Empirical estimates of the impact of a fat tax

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Abstract

We estimate the impacts of a tax on saturated fats. We are particularly interested in what impact such a tax would have in markets where products are differentiated and firms have market power. We use a discrete choice demand model and household purchase level data to estimate responses to a fat tax.

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1 Introduction

Policymakers and nutrition researchers have expressed concern that individuals eat too much saturated fat.[1] For example, a press release by the Food Standards Authority states that, "The UK is currently eating 20% more saturated fat than UK Government recommendations." (FSA, 12 Feb 2009) Consumption of fat and in particular saturated fat is associated with heart disease and other negative health outcomes.[2] Numerous policies aimed at reducing saturated fat consumption have been suggested or tried. These include tax policies that aim to change the relative price of saturated fats. The impact of these policies on diet, and thus on health outcomes, will depend crucially on how consumers adapt their food purchasing behaviour in response to the policy, and on how firms in turn respond in terms of the prices they set and the foods they offer.

In this paper we are interested in evaluating how a tax on saturated fat would affect consumption patterns and who would bear the burden of the tax. Our contribution is to provide empirical estimates of the impact of a fat tax that take account of consumer substitution patterns in differentiated product markets where there is observed and unobserved heterogeneity in consumer preferences by estimate a discrete choice demand model for specific food products using very disaggregated data. Nutritional information is at the product level, allowing us to capture important variation across seemingly similar products. Our empirical

[1] See, inter alia Ascherio et al (1999), Hu et al (1997) Stoeckli and Keller (2004), Willett (2001) and de Agostini (2007).

[2] High saturated fat intake can raise cholesterol levels in the blood. High cholesterol levels are a risk factor for heart and circulatory diseases such as coronary heart disease, heart attacks, angina and stroke - or cardiovascular disease. Cardiovascular disesas is the most common cause of death in the UK and in 2006 was responsible for about one in three premature deaths. See FSA (2009).

application uses data on butter and margarine purchases, the food category that accounts for the highest share of saturated fat consumption.

The existing literature on the impact of a fat tax includes Chouinard et al (2007), Smed et al (2007), Leicester and Windmeijer (2004), Marshall (2000) and Acs and Lyles (2007). Previous authors have used data that is aggregated to the level of food categories (e.g butter, ice cream, cheese ...), and have focused on estimating the effect of a fat tax on substitution *between* food categories. In contrast, we use data that is disaggregated at both the household and product level, and we focus on substitution *within* food category. Products within a food category (e.g. different butter products) are seen by consumers as highly substitutable. Our aim is to capture this potentially important margin of substitution, which has not been included in previous estimates of the impact of a fat tax. We focus on butter and margarine because it is the food category that accounts for the largest share of saturated fat purchased.

There are at least three reasons that policy may potentially have a role to play in influencing saturated fat consumption. First, even if individuals are completely rational in their private choices and consume individually optimal quantities of fat, consuming fat increases the risks of negative health outcomes and may increase the likelihood of high health costs. Since health costs are covered both by state provided and privately provided insurance, and since such increased risks of high health costs are not priced into the insurance system, there is an externality. Private consumption of fat thus raises the public cost of health insurance.[3] Second, if people are altruistic and care about the health outcomes of others, then individually optimal private choices of fat consumption may not take into account negative utility impacts on altruistic individuals. Again there is an externality. Finally, it may be that individuals are not completely rational in their choices of fat consumption. Because keeping up to date with current nutrition research is costly, they may misunderstand the health consequences of fat consumption. Because keeping track of the fat content of foods, and of the optimal amount of fat an individual should consume, is costly, they may make suboptimal decisions. Or, as suggested in the behavioural economics literature,[4] they may discount the future inconsistently or may not consistently weigh the likelihoods of low probability events such as negative health outcomes.

For these reasons, public policy may have a role to play to improve welfare by intervening in food and nutrition markets. If the government has good information about health insurance externalities or about altruism related externalities, it could design a tax system that would improve welfare. Or, if the government has better information about the negative consequences of fat consumption or the fat contents of foods, or if their is good evidence that people make irrational fat consumption choices, then a government intervention could improve welfare.

