	%	$\hat{\delta}_k$	Contribution <sup>a</sup>	Absolute	Aggregated	%	
Ln(Income)	0.039	0.0038	0.004		–27.67	0.0035	0.0039				–30.52
Post-secondary qualification	0.108	0.0357	0.0017***			0.0233	0.0011***				
A-level	–0.036	0.0257	–0.0008*			0.0284	–0.0009**				
O-level	–0.059	0.0281	–0.0012**			0.0353	–0.0015***				
Other qualification	–0.177	0.0210	–0.0017***			0.0351	–0.0029***				
No qualification	–0.375	0.0200	–0.0037**	–0.0057***	36.59	0.0359	–0.0066***	–0.0108***			83.94
Married/Cohabitated	0.052	0.0069	0.001		–6.62	0.0196	0.0030***				–23.02
Sports activity: 3 + week	0.126	–0.0153	–0.0013**			–0.0344	–0.0030***				
Sports activity: monthly	0.089	–0.0149	–0.0018**	–0.0032***	20.20	–0.0189	–0.0023***	–0.0053***			41.55
Frequent walker	–0.001	–0.0109	0.0000		–0.07	–0.0146	0.0000				–0.11
Smoker	–0.177	–0.0123	0.0021**		–13.12	–0.0310	0.0052***				–40.48
Fruits/vegetables:5 + day	0.105	–0.0088	–0.0006		3.80	0.0004	0.0000				–0.20
Perceived financial situation: getting by	–0.174	0.0092	–0.0018			0.0134	–0.0025**				
Perceived financial situation: difficult	–0.325	0.0314	–0.0045***	–0.0063***	40.16	0.0377	–0.0055***	–0.008***			62.34
Material Deprivation: 1–2 items	–0.135	0.0089	–0.001			0.0113	–0.0012				
Material Deprivation: 3 + items	–0.316	0.0162	–0.004*	–0.0050*	31.75	0.0120	–0.0030	–0.0042*			32.78
Age	–0.016	0.0068	–0.0215***			0.0095	–0.0300***				
Age squared	–0.042	–0.0001	0.0224***	0.0009	–5.56	–0.0001	0.0307***	0.0007			–5.23
White	0.018	–0.0102	–0.0007		4.16	0.0404	0.0026***				–20.20
Regional dummies				–0.003**	19.28			–0.0001			1.17
Sum (Predicted CI)			–0.0160		101.80		–0.0127				100.30
GCI (residual)			0.0003		–1.80		0.0001				–0.30
Total CI			–0.0157		100		–0.0128				100

