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Fat tax or thin subsidy? How price increases and decreases affect the energy and nutrient content of food and beverage purchases in Great Britain

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1. Introduction

Poor diets are the second leading risk factor for mortality globally, accounting for nearly one in five deaths (GBD 2016 Risk Factors Collaborators). Diets low in whole grains and fruits, and high in sodium, are leading individual dietary risks to mortality. At the same time consuming too much red meat and sugar-sweetened beverages are individual factors seeing the greatest increase in attributable deaths and DALY's since 1990 (GBD 2016 Risk Factors Collaborators).

Policies to change food price are increasingly recommended to prevent diet-related diseases at population level, particularly in middle- and high-income countries (WHO, 2018). The underlying idea behind these policies is simple: if unhealthy foods became more expensive (e.g. via taxes), or healthy food became cheaper (e.g. via subsidies), consumers would decrease or increase their purchase, and consumption, accordingly.

The reality, however, is more complicated as there are difficulties in measuring the impacts from individual food price changes on total diet as consumers may change their demand for many other foods in response to the policy, negating or exacerbating the intended effect. Thus, the comparative effectiveness of either price increase or decreases in improving the overall quality of diets, at population level, remains unknown.

Reviews of prospective modelling studies of taxes on foods, mostly on sugary drinks, generally suggest that a 20% tax can increase the price sufficiently to reduce purchases of the taxed products (Afshin et al., 2017; Backholer et al., 2016; Thow et al., 2014; Wright et al., 2017). Whether this translates to a reduction in obesity prevalence and associated disease is less clear (Bes-Rastrollo et al., 2016; Nakhimovsky et al., 2016). Studies find nutrient-based taxes (e.g. tax on sugar) to be comparatively more effective than product-based taxes (Harding & Lovenheim, 2017). However, from policy perspective these are also more complex to implement. Recent studies from countries in which taxes have been levied on unhealthy foods or beverages confirm a small reduction in their consumption (Bíró, 2015; Bødker et al., 2015; Colchero et al., 2017; Silver et al., 2017). Small positive health effects have only been shown through modelling actual changes in purchases for the Danish tax on saturated fats in 2011 (Smed & al., 2016) and for the tax on sugary drinks in Mexico (Barrientos-Gutierrez et al., 2017).

For consumers, subsidies on healthy foods are understandably more acceptable than taxes on unhealthy foods (Mazzocchi et al., 2014) prompting a discussion on whether price subsidies (on their own or together with taxes) are a more appropriate solution (Caraher & Cowburn, 2015; Niebylski et al., 2015). Experimental studies demonstrate the effectiveness of subsidies to improve diets in specific contexts (e.g. among limited population, geographical areas or implemented in selected outlets), often in parallel with other interventions, such as provision of information (Afshin et al., 2017; Epstein et al., 2012). Wider subsidy programs covering large population shares (and evaluations of their effectiveness) in the context of improving dietary health, rather than addressing basic food security needs, are rare. Most evidence comes from the recipients of Supplemental Nutrition Assistance Programme (SNAP) in the US, showing an increase in fruit and vegetable consumption when incentivised by a price subsidy (Chang et al., 2015; Kaushal & Muchomba, 2015; Klerman et al., 2014).

This study contributes to the evidence on the impact of price changes on the nutritional quality of diets by exploiting a unique data-set on food purchases. Home-scan data from

Kantar Worldpanel, for a large and representative sample of more than 26,000 British households, opens the way to the estimation of the potential outcomes of price increases and decreases on energy, and nutrients purchased from a range of healthier and less healthy foods and beverages. These cover the whole food basket and thus the full range of own- and cross-price effects.

The novelty in our approach lies in two aspects. First, we measure the impact of price changes on purchases of energy and nutrients and thereby explicitly measure changes in dietary quality while maintaining modelling choices among food groups, rather than nutrients. This is an important distinction because when people shop they shop for specific foods rather than energy and nutrients. By categorising all foods based on their relative healthiness using a nutrient profile model used in Great Britain since 2004 (UK Department of Health, 2011) we also indicate food groups for which price changes may lead to the largest gains, as well as potential trade-offs. For example, an increase in the price of foods high in sugar might have a knock-on effect on fibre consumption if foods have relatively high levels of both, as in many breakfast cereals.

Second, given the highly disaggregated nature of the data over time, our demand model specification is generalised to allow elasticities to depend on the difference with previous shopping prices. Such generalisation is driven by long-standing empirical marketing research (including in food demand) that the same consumer might react with different intensity to price increases and decreases (Bell & Lattin, 2000; Han et al., 2001; Juhl & Jensen, 2014; Kalyanaram & Winer, 1995; Krishnamurthi et al., 1992; Mazumdar et al., 2005; Taludkar & Lindsey, 2013). While it is difficult to summarise the magnitude of such asymmetry in price response, as the papers look at very different products using different models, the conclusions support the existence of asymmetry in price response to increasing and decreasing prices.

The most credited explanation for asymmetry in demand is based on the reference-price concept; where consumers compare current prices with a (reference) price that has been formed from past shopping experiences. If the current price differs from this reference price the consumer experiences gains or losses. This is also consistent with Prospect Theory, which predicts that consumers react more strongly to losses than to gains (Tversky & Kahneman, 1991), such that the impact of price increases produces a more pronounced effect on consumption in comparison to an equivalent price decrease Although traditional demand models assume symmetric response, and we relax this assumption, the case of symmetric response remains as an empirical restriction to the model applied.

2. Methods

2.1 Demand model

We follow the Almost Ideal Demand System (AIDS) specification with modification to allow for inclusion of price variation relative to the prices observed in the previous shopping occasion to identify price increases and price decreases (Cornelsen et al., 2016). This allows estimating price elasticities of both directions of price change. This specification is consistent with the concept of reference prices, under the assumption that the consumer reference prices in current shopping occasion are those of the previous occasion they were in the same shop. The use of reference price is intuitive as it is reasonable to assume that in a weekly context shoppers are very likely to consider a reference price in purchase decisions.

The demand function for the *i*-th item is specified as follows:

$$w_{iht} = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \log p_{jht} + \sum_{j=1}^{n} \delta_{ij} I_{jht} (\log p_{jht} - \log p_{jh,t-1})$$

$$- \sum_{j=1}^{n} \omega_{ij} (1 - I_{jht}) (\log p_{jht} - \log p_{jh,t-1}) + \beta_i \log\left(\frac{x_{ht}}{P_{ht}}\right) + u_{iht} \qquad (1)$$

Where:

w_{iht} is expenditure share of group i (i=1,2,…,26) for household h in week t (t=1,2,…,104)

p_{jht} are prices across food groups j (j=1,2,…,26) for household h in week t (t=1,2,…,104)

I_{iht} is an indicator function which equals to 1 if $p_{jht} > p_{jh,t-1}$ and 0 otherwise

x_{ht} is total household weekly expenditure on foods per household member

$P_{ht}$is a Laspeyers price index u_{iht} is the error term

This empirical specification is obtained from a PIGLOG cost function incorporating reference prices, based on Putler (1992), where the reference prices are equal to the prices faced in the previous shopping trip(Putler, 1992). More intuitively, the price effect in (1) is the combination of three dimensions: the average price effect is captured by the parameter γ_{ij}, the 'loss' dimension is embodied by the parameter δ_{ij} and the 'gain' dimension by the parameter ω_{ij}. Depending on whether the individual consumer in a given time period is experiencing a loss ($p_{jht} > p_{jh,t-1}$) or a gain ($p_{jht} < p_{jh,t-1}$), the resulting price coefficient that will feed into the elasticity equation will be $\gamma_{ij} + \delta_{ij}$ or $\gamma_{ij} + \omega_{ij}$, respectively. The sign before ω_{ij} is reverted relative to the specification in (1) because when a gain is incurred we have that $p_{jht} - p_{jh,t-1} < 0$.