However, government intervention could also reduce welfare if the tax design is based on incorrect information about externalities or about the health consequences of fat consumption, or if it is not possible to design a tax system that

[3] FSA (2007) :"It has been estimated that a reduction in average saturated fat intakes from the current level of 13.3% to the recommended 11% of food energy would equate to approximately 3,500 annual UK deaths averted, or yield an aggregate potential benefit of more than £2.4 billion"

[4] See recent survey in xxxx.

takes account of all relevant nutrition research. We are interested not only in the efficiency properties of any government intervention but also in who bears the burden of the tax. In this paper, we provide evidence on how a tax on fat would affect consumption and who would bear the burden of the tax.

The structure of the rest of the paper is as follows. The next section outlines the model we use. Section 3 discusses the data. Section 4 presents our results and a final section concludes. Further information on how we estimate the model are provided in an Appendix.

2 Model

We first describe household behaviour and then firm behaviour.

2.1 Household behaviour

We consider household demand for a basket of food products. Households' payoff from $g = 1, ..., G$ types of food (e.g. milk, cheese, fresh meat, butter and margarine). We assume payoffs are separable across these different food types. That is,

$$U_i = U\left(u_{i1}\left(.\right), u_{i2}\left(.\right), ..., u_{iG}\left(.\right)\right).$$

For each food category $g \in (1, .., G)$ we assume that household $i \in (1, \ldots, I)$ opts to purchase the product $j \in (1, \ldots, J)$ (including the outside option) that provides it with the highest payoff. Following Lancaster (1966) and the recent discrete choice demand literature we model households' payoff as derived from the characteristics of these foods. We assume that the payoff from any product j can be expressed as a linear function of its observed characteristics, indexed

$k = 1, \ldots, K$, its unobserved characteristics and a random component reflecting the fact that households may simply have idiosyncratic preferences for different products. In particular:

$$u_{ij} = \sum_k x_{jk}\beta_{ik} + \xi_j + \varepsilon_{ij}$$

where x_{jk} and ξ_j are observed and unobserved product characteristics, ε_{ij} captures idiosyncratic household specific preferences and β_{ik} represents the 'taste' of consumer i for product characteristic k. We allow this to vary with observed household characteristics, indexed $r = 1, \ldots, R$, as well as unobserved household heterogeneity:

$$\beta_{ik} = \overline{\beta}_k + \sum_r z_{ir}\beta^o_{kr} + \beta^u_k \tag{1}$$

where z_i is a vector of observed household characteristics. $\overline{\beta}_k$ represents the mean 'taste' across households for product characteristic k, β^o_k captures systematic response heterogeneity, telling us how 'taste' for product characteristic k varies with household characteristics and β^u_k captures unobserved 'taste' heterogeneity. Substituting (2) into (1) yields:

$$\begin{aligned} u_{ij} &= \sum_k \left(x_{jk}\overline{\beta}_k + \sum_r x_{jk}z_{ir}\beta^O_{kr} + x_{jk}\beta^U_{ik} \right) + \xi_j + \varepsilon_{ij} \\ &= \delta_j + \sum_{kr} x_{jk}z_{ir}\beta^O_{kr} + \sum_k x_{jk}\beta^U_{ik} + \varepsilon_{ij} \end{aligned} \tag{2}$$

where

$$\delta_j = \xi_j + \sum_k x_{jk}\overline{\beta}_k.$$

The parameter vectors $\overline{\beta} = (\overline{\beta}_1, ..., \overline{\beta}_K)$ and $\beta^O = \left(\beta^O_{11}, ..., \beta^O_{KR}\right)$ are parameters to be estimated. The variables $\beta^U_i = \left(\beta^U_{i1}, ..., \beta^U_{iK}\right)$, $\xi = (\xi_1, ..., \xi_J)$ and $\varepsilon_i = (\varepsilon_{i1}, ..., \varepsilon_{iJ})$ are unobservable stochastic terms. We assume $\beta^U_i \sim N(0, \Sigma)$, ε_i are i.i.d. Type 1 extreme value random variables, and that ξ are drawn from an unknown distribution.