Panel B: Females (n = 7486)													
	CI		BF%			WC							
	$\hat{\delta}_k$	Contribution <sup>a</sup>	Absolute	Aggregated	%	$\hat{\delta}_k$	Contribution <sup>a</sup>	Absolute	Aggregated	%			
Ln(Income)	0.040	0.0039	0.0044		–19.65	0.0004	0.0005		–2.88	0.0025	0.0029	–11.8	
Post-secondary qualification	0.151	0.0265	0.0022***			0.0271	0.0022***			0.0203	0.0017***		
A-level	–0.002	0.0281	0.0000			0.0286	–0.0001			0.0183	0.0000		
O-level	–0.106	0.0333	–0.0029***			0.0360	–0.0031***			0.0295	–0.0026***		
Other qualification	–0.175	0.0322	–0.0025***			0.0245	–0.0019***			0.0316	–0.0024***		
No qualification	–0.305	0.0496	–0.0101***	–0.0132***	59.08	0.0364	–0.0074***	–0.0102***	57.15	0.0453	–0.0092***	–0.0125***	50.89
Married/Cohabitated	0.114	0.0039	0.0011	–5.07		0.0035	0.0010		–5.67	0.0064	0.0019*		–7.54
Sports activity: 3 + week	0.148	–0.0151	–0.0011**			–0.0112	–0.0008**			–0.0194	–0.0015***		
Sports activity: monthly	0.128	–0.0099	–0.0015**	–0.0026***	11.73	–0.0052	–0.0008	–0.0016**	9.15	–0.0114	–0.0017***	–0.0032***	12.92
Frequent walker	–0.004	–0.0227	0.0002	–0.83	–0.0198	0.0002		–0.91	–0.0188	0.0002		–0.63	
Smoker	–0.162	–0.0353	0.0048***	–21.52	–0.0295	0.0040***		–22.62	–0.0218	0.0030***		–12.1	
Fruits/vegetables:5 + day	0.102	–0.0042	–0.0004	1.78	–0.0047	–0.0004		2.50	–0.0053	–0.0005**		2.03	
Perceived financial situation: getting by	–0.148	0.0154	–0.0025***			0.0096	–0.0016**			0.0155	–0.0025***		
Perceived financial situation: difficult	–0.289	0.0168	–0.0024**	–0.0049***	22.00	0.0154	–0.0022**	–0.0038***	21.35	0.0198	–0.0029**	–0.0054***	21.92
Material Deprivation: 1–2 items	–0.086	0.0206	–0.0015***			0.0158	–0.0011***			0.0182	–0.0013***		
Material Deprivation: 3 + items	–0.297	0.0395	–0.0115***	–0.013***	58.08	0.0265	–0.0077***	–0.0089***	49.80	0.0359	–0.0105***	–0.0118***	48.05
Age	–0.018	0.0061	–0.0220***			0.0082	–0.0293***			0.0064	–0.0230***		
Age squared	–0.046	–0.0001	0.0262***	0.0041***	–18.47	–0.0001	0.0330***	0.0037**	–20.74	0.0000	0.0239***	0.0010	–3.88
White	0.011	–0.0018	–0.0001	0.31	0.0045	0.0002		–1.02	0.0060	0.0002		–0.94	
Regional dummies				–0.0024***	10.73			–0.002***	13.17			–0.0004	1.74
Sum (Predicted CI)			–0.0219		97.58		–0.0176		98.90		–0.0247		100.7
GCI (residual)			–0.0005		–2.42		–0.0002		0.10		0.0002		–0.70
Total CI			–0.0224		100		–0.0178		100		–0.0246		100

CI: concentration index.

\*\*\*P < 0.01; \*\*P < 0.05; \*P < 0.10.

<sup>a</sup> Bootstrapped significance level of contributions (500 replications). Negligible contributions from the time gap variable are omitted.

although larger in magnitude, were evident for the discrete obesity measures.

This study highlighted the importance of considering

alternative adiposity measures in the context of income-related inequalities in adiposity. Our results were in accordance with other studies in different countries –limited to BMI-based

**Table 3**  
Decomposition of income-related inequalities in discrete obesity measures.

Panel A: Males (n = 5652)											
	Obesity ACE-BF%			Obesity Gallagher-BF%			Abdominal obesity				
	Contribution <sup>a</sup>			Contribution <sup>a</sup>			Contribution <sup>a</sup>				
	Absolute	Aggregated	%	Absolute	Aggregated	%	Absolute	Aggregated	%		
Ln(Income)	-0.0041		-7.31	0.0107		-25.09	-0.0147		23.83		
Educational attainment		-0.0166**	29.21		-0.0188***	43.84		-0.0281***	45.42		
Marital status	0.0050*		-8.77	0.0025		-5.85	0.0072***		-11.69		
Sports activity		-0.0086***	15.19		-0.0084***	19.62		-0.0138***	22.30		
Walking status	0.0000		-0.06	0.0000		-0.06	0.0000		-0.08		
Smoking status	0.0051		-8.97	0.0041		-9.52	0.0096***		-15.55		
Fruits/vegetables	-0.0024*		4.18	-0.0021**		5.09	-0.0001		0.24		
Perceived financial situation		-0.0164**	28.83		-0.0136**	31.66		-0.0230***	37.12		
Material Deprivation		-0.0189**	33.40		-0.0183**	42.63		-0.0044	7.12		
Age (total contribution)		-0.0036	6.43		0.0066**	-15.38		0.0017	-2.72		
White	-0.0004		0.70	-0.0018		4.25	0.0049**		-7.87		
Regional dummies		-0.0043	7.60		-0.0073*	16.94		0.0010	-1.66		
Sum (Predicted CI) <sup>a</sup>		-0.0565	99.70		-0.0463	108.17		-0.0591	95.63		
GCI (residual)		-0.0002	0.30		0.0035	-8.17		-0.0027	4.36		
Total CI		-0.0567	100		-0.0428	100		-0.0618	100		