To reduce possible endogeneity between expenditure share (w_{iht}) and total expenditure (x_{ht}) we regress household per capita food expenditure on household socio-demographic characteristics (tenure, income, income squared, household size, presence of children) and 4-weekly dummies for seasonality, and use predicted values from the regression as instruments for total expenditure (Blundell et al., 1993).

Our base unit is household-week and as we model a large number of relatively disaggregated food groups, we observe a significant proportion of non-purchases as not all households purchase items in each food group on weekly basis. To correct for the potential bias which may arise from including the zero-purchases we adopt a two-step approach by Shonkwiler and Yen (1999) (Shonkwiler & Yen, 1999) which is regularly used in food demand studies (Caro et al., 2017; Ecker & Qaim, 2011). In the first step, the decision to purchase foods in any food group in a given week by a household is modelled using a probit model. The decision (a binary variable equal to one if expenditure is positive) is modelled as a function of household socio-demographic variables: household size, presence of children, age of the main respondent, socio-economic status, tenure, income and education level of the main respondent, lagged volume of purchases to account for possible stockpiling, and monthly time dummies to take into account seasonal effects. From the probit model, we estimate the probability density function (ϕ_i) and cumulative density function (Φ_i) of the linear predictions of the fitted model. These are applied in the second step (2) to estimate the demand function in (1) which accounts for the probabilities of purchase, on the full panel-data set:

$$w^*_{iht} = \Phi_{iht}\,(w_{iht}) + \varphi_i \phi_{iht} + \sum_{t=1}^{26} \rho_{it} T_{it} + v_{ih} + \varepsilon_{it} \qquad (2)$$

Where T_{it} are dummy variables, added to capture any seasonal or other time effects (n=26 4-week periods) and v_{ih} is a fixed household effect. These fixed effects act as shifter of the "average" demand model intercept α_i and the model is estimated with a fixed effects estimator.

For each food group i=1, 2,…,26 we estimate (2) with robust standard errors to allow for any misspecification, particularly serial correlation of observations within the households. Standard errors are further adjusted for clustering to the geographical area used in estimating prices (n=110).

Marshallian demand elasticities (% response in demand to 1% change in price) unconditional of purchase, were calculated for price increases (e_{ij}^{UP}) and decreases (e_{ij}^{DOWN})(Yen et al., 2002):

$$e_{ij}^{UP} = \Phi_i * \left(\frac{\gamma_{ij}+\delta_{ij}}{w_i} - \frac{\beta_i w_j}{w_i}\right) - \Delta_{ij}$$

$$e_{ij}^{DOWN} = \Phi_i * \left(\frac{\gamma_{ij} \mp \omega_{ij}}{w_i} - \frac{\beta_i w_j}{w_i}\right) - \Delta_{ij}$$

2.2 Estimation of prices

The dataset includes ~75m individual item purchases by households over a two-year period. For manageable estimation we divide products into 26 categories of foods and beverages and aggregate individual item purchases to weekly expenditures and quantities in each group from which we calculate weekly unit prices as a ratio of the two. Such unit values are known to suffer from quality and aggregation bias and should not be used directly (Deaton, 1988). To address this we assume that in a relatively small geographical area households face the same prices in the same time period (Deaton, 1988) and estimate average weekly unit prices for each of the 26 food and beverage groups in postcode areas (n=110) observed in the data. A specific feature in the UK is that food retailers and the UK Competition Commission have an agreement on national pricing policy (Griffith et al., 2010; UK Competition Commission, 2008). The agreement implies that large chain supermarkets apply same pricing (and promotions) in same types of branches across its chain nationally (i.e. price may vary between different types of branches but not within one type of branches). Price variation in food groups by geographical area could occur across the regions due to differences in the distribution of shop types or product range in the shops, of which some could be due to local demand shocks. However, given our time unit is one week, we can safely assume that such demand shocks do not influence the concentration of shop types in the area or the product range available within this short time unit. Thus, the geographical average weekly prices we use are assumed to be exogenous to local demand.

Household-weeks where no expenditure on any foods or beverages were made were excluded and thus the difference in the current and previous purchase price for any single household is based on the difference in the price between purchase occasions rather than calendar weeks. Finally, to avoid introducing marginal price changes through the process of estimating average geographical prices, we limit price increases or decreases to only changes with difference between current and previous purchase price greater than 5%.

2.3 Data

The household expenditure data comes from a large commercial home-scan panel (~32,000 households annually) operated by Kantar Worldpanel. Our dataset covers the period from January 2012 to December 2013. The panel is nationally representative of the population in Great Britain with respect to household size, number of children, social class, geographical region and age group. Participants to the panel are recruited by Kantar Worldpanel via postal mail and e-mail and panel representativeness is assessed by Kantar Worldpanel at 4-week intervals. Households supply data on items purchased and brought home by scanning barcodes of the bought products and by sending in digital images of till receipts. Households are additionally supplied with barcodes to record purchases of unpackaged products, such as fruits and vegetables. Our dataset covers information on purchases (volume and expenditure) of food and drinks from large retailers, supermarkets, butchers, greengrocers, and corner shops. The data exclude all purchases of food and beverages not brought home (e.g. consumed out of homes). Participants are offered vouchers for retailers and for leisure activities of an average value of less than £100 per household per year.

Socio-demographic data are collected annually and describe household size and presence of children, age, and highest qualification of the main shopper, geographical location (postcode area), income group, occupational socio-economic status (SES) and tenure of the household. For the analysis we divide households by SES into three groups: high-SES (A&B: higher managerial and professional workers), mid-SES (C1&C2: white collar and skilled manual workers), and low-SES (D&E: semi-skilled, unskilled and retired worker) households.

The data also include information on nutritional composition of each of the foods purchased: energy (kcal), carbohydrates (g), sugar (g), fats (g), sodium (g), fibre (g), and protein (g). These data are compiled by Kantar Worldpanel based on information on product packaging. Although Kantar Worldpanel does not collect fruit and vegetable content of products, they have provided a score (low – 0, some – 1 and high– 5) for content of fruit and vegetables.

2.4 Food groups

Food groups are first created following the market classifications in the dataset. In order to classify foods and beverages into less healthy and healthier products we use a nutrient profiling model (see supplementary material [INSERT LINK TO ONLINE FILE A]) (UK Department of Health, 2011). The underlying principle is that energy, sugar, sodium and saturated fats contribute to 'positive' points and fibre, protein and fruit and vegetable content contribute to 'negative' points, which are added together. The higher the score, the less healthy the product is. We apply the cut-off point suggested in the guidance and consider a product to be less healthy if it scores above four points or a drink scores above one (UK Department of Health, 2011).

Based on the profiling model, eight food groups (bread & morning goods; cereal & cereal bars; dairy; fresh & frozen red meat; processed meat & fish; ready meals & convenience foods; sauces & condiments; non-alcoholic beverages) were divided into healthier and less healthy categories (see table 1 in supplementary material for detailed description [INSERT LINK TO ONLINE FILE A]). For the remaining healthier (pasta, rice, grains, dry pulses; eggs, fresh & frozen fish & white meat; fruits; vegetables) and less healthy food groups (fat & oil; savoury snacks; sweet snacks; desserts & puddings; alcohol and other foods (including table salt and sugar)) such differentiation was not made as most products in each (>80%) were either healthier or less healthy.