We allow households to alter the quantity of butter or margarine they purchase by including pack size in x_{jk} as a product characteristic in our empirical specification. This means that two products that are identical except for their pack size are treated as separate products, and in response to the imposition of a tax households can purchase larger or smaller quantities of the same product.

For each household we choose a random shopping trip, and if the household did not purchase any butter or margine on that trip then they purchased the outside option. The value of the outside option is given by

$$u_{i0} = \xi_0 + \varepsilon_{i0}.$$

Including the outside option allows for households to respond to a tax by either stopping consuming both butter and margarine or by purchasing the products less frequently. The importance of the first response depends on the degree to which households view alternative products from different food categories as substitutes, while the importance of the second response depends on the durability of the product.

2.2 Price elasticities

Denote the unconditional probability that household i chooses option j at price P_j as

$$\pi_i(j, P_j) = \int L_i(j, \theta_i, P_j)\, \phi(\theta_i,)\, d\theta_i, \tag{3}$$

where θ_i denotes all the coefficients in the model, and where

$$L_i(j, \theta_i, P_j) = \frac{e^{V_j(\theta_i, P_j)}}{\sum_k e^{V_k(\theta_i, P_k)}} \tag{4}$$

is the probability that i chose j conditional on θ_i.

The price elasticity is

$$\epsilon_{ij} = \frac{\partial \pi_i(j, P_j)}{\partial P_j} \frac{P_j}{\pi_i(j, P_j)} \tag{5}$$

where

$$\frac{\partial \pi_i(j, P_j)}{\partial P_j} = \int \frac{\partial L_i(j, \theta_i, P_j)}{\partial P_j} \phi(\theta_i)\, d\theta_i, \tag{6}$$

We can approximate (3) with

$$\pi_i \widehat{(j, P_j)} = \frac{1}{M} \sum_m L_i(j, \theta_i^m, P_j) \tag{7}$$

where M is the number of draws from the density $\phi(\theta_i)$, and we can approximate (6) with

$$\frac{\partial \pi_i \widehat{(j, P_j)}}{\partial P_j} = \frac{1}{M} \sum_m \frac{\partial L_i(j, \theta_i^m, P_j)}{\partial P_j} \tag{8}$$

We find the mean derivative (to approximate the integral) taking 10 draws of the random coefficient and using (8), and then finding the elasticity using

$$\frac{\partial \pi_i (j, \widehat{P_j)}}{\partial P_j} \frac{P_j}{\pi(j, P_j)} = \frac{\partial \pi_i \widehat{(j, P_j)}}{\partial P_j} \frac{P_j}{\pi_i \widehat{(j, P_j)}} \tag{9}$$

We also calculate the cross-price elasticities, and the elasticity with respect to saturates (and other product characteristics).

2.3 Firm behaviour

Holding the menu of products on offer constant, firms will respond to a tax by changing the prices. We assume that retailers set prices and compete in a Nash-Bertrand game. Profits for firm f which produces and sells products $j \in F_f$ are given by

$$\Pi_f = \sum_{j \in F_f} (p_j - mc_j) M s_j (p + \tau f) - C_j \tag{10}$$

where p: price, mc: marginal cost, M: market size, $s(.)$: market share, C: fixed costs. The firm's first-order conditions are given by

$$s_j (p + \tau f) + \sum_{j \in F_f} (p_j - mc_j) \frac{\partial s_j (p + \tau f)}{\partial p_j} = 0. \tag{11}$$

We observe p and s and we estimate $\frac{\partial s_j(p)}{\partial p_j}$ so we can recover mc_j.

2.4 The impact of a tax on fat

The impacts of a fat tax will depend on the demand relationships and on retailer responses. We start by analysing the immediate demand responses to a fat tax, assuming that the taxes are fully passed on to consumers in prices and that retailers make no other responses. We assume that the tax takes the form

$$p_j^\tau = p_j + \tau f_j \tag{12}$$

where f_j is the saturated fat content of product j and τ is the tax rate.