Panel B: Females (n = 7486)												
	Obesity-BMI (≥30)			Obesity ACE-BF%			Obesity Gallagher-BF%			Abdominal obesity		
	Contribution <sup>a</sup>			Contribution <sup>a</sup>			Contribution <sup>a</sup>			Contribution <sup>a</sup>		
	Absolute	Aggregated	%	Absolute	Aggregated	%	Absolute	Aggregated	%	Absolute	Aggregated	%
Ln(Income)	0.0053		-5.89	-0.0061		11.09	0.0088		-15.77	0.0050		-5.31
Educational attainment		-0.0456***	50.35		-0.0233***	42.34		-0.0406***	72.76		-0.0417***	44.75
Marital status	0.0012		-1.34	0.0074*		-13.39	0.0004		-0.80	0.0060		-6.43
Sports activity		-0.0089***	9.81		-0.0013	2.44		-0.0064**	11.46		-0.0081**	8.71
Walking status	0.0005		-0.50	0.0004		-0.76	0.0006		-1.02	0.0005		-0.52
Smoking status	0.0095***		-10.49	0.0079***		-14.46	0.0119***		-21.27	0.0087***		-9.33
Fruits/vegetables	-0.0025**		2.80	-0.0001		0.20	-0.0032**		5.70	-0.0024*		2.52
Perceived financial situation		-0.0176***	19.47		-0.0114**	20.66		-0.0167***	29.93		-0.0166***	17.79
Material Deprivation		-0.0366***	40.41		-0.0191***	34.73		-0.0289***	51.75		-0.0387***	41.50
Age (total contribution)	0.0078**		-8.58	0.0047		-8.51	0.0226***		-40.52	-0.0044		4.74
White	0.0000		-0.03	0.0000		-0.02	0.0002		-0.32	-0.0002		0.19
Regional dummies		-0.0081***	8.94		-0.0066***	11.96		-0.0096***	17.18		0.0003	-0.31
Sum (Predicted CI) <sup>a</sup>		-0.0944	104.94		-0.0470	86.27		-0.0610	109.22		-0.0920	98.67
GCI (residual)	0.0038		-4.94	-0.0079		13.73	0.0051		-9.22	-0.0012		1.33
Total CI		-0.0906	100		-0.0549	100		-0.0559	100		-0.0932	100

CI: concentration index.

\*\*\*P < 0.01; \*\*P < 0.05; \*P < 0.10.

<sup>a</sup> Bootstrapped significance level of contributions (500 replications). Negligible contributions from the time gap variable are omitted.

measures-which find that socio-economic inequalities in BMI-based obesity measures were, in general, not evident in males but were more pronounced in females (Ljungvall and Gerdtam, 2010; Madden, 2013; Zhang and Wang, 2004). However, we found no gender differences in the pro-rich inequalities when alternative measures of adiposity were used. Considering the inability of BMI to unpack body composition, our evidence may reflect the fact that fat-mass accounts for a considerable part of BMI in females, whereas muscle-mass contributes more to BMI in males (Burkhauser and Cawley, 2008; O'Neill, 2015; Kyle et al., 2003). Given the absence of a gold standard adiposity measure, it might be argued that potential imperfections of the alternative adiposity measures, beyond those of BMI, may affect our conclusions. However, the similarity of our results between BF%- and WC-based measures may alleviate these concerns, especially because WC-based measures have been found to be the most accurate measures of the true underlying obesity rates (O'Neill, 2015). Employing BMI alone therefore may mask the presence of income-related inequalities in adiposity in men.