2.5 Simulations of changes in nutrient purchases

Assuming a linear price response, we apply an increase of 20% on the price of all less healthy food groups (where explicitly specified) and on fat & oil, savoury snacks, sweet snacks, desserts & puddings, other foods and alcohol. A decrease of 20% is applied on the price of healthier food groups (where specified); pasta, rice, grains & dry pulses; fresh & frozen white meat & fish, eggs; fruits; and vegetables. The outcomes measured are changes in the energy (kcal) and nutrient (sugar (g), saturated fats (g), sodium (g), protein (g) and fibre (g)) content of average per capita daily take-home purchases, due to price changes in individual food groups and in all groups combined.

For each outcome measure *k* we estimate the change in purchases Z_k due to the change in the price in food group *i*:

$$Z_k = \sum_{i,j=1}^{26} x_{ik} * e_{ij}^{up/down} * \Delta p_i$$

Where e_{ij} is price elasticity (increasing or decreasing price) and Δp_i is the price change of 20% (either increase or decrease). Baseline purchases of energy or each nutrient (per capita/day) in each food group (x_{ik}) in 2013 were estimated by first aggregating individual purchases in 2013 dataset to weighted population purchases which we then divide by number of days in the year (365) and population size. The latter is calculated from data provided by

Kantar Worldpanel on the number of households and household size (including by SES) in Great Britain. Kantar Worldpanel provided gross-up weights that account for sampling and non-response in the panel.

3. Results

3.1 Household demographics and food purchases

The final sample includes 2,057,204 weekly purchase observations from 26,799 households. Due to missing values for income, we had to exclude 392,818 weekly observations. Even with this deletion, the distribution of households over SES is broadly in line with national figures (see table 1 for descriptive statistics). The number of weeks households had positive expenditure ranged from 1 to 104, with on average 72 weeks over the two years.

Table 1 here

Table 2 describes the share of non-zero observations, weekly expenditure shares and average prices. On average, 53% of expenditures was towards healthier foods. Across the food groups, households spent most on vegetables (9%, average weekly expenditure £4.70), healthier ready meals and convenience foods (8%, £4.10), alcohol (7%, £5.01), sweet snacks (7%, £3.30) and healthier dairy (7%, £2.90).

Table 2 here

Across the SES groups (table 2 in supplementary material) [INSERT LINK TO ONLINE FILE A], high-SES households spent relatively more of take-home food expenditure on healthier foods (55% in comparison to 52% for low-SES), including more on fruits and vegetables, and fresh & frozen white meat, fish, eggs. Low-SES households spent overall relatively more on less healthy foods (48% in comparison to 45% for high-SES), including on sweet snacks but they also spent relatively more on healthier bread & morning goods and healthier ready meals & convenience foods.

Highest average price (per Kg/L) was observed for savoury snacks (£6.63), fresh and frozen red meat (£6.34, £6.15), and less healthy ready meals and convenience foods (£5.88). Healthier dairy (£0.84), less healthy beverages (£1.12), healthier bread & morning goods (£1.17), healthier beverages (£1.33) and vegetables (£1.59) had the lowest average unit prices. Average price difference between current and previous price was £0.11 with average increase and decrease only marginally different. Largest price differences between purchases occasions were among healthier sauces & condiments (£0.50-0.57), fresh & frozen white meat, fish eggs (£0.10-0.11), less healthy bread & morning goods (£0.10), and healthier drinks (£0.07).

3.2. Nutrient composition of purchases

A summary of average energy and nutrient content of daily per capita purchases is shown in table 3, and by food groups in table 4. On average, households purchased 2,111 kcal of energy per day per capita. Low-SES household purchases yielded to slightly more energy (2,161 kcal) in comparison to mid- and high-SES households (2,078 kcal and 2,119 kcal per capita/day, respectively).

Table 3 here

When comparing purchases to reference daily intake level (RDI) across the SES, purchases of sugar, sodium, saturated fat and protein were well above the RDI while purchases of fibre were close to reference level. On average, mid-SES households were closest to the RDI level.

Across the food groups, sorted by the average nutrient profile score (table 4 and tables 3-5 by SES in supplementary material [INSERT LINK TO ONLINE FILE A]), purchases contributing most to energy were healthier bread & morning goods (229.1 kcal), desserts & puddings (205.5 kcal), sweet snacks (202.1 kcal) and fat & oil (159.8 kcal).

Table 4 here

Fat & oils were the biggest source of saturated fats followed by sweet snacks, desserts & puddings and less healthy dairy. Desserts & puddings, and sweet snacks were the largest sources of sugar purchases, followed by other foods (includes table sugar), healthier dairy and fruits. Sodium purchases were largest in other foods (includes table salt), healthier bread & morning goods, less healthy processed meat & fish, and in ready meals & convenience foods.

3.3. Demand elasticities and asymmetry

Figure 1 presents the own-price elasticities (food groups on the x-axis are sorted based on the average nutrient profile score starting from healthiest on the left hand side on both panels) with a linear trend through the estimates. Overall, the own-price elasticities range from -0.380 to -1.074 (the full set of price elasticities with confidence intervals, are in supplementary material [INSERT LINK TO ONLINE FILE A] tables 6-9). On average, household response is stronger to price increases, with mean own-price elasticity for increasing prices of -0.847 in comparison to that for decreasing prices of -0.780. From the 26 food groups, ten have a statistically significant difference ($p<0.05$) between the elasticity of price increases and decreases with an average difference of 0.119. This implies that if price increases by 10% there would be a 1.19 percentage point greater response in demand compared to a price decrease of 10% for the same food. The largest asymmetry (0.313) was in the demand for less healthy fresh & frozen red meat. If comparing based on healthiness of the foods, own-price elasticities for healthier foods tended to have on average a smaller asymmetry (0.047) in comparison to less healthy foods (0.084).

High-SES households were less sensitive to price changes in comparison to mid-SES and low-SES households. Low-SES households also had greater asymmetry in own-price elasticity (on average 0.183) in comparison to high-SES (0.074).

Figure 1 here

Looking across the x-axis in both panels on Figure 1 where foods on the left are relatively healthier and less healthy on the right, it can be seen that the gap between the price response of high-SES and low-SES households becomes wider. For increasing prices, this gap is driven more by low-SES group being more price responsive as foods become less healthy (high-SES response stays relatively stable), whereas for decreasing prices the gap is mainly driven by high-SES group becoming relatively less responsive as foods become less healthy (low-SES household price response to decreasing prices stays relatively stable).

Cross-price effects

The magnitudes of cross-price elasticities were generally small, with most within |0.2| with a mix of (complement) income and substitution effects (see supplementary material [INSERT LINK TO ONLINE FILE A] tables 6-9). Price changes of sweet snacks, and healthier dairy affected the demand for largest number of groups (20 and 19 significant cross-price effects, $p<0.05$, respectively). Price changes in less healthy fresh and frozen red meats, and in fat and oil affected the least (3-4 significant cross-price effects, $p<0.05$).