We then analyse how producers/retailers would respond to the tax by adjusting prices, but maintain the assumption that there is no change in the menu of products on offer.[5] We compute mc_j when $\tau = 0$, then compute the new

[5] In future work we hope to also consider the impact on the menu of prices on offer.

optimal prices p when $\tau > 0$. Using these we can compute the new level demand and from this find the changes in consumer expenditure, firm profits and government tax revenue.

3 Data

The data used come from the TNS World Panel for calendar year 2006. We observe all purchases of food brought into the home made by 15,764 households. Households record purchases of all items bought using handheld scanners and record prices from till receipts. The data also contain a large set of product attributes (at the barcode level) as well as household characteristics. See Leicester and Oldfield (2009) for further information on the TNS data, and Griffith and O'Connell (2009) for further discussion of the nutrition data.

We focus on butter and margarine because in our data it is the single food category that accounts for the highest proportion of saturated fat purchases made by UK households, contributing 13.3% on average.[6]

For each household we choose a random shopping trip during the calendar year 2006. We define a 'shopping trip' as all goods purchased by a household on a single day.[7] We exclude shopping trips in which less than five purchases

[6] Together dairy products (cheese, butter, margarine, milk, ice cream and cream) contributing 35.1% to the average household purchases of saturated fats. Snacks and meat are also significant contributors. Our calculations accord with other data. NDNS 2000/2001 suggest that fat spreads including butter account for 11% of saturated fat in the diets of UK adults. Mintel (2005) reported a decline in volume sales of yellow fats (butter, margarine and spreads) by 3% between 2000 and 2004, which it attributed to a general decline in home cooking and baking, as well as a greater reliance on foods prepared outside of the home. Butter is the one category of fat spread that appeared to be bucking this trend with a rise of 8% in volume sales between 2002 and 200438. Defra (2007) show a continuation of this trend with an 8.3% rise in household purchases of butter in 2005-6. See FSA (2007), Henderson et al (2003), Gregory et al (2000).

[7] We exclude a small nubmer of households which only purchase very infrequently (fewer than 125 items purchases over the year), households with missing income data, and purchases

were made and consider only products that we observe being purchased at least five times in each month. After taking a random sample of shopping trips we observe 5,108 purchases of butter or margarine (the other 10,656 households don't purchase any butter or margarine on the selected trip) - of these 2,055 purchases are of 58 different butter products and 3,053 purchases are of 96 different margarine products.

3.1 Product characteristics

We include the price of each product in the vector of product characteristics. In our data there is price variation over time, across regions and within regions across fascia that arises due to differences in pricing strategies of firms and differences in their costs. For purchases that we observe we use the observed purchase price. For purchases that we do not observe we use the average price for a product in the month and region of purchase.

In addition to price, our data contain information on the nutritional content of individual products, as well as their size, what type of butter or margarine they are and whether or not they are from a retailer's budget range. Table 1 lists the product characteristics we include in our empirical specification, as well as the means and standard deviations for all butter and margarine products. It shows that on average butter and margarine products tend to have similar prices, but since margarine tends to come in bigger pack sizes, it has a lower unit price. Butter products tend to have more saturated fat than margarine products, but in contrast margarine tends to have higher sodium content. This

where recorded values are extremely large or small.

suggests that if a tax on saturated fat induces households to substitute towards margarine, it may succeed in reducing the amount of saturated fat purchased at the expense of increasing the amount of sodium purchased. However, although the correlation coefficient across all butter and margarine purchases between saturated fat and sodium per 100g of product is negative (-0.12), it is positive within butter products and margarine products (0.24 and 0.62 respectively). Therefore, there is scope for households to reduce the amount of saturated fat they buy without necessarily increasing the amount of sodium.