Other studies have also shown that socio-economic inequalities (using several measures, such as social class and deprivation measures) are larger for central adiposity measures than for BMI in males but not females (Chen and Tunstall-Pedoe, 2005; Martikainen and Marmot, 1999). Additionally, Ljungvall et al. (2015) found significant differences in income and education gradients between generalized and abdominal obesity for males; these differences were driven by the fact that classification disparities between the BMI- and WC-based obesity measures themselves systematically differed by socio-economic status. Our finding that fat-free mass was more concentrated among relatively poor females might be attributed to two factors (although further research is needed): a) physically demanding jobs are associated with both lower income and higher FFMi and b) females may engage in fitness-related activities (more likely among those in a higher socio-economic status) that aim for thinness not muscularity to conform with body image norms (Strahan et al., 2006).

Decomposition analysis showed that the pro-rich inequalities in adiposity resulted from confounding effects, i.e., factors that were



correlated with income as well as adiposity, rather than income itself. Indeed, SFW measures and education were the main contributing factors to the income-related adiposity inequalities, with the relative contribution of the former being more evident in females compared to males. These results may reflect the presence of stronger financial hardship-obesity associations in females than in males (Averett and Smith, 2014). A similar large contribution of schooling was evident in other studies decomposing income-related inequalities in BMI measures (Costa-Font and Gil, 2008; Hajizadeh et al., 2014; Madden, 2013).

Inequalities in health behaviours played less of a role in the pro-rich adiposity inequalities, with physical activity having the highest contribution; this result, could be of particular importance given the focus on public health campaigns on behavioural change. Smoking appeared to be a notable counteracting factor (Hajizadeh et al., 2014); if smoking was evenly distributed over income, the income-related inequalities in adiposity would have been larger, *ceteris paribus*. Identifying inequality contributors that are not subject to policy is also important. In this context, age, ethnicity and marital status contributed to reducing the income-related adiposity inequalities, although these results were not robust across adiposity measures. For instance, variations in the contributions of ethnicity and age may reflect disparities in the association with different adiposity measures (Lear et al., 2007; Shaw et al., 2014).

Our study suggests that policy makers should consider central adiposity and body composition measures in health policy agendas, rather than relying primarily on BMI-based measures (House of Commons Health Select Committee, 2015; OECD, 2014), as the latter may underestimate the income-related inequalities in adiposity in males. These findings are important beyond the UK, such as the USA, Sweden and Ireland, where existing evidence, limited to BMI-based obesity, suggest the absence of income-related inequalities in males vs females (Ljungvall and Gerdtam, 2010; Madden, 2013; Zhang and Wang, 2004). Although decomposition analysis cannot be interpreted as causal, it may allow policy makers to target areas that make the larger contribution to tackling socio-economic inequalities in adiposity. Overall, our decomposition analysis highlights the role of psycho-social mechanisms related to individuals' perceptions of their financial conditions rather than income itself; financial management training for those experiencing poor SFW may be helpful (Zyphur et al., 2015). The considerable contribution of education suggests that fostering educational opportunities for children (or adults) in lower socio-economic groups may result in lower obesity prevalence (Conti et al., 2010) and consequently lower socio-economic obesity inequalities in the long-run.

Our study has some limitations. By definition SFW was self-reported as it measures people's perception of their situation. There may be systematic biases in reporting such perceptions. In particular, a potential source of bias that could be relevant to our study is that respondents may view SFW as a socially acceptable rationalization for obesity and, thus -in an interview setting-they may have modified their reporting behaviour accordingly. However, because the SFW questions were asked before the adiposity measurements were obtained (five months on average) these concerns may be alleviated, although further research is needed. Decomposition analysis is a descriptive method that provided potential explanations to the observed income-related inequalities in adiposity rather than evidence about causation. The absence of longitudinal data prevented the consideration of the interplay between income dynamics and adiposity (Ljungvall and Gerdtam, 2010) as well as the use of more complex techniques to address the potential endogeneity bias that may arise from unobserved heterogeneity and reverse causality.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.socscimed.2016.08.032>.

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