Of the 650 pairs of cross-price elasticities, on average 36-37% were significant at 5% level (242 for increasing and 234 for decreasing prices). Of these 45 (18%) had a statistically significant difference in the elasticity of price increase and decrease ($p<0.05$). The majority of the asymmetries were due to only one of the elasticities (of either price increase or decrease) being statistically different from zero. The average magnitude of the asymmetry was -0.1 where it was negative and 0.08 where positive. Considering the overall magnitudes of cross-price effects being generally small, these are relatively large differences.

3.4 Simulation of price changes

Figure 2 shows how energy and nutrient content of purchase change following a 20% price increase in each of the less healthy food groups and a 20% price decrease in each of the healthier food groups individually. Full results, including by SES with confidence intervals are shown in table 10 in the supplementary material [INSERT LINK TO ONLINE FILE A].

Combining own- and cross-price effects, we find the largest reduction in energy purchases per capita/day when the price of sweet snacks (46.0kcal 95%CI -55.3 to -36.7kcal), desserts & puddings (38.8kcal 95%CI -47.3 to-30.4kcal), and fat & oil (28.5kcal 95%CI -37.1 to -20.0kcal) increases. Purchases of sugar decreased most if the price of desserts & puddings, sweet snacks, and 'other' foods (including table sugar) increases: -4.0g (95%CI -4.9 to -3.2g), -3.8g (95%CI -4.6 to -2.9g), and -2.4g (95%CI -3.0 to -1.8g), respectively. Reduction in saturated fat purchases was greatest if price of fat & oil increased (-1.0g 95%CI -1.2 to -0.7), followed again by sweet snacks (-0.9g 95%CI -1.1 to-0.6g) and dessert & puddings (-0.7g 95%CI -0.8 to -0.5g). In all of the above food groups, the reduction in purchases is relatively larger among low-SES households. Sodium purchases reduced most through increased price of 'other' foods (including table salt) (-0.08g 95%CI -0.11 to -0.06g), processed meat & fish (-0.05g 95%CI -0.06 to -0.03g), less healthy ready meals & convenience foods as well as less healthy sauces and condiments (for both -0.04g 95%CI -0.05 to -0.03g).

In terms of trade-offs with fibre and protein, price increases reduce purchases of fibre most from sweet snacks and desserts & puddings (0.33g 95%CI -0.37 to -0.28g and -0.27g 95%CI -0.32 to -0.22g, respectively). Protein purchases are reduced most by increasing the price of less healthy dairy (1.1g 95%CI -1.3 to -0.9g) and less healthy processed meat & fish or less healthy ready meals and convenience foods (1.0g 95%CI -1.2 to -0.7g in each).

Greatest changes in the purchases of fibre were observed if the price of vegetables and healthier bread & morning goods decreases (by 0.6g in each (95%CI 0.4 to 0.8g)). However, a reduction in prices of healthier foods leads also to higher energy and purchases of other nutrients. The largest effect in energy purchases is observed when the price of healthier bread & morning foods decreases (energy purchases increase by 34.8kcal 95%CI 23.7-45.9kcal). A price decrease in this group would also contribute, relative to other food groups, to a larger increase in the purchases of sodium (0.05g 95%CI 0.03-0.07g). Sugar purchases would also increase, particularly from the decrease of price of fruits (1.7g 95%CI 1.1-2.4g) and among high-SES households who are relatively more responsive to changes in the price of fruits (2.5g 95%CI 1.4-3.6g). However, reduction in the price of fruit would have an additional benefit, through cross-price effects, of reducing purchases of saturated fats (-0.13g 95%CI -0.06 to -0.2g), while for vegetables a price decrease would lead to greater purchases of saturated fats through substitution effects (0.47g 95%CI 0.11-0.55g). To understand the impact on purchases of vegetables and fruit in daily portions, we can use the estimated increase in calories from own-price effects (18kcal and 9kcal, respectively). Assuming a portion of 80g of fruits or vegetables has approximately 50-60 kcal, the 20% price reduction in both would increase purchases by approximately half a portion per day/person.

Finally, table 5 shows the extent of changes in purchases of energy and nutrients if prices of all less healthy foods as defined above increased, and prices of all healthier foods decreased.

Table 5 here

In the full sample such a scenario would lead to a net reduction of 67.6kcal purchased per day per capita which increases to 91.3kcal in low-SES households reflecting larger asymmetry in price response in that group as well as greater responsiveness to price increases in less healthy foods. Alongside energy, the sugar, saturated fat and sodium content would also decrease whereas protein and fibre content would increase. With respect to household expenditure, such price changes led to a small reduction in the total expenditure (£1.37 per day) with smallest saving (£0.95) for low-SES and greatest saving for mid-SES households (£0.145).

4. Robustness analysis

Given the modifications done in the AIDS modelling approach, we carried out two analyses of robustness of the simulation results. First, we applied elasticities that are estimated from a model applying two restrictions - adding-up and homogeneity on the parameters in the demand model in (1) which ensure theoretical consistency of the AIDS model. The panel structure of the data, the consideration of fixed effects, and the large number of food groups in our model make it unfeasible to test or impose cross-price symmetry across equations. While this is certainly a limitation, the generalization of the demand model, allowing different response to cross-price increases and decreases, also makes the requirement of symmetric cross-price coefficients less straightforward. Using elasticities from the model with restrictions, there were marginal differences in the estimated changes in energy and nutrient purchases (see table 11 in supplementary material [INSERT LINK TO ONLINE FILE A]). Assessing the confidence intervals, these differences were significant for protein purchases from four food groups and sugar purchases from two food groups.

Second, we applied elasticities estimated from a symmetric demand model in the simulation. Using these would be expected to lead to smaller differences between price increases and decreases. Again, the differences in simulation results are marginal, with significant differences only in a handful of food groups (sugar purchases in five food groups, saturated fat and protein purchases in two groups and fibre in three food groups). Summing the differences across all food groups, as expected, the symmetric model estimated higher effect for price decreases and lower effect for price increases.

5. Discussion

This paper contributes to the literature by exploring the effects of price increases and decreases on purchases of energy and nutrients from a large number of healthier and less healthy food groups. While taxes on SSBs in particular have received recent policy focus, it is important to continue considering the whole diet, including how to increase consumption of healthier foods.

We found, that on average, the energy and nutrient content of take-home food and beverage purchases were generally above the reference daily intake level, and this is without considering any foods or beverages consumed out-of-homes, which can count up to 28% of total food and beverage expenditures (The Food Foundation, 2018). Low-SES spent, on average, a greater share of expenditures on less healthy foods (48%) in comparison to high-SES (45%), who in turn spent relatively more on healthier foods.

Based on simulations by individual food groups, a price increase of 20% would reduce purchases of energy most among sweet snacks or desserts & puddings (46kcal and 39kcal per capita/day, respectively). In addition, sugar purchases would drop by 3.7g and 4.0g per capita/day respectively. This compares to the average of 3.2kcal and 1.1g sugar reduced from increasing the price of less healthy beverages that are subject to recent policies in Britain and other countries. However, increasing the price of sweet snacks and desserts also lead to a reduction in fibre and protein purchases to a greater extent, in comparison to less healthy beverages. An additional 2.2g of sugar could be reduced by increasing the price of caloric sweeteners (table sugar, honey, syrup).

Sodium purchases were reduced most through increases in the price of table salt (0.8g), but even higher reductions (0.12g) could be achieved by increasing the price of less healthy processed meat, ready meals, and table sauces. All these changes were found to be higher among low-SES households, driven from greater price sensitivity when foods are less healthy, and also a slightly higher baseline contribution of less healthy foods.