In previous studies authors have typically used some form of aggregated data. For example Chouinard et al (2007), who analyse the implications of an ad valorem tax on the fat content of dairy products, have data on purchases and attributes of several categories of dairy produce (butter, ice cream, natural cheese etc.). This means that the substitution patterns that result from the imposition of a tax will consist of households substituting between food categories (e.g. from butter to ice cream) but not within food categories (e.g. from one butter product to another). Yet it is likely that consumers consider alternative products within the same food category as being close substitutes. Therefore, if the saturated fat intensity of products within the same food category varies, within food category substitution may be an important margin of substitution.

To get an idea of how important this may be in practice, Figure 1 shows the distribution of saturated fat intensity across all the butter and margarine products purchased in our random sample of shopping trips. It illustrates that the saturated fat intensity varies from 0g to 57g, with a mean value of 27g and a median of 24g. Even within butter products there is considerable variation; the least saturate intensive butter product has 24g of saturated fat per 100g while the most intensive has 57g; similarly for margarine, the most intensive margarine product has 27g while the least intensive has 0g. Estimates based on aggregate data fail to account for the substitution within products. However, following the introduction of a 'fat tax', the most like substitution by households would be from e.g. a 250g tub of Country Life Standard (which has a saturates intensity of 54g) to a 250g tub of Lurpak Lighter Spreadable (which has a saturates intensity of 26g), rather than substituting away to an entirely different food product. Our highly disaggregated data (at the barcode level) allows us to capture this form of substitution and thus to model more realistic changes in consumer behaviour.

3.2 Household characteristics

In our empirical specification we include as household characteristics household size, income (banded into five categories), region, household class and type (household without children, pensioner household, couple with children or single parent) and whether the main shopper is classified as overweight (including obese). Table 2 reports the mean and standard deviations for household characteristics by household type across all 15,764 households in our sample.

4 Results

4.1 Estimated coefficients

Table 3 shows the estimated coefficients from our random coefficients demand model for butter and margarine. The appendix describes the estimation methodology. The first column reports the mean impact of each product characteristic (this is the $\overline{\beta}_k$ in equation (1)). These coefficients on price and the nutrient variables are identified from the within brand variation in these characteristics. The δ_j that we include are brand level fixed effects (not reported in Table 3). The product characteristics vary within brands, for example, over different pack sizes, or different regions or shops. The second column reports the estimated random coefficients. We allow for random preference variation for price and on saturated fat content. The remaining columns report the coefficients on the product-household characteristic interactions. These coefficients can be interpreted as the average incremental effect a given product characteristic has for a household with a given household characteristic. For example, the interaction of price with household income is increasing in income. This suggests that richer households, on average, are less sensitive to price, or prefer more expensive products. However the negative, and larger in absolute terms, coefficient on price ensures that, on average, households in all income bands reduce their demand in response to an increase in price. The random coefficient on price allows for random variation in households' responsiveness to price within each household income band.

We control for pack size using discrete measures as described in Table 1. Because some of the size categories contain only a few products we interact only three size group with household characteristics, as reported in Table 3. The interaction of large pack size and household size is positive and significant, which accords with intuition.

4.2 Elasticities

The estimated coefficients allow us to calculate own and cross price elasticities for each household and product, as described in equation (9). Table 4 shows the mean and standard deviation of the own-price elastiticies for each of the 154 products, averaged across households. The median is around -1.6, all but 6 of them are negative, and all but 16 are greater in absolute terms than -1. Figure 2 shows the distribution of the own-price elasticity across households of for four example products (these are the three products with the largest market share in our data -Tesco value blended 250g, St Ivel Utterly Butterly spreadable 500g and Clover dairy spread 500g - and the product that had the highest mean own-price elasticity - Asda soft margarine 2kg). The show that there is a large amount of variation in the own-price elasticities across households. This variation is driven by both observed and unobserved characteristics.

Figures 3a and 3b show the distribution of the cross-price elasticities between Clover dairy spread 500g and four other products. In Figure 3a we see that Yorkshire English Butter 250g has a very low cross-price elasticity - it is a very different product, and the cross-price elasticity shows that virtually no household view these products as substitutes. Figure 3b contains the same products as in 3a but omits Yorshire English Butter 250g. We see that on average households view Flora Light spread 500g as a close substitute to Clover Dairy Spread 500g, while the same product in a large pack size - Flora light spread 1kg - is viewed as a less good substitute by most households, though a few view it as very substitutable. We also see that I Can't Believe It's Not

Butter 500g is a fairly close substitute.