The trade-offs were apparent when reducing the price of healthier foods. For example increasing fibre purchases via reduced price of healthier bread and morning foods would also lead to the greatest increase in energy and sodium purchases. Decreasing the price of vegetables led to the greatest increase in saturated fats purchases (through cross-price effects). Purchases of fibre from fruits would increase relatively less if its price reduced but this would also lead to substitution effects towards less saturated fats purchased. These findings indicate a complex picture on how changes in prices of different foods may affect food and nutrient purchases and the need to consider the full range of cross-price effects.

Combining price increases on all less healthy food groups with a price decrease on all healthy groups showed that diet overall is likely to improve from such changes, with a reduction in energy purchases by 55-91kcal, and sugar purchases by 5-9g, with the higher values seen for low-SES group. Fibre purchases would increase by 0.8-1.1g (4-5% of RDI), with the largest effect in the mid-SES group, as well as protein purchases by 3-4g. Protein purchases however are already well above (by 20g on average) the RDI level (50g), which suggest that this change is not necessarily positive. Combined price changes would lead to an average of £1.37 saved per day per household, with the greatest savings observed among mid-SES households.

When looking at how much households spend on average, and how frequently, it is striking that sweet snacks (i.e. biscuits, confectionary, chocolate) have a relatively high expenditure share (7%) and households buy these frequently (69% of week) even though its shelf-life is relatively long. As a comparison, 6% was spent on fruits, which were bought in 67% of the weeks. High-SES households purchased more fruits with higher expenditure share (7% vs 5%) and energy purchased (76kcal vs 58kcal) per capita/day in comparison to low-SES households. To the contrary, low-SES households spent relatively more on sweet snacks (8% vs 6%) and purchased more energy from these (226kcal vs 182kcal). These findings, however, do not mean that low-SES households necessarily have a worse diet, as the data exclude purchases for consumption outside of homes, which are likely to be higher among mid- and high SES households due to higher average earnings(The Food Foundation, 2018).

Our estimates are consistent with existing literature modelling the demand for foods and beverages in the UK (Green et al., 2013). For example based on data from 2009, own-price elasticity for dairy & egg was reported -0.505, meat -0.804, fish -0.441, fruits & nuts -0.698, vegetables -0.633, and fats & starches -0.847 (Tiffin et al., 2011). In comparison to simulation studies of price changes we find the same results as Briggs et al. (2013) who modelled a 3kcal reduction per capita/day reduction from a 20% tax on sugar-sweetened beverages (Briggs et al., 2013). Another study using expenditure data from 2002-2006 applied as one of the strategies a VAT style tax of 17.5% on less healthy foods based on a 'WXYfm' nutrient profile index, finding a reduction in energy intake on average by 2.4% and of saturated fats by 3.1% (Nnoaham et al., 2009). When we sum the effect of price increases across the less healthy foods, we see an 11% decrease in daily energy and 13% in saturated fats purchases, which considering different data, years under study and greater price change, are relatively consistent.

With respect to asymmetry, the results agree with marketing research that consumer response is generally stronger to price increases (Hardie et al., 1993; Koszegi & Rabin, 2006; Pauwels et al., 2007; Putler, 1992). For individual food groups the difference between the impact of price change when using symmetric demand model for elasticities in comparison the asymmetric model, was small and generally towards symmetric model providing a greater effect for price decreases and smaller effect for price increases. This result is intuitive as it can be thought of providing an average response over increasing and decreasing prices. Such asymmetry has implications for policy suggesting that subsidies need to be relatively larger in magnitude in comparison to taxes to achieve an equivalent change in demand.

Our analysis has a number of strengths. First, we were able to analyse the demand through food groups but apply simulations directly to nutrient purchases, which is more relevant when considering potential health impacts of changing food prices and thus fiscal policy. Second, we take into account household fixed effects controlling for heterogeneous and diverse consumption patterns for each specific food. By incorporating price differences across purchase occasions we allow for greater flexibility in consumers response to decreasing and increasing prices. The nutrient profile model we use has been used in existing policies (Mayor of London, 2018; Office of Communications, 2007) and continues to be used in health-related food policies put forward (Department of Health & Social Care, 2019), strengthening its applicability in real settings.

Some limitations to the analysis need to be considered. We do not impose restrictions assumed in the traditional AIDS framework and estimate the model equation-by-equation, rather than as a system. We do this to be able to include fixed-effects in a relatively simple framework, as household heterogeneity in the marketing literature has been argued as a potential driver of asymmetry and we considered this crucial to control for. We tested the robustness of simulation results by using elasticity estimates from a model with adding-up and homogeneity restrictions applied and found only small changes in the simulation estimates. The impact of not imposing the symmetry restriction on cross-price elasticities is more difficult to disentangle, as we cannot run a robustness model with this restriction imposed without formidable estimation difficulties and thus this should be considered in the interpretation of cross-price elasticities. To the best of our knowledge, all previous studies allowing for a different response to price increases and decreases were estimated on an equation-by-equation basis, and without imposing symmetry on cross-price coefficients. Given our adjustment to the standard modelling approach to allow for asymmetric price response, it remains an open research question whether and how symmetry should be tested and imposed. We also estimate separately, rather than jointly, the first step probit equations to address biases related to zero expenditures. This does not affect the consistency of our estimated parameters, and makes our estimates less efficient, but given the large sample we do not believe this limitation to question our findings.

We excluded ~15% of observations due to missing household income value. Regardless, the sample distribution across SES remains relatively similar to the distribution of households across SES in the population. We did not have information on the age and sex of all household members and therefore could not adjust purchases to household composition. Finally, as we do not have food waste estimates our results are more likely to be biased upwards for actual consumption.

In conclusion, the analysis demonstrates that on average energy and nutrient content of take-home food purchases is already higher that recommended for total daily intake, without considering food consumed out-of-homes. However, this can be improved, without detrimental consequences on food expenditures, if the price of less healthy foods increased and the price of healthy foods decreased, with relatively bigger improvements seen in the nutritional quality of purchases of low-SES households.

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Table 1. Household demographics

	Low-SES	**Mid-SES**	**High-SES**	**Full sample**
Population (2013 in Great Britain)	17,219,584 (27%)	30,508,779 (49%)	14,666,726 (24%)	62,395,091
Number of households in sample (%)	6,200 (23%)	14,938 (56%)	5,661 (21%)	26,799
	Average			
Age of main shopper (SD)	51.4 (15.1)	48.6 (14.8)	48.7 (15.0)	49.3 (15.0)
Household size (SD)	2.5 (1.4)	2.7 (1.3)	2.8 (1.3)	2.7 (1.3)
Share (%) of households with children (SD)	0.3 (0.5)	0.4 (0.5)	0.4 (0.5)	0.4 (0.5)
Average number of children (if have) (SD)	1.9 (0.9)	1.8 (0.8)	1.8 (0.8)	1.8 (0.8)
Single person households (%)	1,608 (26%)	2,640 (18%)	926 (16%)	5,177
Income	**% by SES**			
up to 20,000 pa	71.3	30.12	10.3	
20-49,000 pa	27.6	57.3	51.1	
> 50,000 pa	1.3	12.5	38.6	
Highest qualification				
Degree or higher	9.3	25.1	60.7	
Higher education	12.9	18.5	13.6	
A Level	11.5	16.5	10.1	
GCSE	31.3	24.0	9.6	
Other	13.2	9.3	4.2	
None	21.8	6.6	1.8	
Tenure				
Owned outright	22.4	27.2	31.7	
Mortgaged	21.8	45.9	54.4	
Rented	54.2	25.4	12.8	
Other	1.6	1.5	1.1	
Region				
London	12.3	15.5	18.1	
Midlands	15.1	14.4	15.9	
North East	5.7	4.8	4.7	
Yorkshire	14.6	13.8	12.7	
Lancashire	11.2	10.5	10.0	
South	10.4	10.8	11.5	
Scotland	9.3	8.9	7.9	
East of England	9.0	9.0	8.2	
Wales and West England	8.8	8.6	8.3	
South West	3.6	3.7	2.7	