4.3 Direct demand impacts of tax

We start by considering the impact of a tax that adds 10 pence to the price for each 100g of saturate fat, which implies a tax rate $\tau = 0.1$ in equation (12). We consider the short term impact when there is no response by firms through either changing prices or the products available. We first discuss the results in terms of the change in the market share of products, and then by looking at the impact on household's predicted purchases.

4.3.1 Product level

A 10p tax on 100g of saturated fat least to an increase in the price of 12.5% on average across all products, 14.9% across butter products and 11.1% across margarine products. The percentage increase in unit prices ranges from 0% for a 500g pack of Gold Lowest Extra Light, which was a type of margarine with no saturated fat, to 50% for a 500g pack of Netto vegetable spread, which was a relatively very cheap margarine product. This is shown for all products in Figure 4. Each dot represents a product. The saturated fat intensity is on the x-axis and the change in the predicted market share is on the y-axis. The predicted change in market share of each product is negatively correlated with its saturated fat intensity. However, there is substantial heterogeneity. Some high saturate products are still purchased, despite the higher price - consumers have stronger preferences for these products and not all low saturate products increase their market share. In fact the product that looses the most is a 1kg pack of I Can't Believe it's not Butter (which a type of margarine relatively high in saturated fat with 24g per100g) which sees its market share reduced by around 0.4%. The product that gains the most is a 500g pack of Flora Light Spread which has 9.3g of saturated fat per 100g and sees its market share increase by over 0.4%. The aggregate effect is shown in Figure 5 which also shows the saturated fat intensity on the x-axis and the change in the predicted market share on the y-axis. In general products with high saturated fat intensity loose market share while those with low intensity gain. This figures shows a clear shift away from products with high saturated fat intensity towards ones with lower intensity. A consequence of this is that more households opt to purchase margarine products; the market share of margarine products considered together increases by 2.2% at the expense of butter products.

4.3.2 Household level

What impact does the tax have on the volume and intensity of saturate fat purchased by households? Table 5 summarises the results. We consider the impact of the tax on saturated fat and sodium purchased. The top panel shows the impact in terms of the intensity (saturated fat per 100g), and the bottom panel shows the impact in terms of the total volume of saturated fat. The first column shows the initial mean value of each measure prior to simulating the imposition of the tax. Columns two and three summarise the impact in terms of absolute changes and the final column in percentage changes (relative to the initial level).

On average, households substitute to products which have lower saturated fat intensity (and lower fat intensity) since the tax makes products that are high in saturated fat relatively more expensive. As previously discussed, it is interesting to consider what impact substitution to products with lower saturated fat intensity has for the sodium intensity of products purchased. Table 5 suggests that, in practice, the substitution that consumers make leaves sodium intensity relatively unchanged.

The volume of saturated fat and sodium purchased also fall. The reason is that, on average, households substitute to smaller pack sizes. Figure 5 shows this - the market share of smaller pack sized margarine products gain at the expense of larger margarine products and butter products. This means the percentage reduction in the average volume of saturated fat purchased exceeds the average reduction in intensity.

The non-zero standard deviations reported in Table 5 indicate some heterogeneity in households' responses to the tax. Figure 6 illustrates this heterogeneity with respect to the change in the volume in saturated fats purchased across all households.

Tables 6 and 7 illustrate that only some of this heterogeneity can be explained by observable household characteristics, while the standard deviations in these table suggests that some heterogeneity in households' responses remains unexplained by observable household characteristics and can therefore be attributed to unobserved (and so, from our perspective, random) preference variation.