Table 2. Expenditure shares, prices and extent of censoring in the data

n=2,057,204	**Share of non-zero observations**		**Expenditure share**		**Price (£)[1]**	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Bread & morning goods (healthier)	0.77	0.42	0.05	0.07	1.17	1.06
Bread & morning goods (less healthy)	0.31	0.46	0.01	0.03	1.86	1.15
Cereals & cereal bars (healthier)	0.22	0.41	0.01	0.03	2.99	1.11
Cereals & cereal bars (less healthy)	0.28	0.45	0.02	0.04	4.26	1.08
Pasta, rice, grains, dry pulses	0.34	0.48	0.01	0.03	1.93	1.12
Dairy (healthier)	0.80	0.40	0.07	0.09	0.84	1.07
Dairy (less healthy)	0.59	0.49	0.04	0.06	4.93	1.07
Fresh & frozen white meat & fish, eggs	0.56	0.50	0.06	0.08	1.39	1.19
Fresh & frozen red meat (healthier)	0.22	0.42	0.02	0.06	6.34	1.09
Fresh & frozen red meat (less healthy)	0.16	0.37	0.01	0.04	6.15	1.10
Processed meat & fish (healthier)	0.29	0.45	0.02	0.04	5.09	1.10
Processed meat & fish (less healthy)	0.43	0.50	0.03	0.06	4.90	1.08
Ready meals & convenience foods (healthier)	0.71	0.45	0.08	0.10	3.32	1.08
Ready meals & convenience foods (less healthy)	0.66	0.47	0.05	0.07	5.88	1.07
Fruits	0.67	0.47	0.06	0.08	1.75	1.09
Vegetables	0.83	0.37	0.09	0.09	1.59	1.10
Sauces & condiments (healthier)	0.19	0.39	0.01	0.02	4.98	1.28
Sauces & condiments (less healthy)	0.35	0.48	0.01	0.03	3.63	1.11
Fat & oil	0.41	0.49	0.02	0.04	2.91	1.08
Non-alcoholic drinks (excl. dairy) (healthier)	0.64	0.48	0.06	0.08	1.33	1.16
Non-alcoholic drinks (excl. dairy) (less healthy)	0.33	0.47	0.02	0.05	1.12	1.12
Savoury snacks	0.49	0.50	0.03	0.05	6.63	1.05
Sweet snacks	0.69	0.46	0.07	0.10	1.40	1.17
Desserts & puddings	0.70	0.46	0.06	0.08	2.09	1.09
Other foods	0.24	0.43	0.01	0.04	1.75	1.14
Alcohol	0.30	0.46	0.07	0.15	4.68	1.15
Total/average	**0.47**		**£52.4**		**£3.27**	

Notes: [1]Average geographical unit value

Table 3. Energy and nutrient content of daily per capita take-home purchases

Energy/nutrient (reference daily intake)	**Full sample**	**Low-SES (D&E)**	**Mid-SES (C1&C2)**	**High-SES A&B**
Energy (2,000kcal)	2,111	2,161	2,078	2,119
Sugars (90g)	117.5	120.9	114.7	119.5
Sodium (<2.3g; eqv. <6g of salt)	2.8	2.9	2.7	2.7
Saturated fat (20g)	32.1	33.1	31.5	32.1
Fibre (18g)*	18.2	17.7	17.9	19.3
Protein (50g)	70.2	70.5	69.3	71.6

* non-starch polysaccharides (NSP) fibre

Table 4. Energy and nutrient content of daily per capita take-home purchases by food group

	NPM score[1]	Energy (kcal)	Sugar (g)	Sod.[2] (g)	Sat. fat (g)	Fibre[3] (g)	Prot. (g)
Vegetables	-7.3	116.1	5.51	0.07	0.37	4.24	4.56
Fruits	-4.2	64.1	13.12	0.00	0.06	1.51	0.89
Cereals & cereal bars (healthier)	-2.9	40.4	1.10	0.01	0.10	1.00	1.14
Bread & morning goods (healthier)	-1.6	229.1	3.63	0.34	0.80	3.55	8.57
Non-alc. drinks (healthier)	-1.3	26.7	5.50	0.01	0.05	0.27	0.34
Pasta, rice, grains, dry pulses	-1.1	67.4	0.38	0.03	0.14	0.67	2.08
Fresh & frozen red meat (healthier)	-0.4	24.2	0.01	0.01	0.56	0.02	3.24
Ready meals & conv. foods (healthier)	-0.4	105.9	1.85	0.18	1.11	1.42	4.36
Sauces & condiments (healthier)	-0.3	3.7	0.24	0.02	0.03	0.08	0.09
Dairy (healthier)	0.1	87.2	0.12	0.09	1.32	0.11	10.04
Fresh & frozen white meat & fish, eggs	0.1	141.1	13.83	0.12	3.17	0.27	9.20
Processed meat & fish (healthier)	0.4	20.1	0.17	0.04	0.21	0.12	1.94
Alcohol	0.4	73.9	1.93	0.01	0.00	0.00	0.20
Non-alc. drinks (less healthy)	3.3	27.6	5.87	0.03	0.07	0.05	0.11
Desserts & puddings	9.5	205.5	21.23	0.08	3.73	1.21	2.86
Fresh & frozen red meat (less healthy)	9.6	22.3	0.04	0.02	0.72	0.01	1.92
Cereals & cereal bars (less healthy)	10.1	49.2	3.26	0.04	0.29	0.68	0.93
Other foods (incl. table salt and table sugar)[4]	10.2	63.3	14.51	0.57	0.02	0.15	0.31
Savoury snacks	10.7	76.4	0.63	0.10	0.67	0.64	1.34
Bread & morning goods (less healthy)	10.8	51.2	1.09	0.06	0.94	0.35	1.21
Ready meals & conv. foods (less healthy)	10.9	70.4	1.05	0.19	1.54	0.48	3.13
Sauces & condiments (less healthy)	12.8	29.0	1.98	0.18	0.28	0.11	0.28
Proc. meat & fish (less healthy)	14.7	64.8	0.29	0.24	1.69	0.21	4.54
Dairy (less healthy)	16.2	89.3	1.95	0.13	4.45	0.08	4.36
Sweet snacks	19.7	202.1	18.11	0.08	4.60	0.93	2.46
Fat & oil	21.0	159.8	0.11	0.10	5.20	0.03	0.09

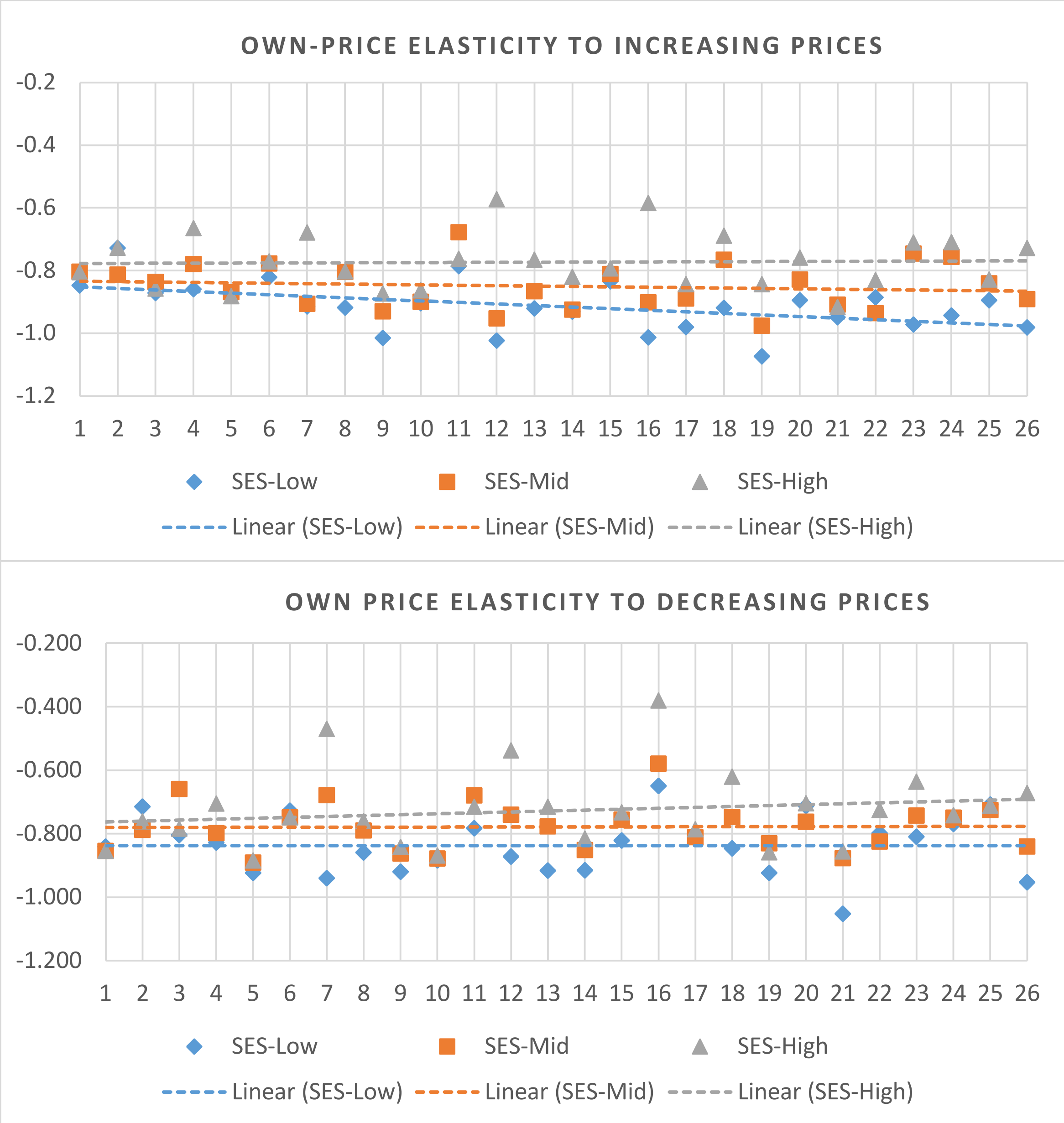
Notes:[1]weighted to number of purchases; [2]2.3g of sodium equivalent to <6g of salt; [3]non-starch polysaccharides (NSP) fibre; [4] table salt accounts for 78% (0.44g) of sodium in the sodium content and table sugar accounts for 92% (13.3g) of sugar content in 'other foods'.

Table 5. Change in energy and nutrient purchases per capita/day by SES if the price of all healthier foods decreased by 20% and the price of all less healthy foods increased by 20%

		Change in energy and nutrient content of daily per capita take-home purchases						Change in weekly household expenditure (£)[3]
		Energy (kcal)	**Sugar (g)**	**Sat. fat (g)**	**Sod.[1] (g)**	**Prot. (g)**	**Fibre[2] (g)**	
Full sample	Price decrease of healthy foods	168.31	7.28	1.80	0.15	8.83	2.22	5.92
	Price increase of less healthy foods	-235.94	-13.61	-4.13	-0.36	-5.39	-1.30	-7.29
	Difference	***-67.63***	***-6.33***	***-2.34***	***-0.21***	***3.44***	***0.92***	***+1.37***
Low-SES	Decrease	161.18	6.15	1.55	0.16	9.37	2.21	5.67
	Increase	-252.47	-14.87	-4.21	-0.43	-6.14	-1.46	-6.62
	Difference	***-91.29***	***-8.72***	***-2.65***	***-0.27***	***3.23***	***0.75***	***+0.95***
Mid-SES	Decrease	172.24	7.36	1.85	0.14	8.49	2.27	5.77
	Increase	-227.05	-12.58	-4.08	-0.34	-5.24	-1.15	-7.22
	Difference	***-54.81***	***-5.23***	***-2.23***	***-0.19***	***3.25***	***1.12***	***+1.45***
High-SES	Decrease	169.29	9.45	1.83	0.17	9.13	2.22	6.53
	Increase	-241.10	-14.39	-4.29	-0.32	-5.17	-1.46	-7.61
	Difference	***-71.80***	***-4.94***	***-2.46***	***-0.15***	***3.96***	***0.76***	***+1.08***

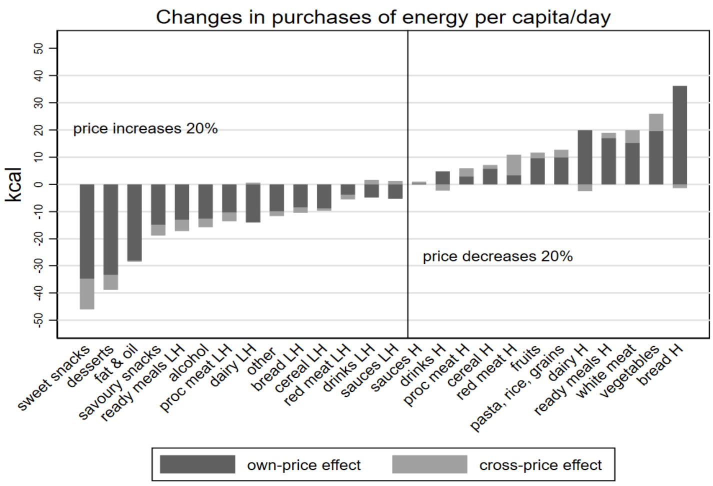
Notes: [1]2.3g of sodium equivalent to <6g of salt; [2]non-starch polysaccharides (NSP) fibre; [3] weighted expenditure at population level.