5 Summary and Conclusion

[to be written]

6 Appendix A: Estimation

We estimated the random coefficient logit model given in (2). For ease of exposition we drop the subscript i and rewrite equation (2) as

$$\begin{aligned} u_j &= \sum_k \left(x_{jk}\overline{\beta}_k + \sum_r x_{jk} z_r \beta^O_{kr} + x_{jk}\beta^U_k \right) + \xi_j + \varepsilon_j \\ &= \delta_j + \sum_{k,r} x_{jk} z_r \beta^O_{kr} + \sum_{k=1}^{K_U} x_{jk}\beta^U_k + \varepsilon_j \end{aligned}$$

The variable u_j is the payoff the household obtains from product j. We assume that $\beta^U \in \mathbf{R}_{K_U}$ with

$$\beta^U \sim N(0, \Sigma).$$

Define the change of variables $\beta^U = \sqrt{2}\Sigma^{0.5}\varepsilon$ where $\varepsilon \sim N(0, 0.5)$.

We estimate the model by maximum likelihood. Assume that for each household the data have been sorted so that option 1 is the option chosen. Let $P\left(\beta^U\right)$ be the probability that a household chooses option 1. Then

$$P\left(\beta^U\right) = \frac{1}{1 + \sum_{j \neq 1} \exp\left(v_j\left(\beta^U\right) - v_1\left(\beta^U\right)\right)}$$

where we define

$$v_j\left(\beta^U\right) - v_1\left(\beta^U\right) = (\delta_j - \delta_1) + \sum_{k,r} (x_{jk} z_r - x_{1k} z_r)\beta^O_{kr} + \sum_k (x_{jk} - x_{1k})\beta^U_k.$$

The likelihood for a single household can be written as

$$\begin{aligned} L &= \log\left(\int P\left(\sqrt{2}\Sigma^{0.5}\varepsilon\right) \frac{e^{-\varepsilon'\varepsilon}}{\pi^{1.5}} d\varepsilon \right) \\ &= \log\left(\sum_i \frac{w_i}{\pi^{0.5K_U}} P\left(\sqrt{2}\Sigma^{0.5}\varepsilon_i\right) \right) \end{aligned}$$

where $\{(w_i, \varepsilon_i)\}_{i=1}^{N}$ are the weights and nodes for a K_U dimensional integration rule. When K_U is small $(K_U \leq 9)$, we use the K_U dimensional tensor product of one dimensional Gauss-Hermite quadrature rules with at most 5 points in each dimension (with $K_U = 2$, this implies $N \leq 25$ while with $K_U = 9$, this implies $N \leq 1,953,125$). Given our current computing resources, these are both feasible. When K_U is large $(K_U > 9)$, we use Monte Carlo integration with $w_i = \pi^{0.5K_u}$ and with $N \leq 2,000,000$.

We sum the household specific likelihood contributions across households and maximise the sum.