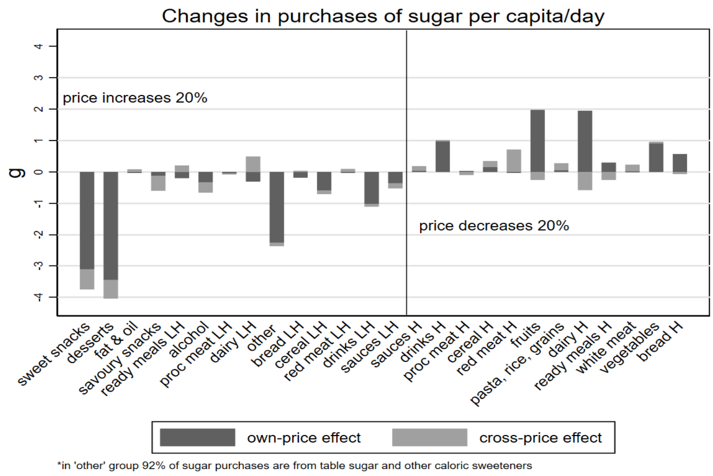
Figure 1. Own-price elasticity estimates by household SES, with food groups sorted by the average nutrient profile score (from left - healthier to right - less healthy).



***Notes: Food groups on x-axis: 1** – vegetables (score -7.3); **2** – fruits (-4.2); **3** – cereal bars (healthier) (-2.9); **4** – bread&morning goods (healthier) (-1.6); **5** – non-alc drinks (healthier) (-1.3); **6** – pasta, grains, rice, dry pulses (-1.1); **7** – fresh&frozen read meat (healthier) (-0.4); **8** – ready meals&convenience (healthier) (-0.4); **9** – sauces&condiments (healthier)(-0.3); **10** – fresh&frozen white meat&fish, eggs (0.1); **11** – dairy (healthier)(0.1); **12** – processed meat&fish (healthier)(0.4); **13** – alcohol (0.4); **14** - non-alc drinks (less healthy) (3.3); **15** – desserts&puddings (9.5); **16** – fresh&frozen red meat (less healthy) (9.6); **17** – cereals&cereal bars (less healthy)(10.1); **18** – other foods (10.2); **19** – savoury snacks (10.7); **20** – bread&morning goods (less healthy) (10.8); **21** – ready meals&convenience (less healthy) (10.9); **22** – sauces&condiments (less healthy) (12.8); **23** – processed meat&fish (less healthy) (14.7); **24** – dairy (less healthy) (16.2); **25** – sweet snacks (19.7); **26** – fat&oil (21.0).*

Figure 2. Changes in energy and nutrient content of take-home per capita daily purchases





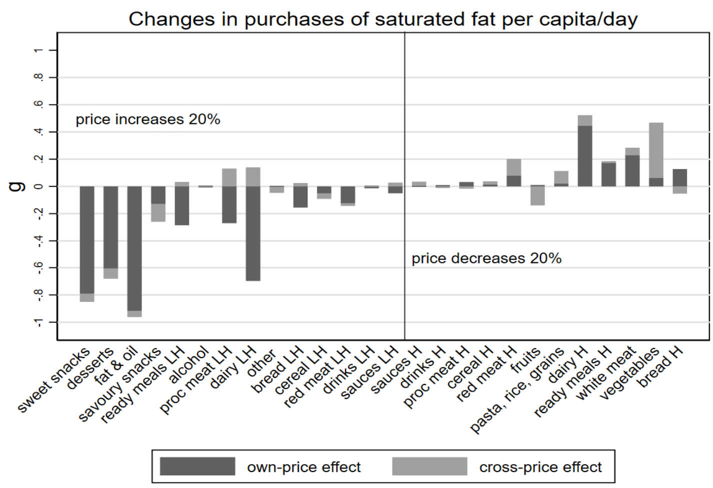
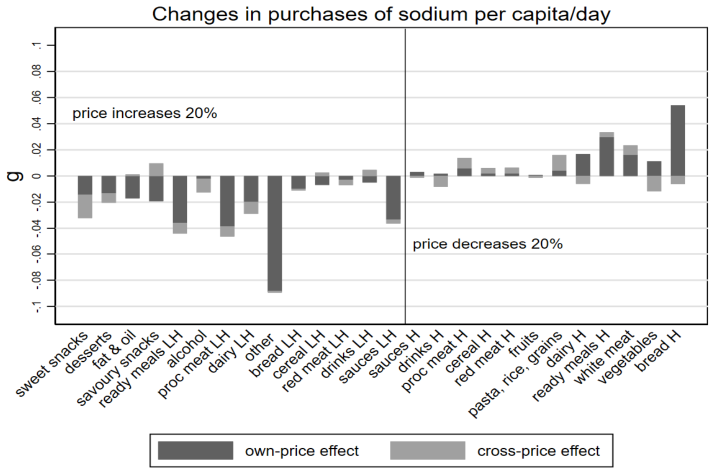
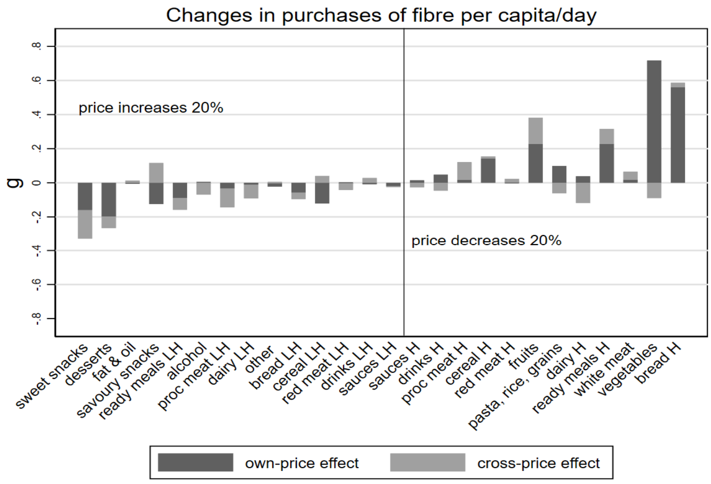
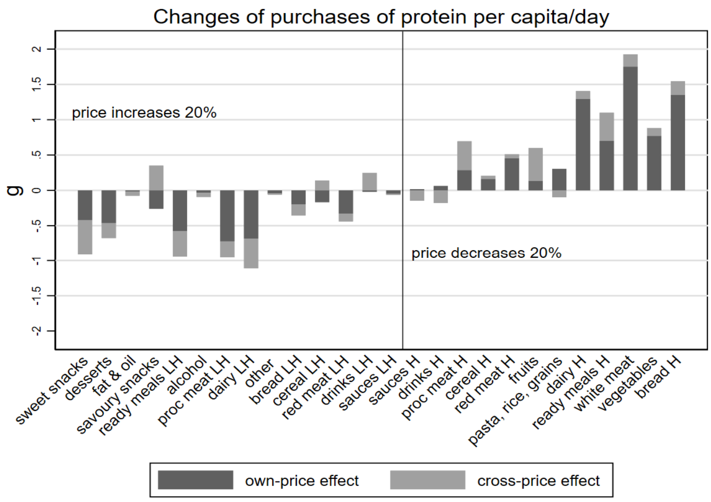


Fig.2 continued



*in 'other' group 78% of sodium purchases are from table salt





Notes: Each bar on the figure represents the total change in energy or nutrient content of purchases due to price change in that particular food group only. See table 10 in supplementary material [INSERT LINK TO ONLINE FILE A] *for standard errors and confidence intervals for total, own- and cross-price effects.*

Fat tax or thin subsidy? How price increases and decreases affect the energy and nutrient content of food and beverage purchases in Great Britain

Highlights

- Energy and nutrient content of take-home purchases is above reference daily intake
- Demand for food is more responsive to price increases than to price decreases
- Price changes based on healthiness of food have a positive net effect on diet
- Price changes improve dietary quality of low-SES household food purchases most
- Greatest impact seen if price of sweet snacks, desserts, and fats/oils increases