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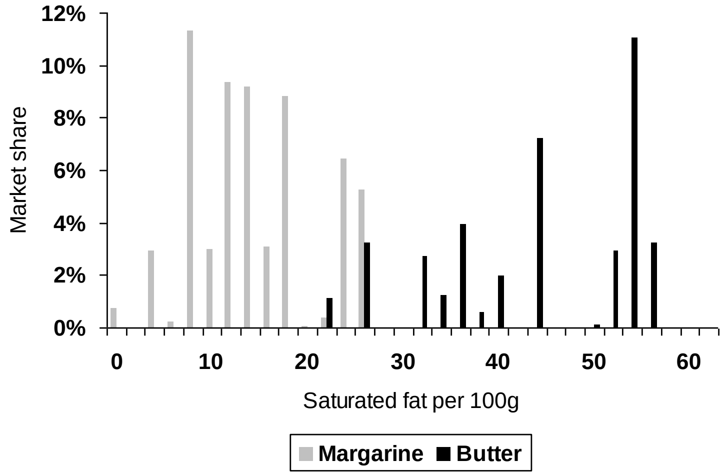
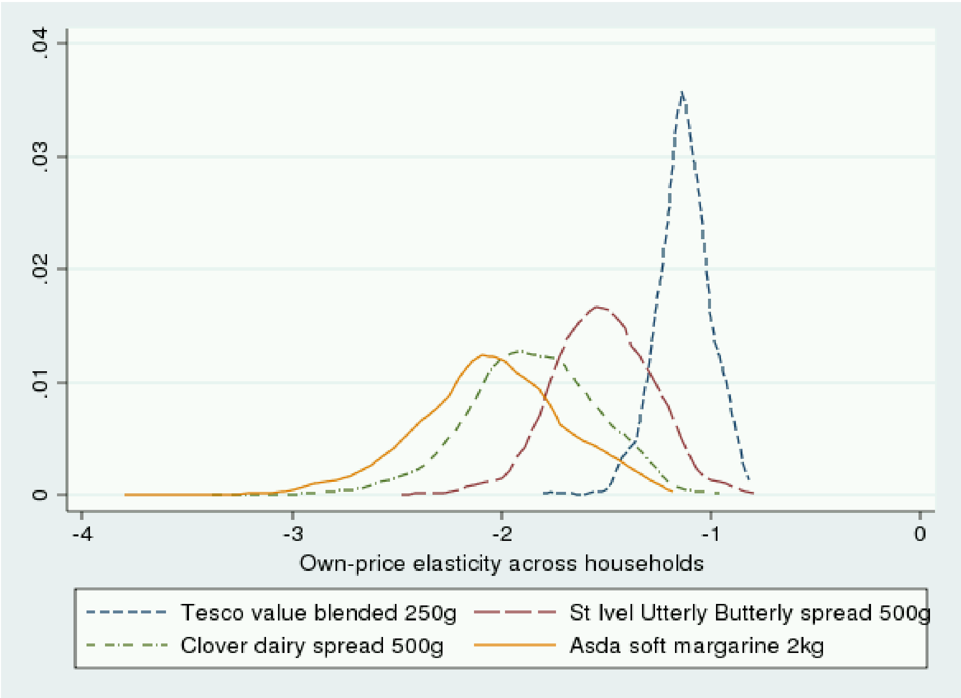
Figure 1: Market shares of butter and margarine, by saturated fat intensity



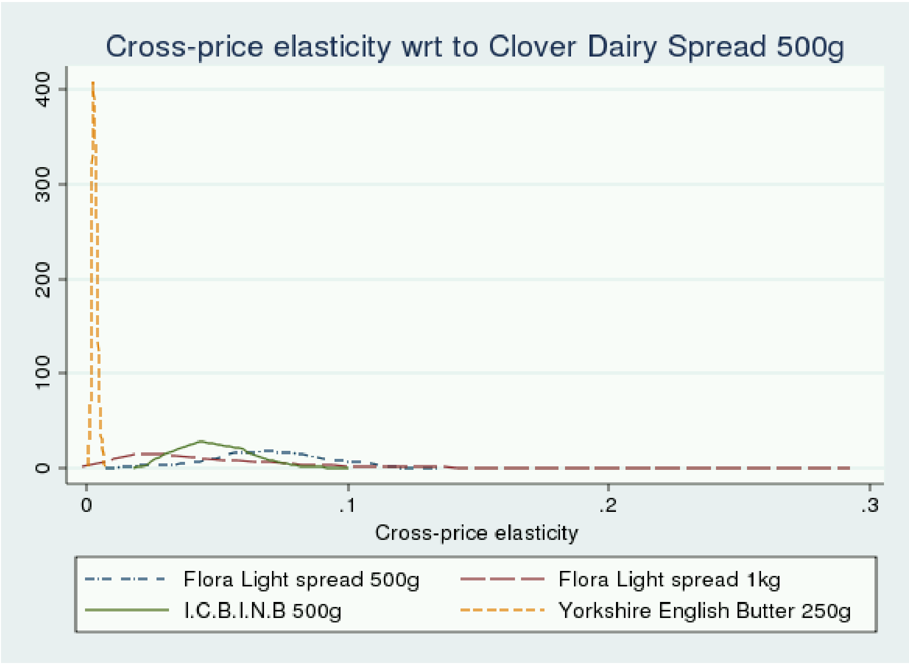
Notes: Market shares are based on a sample of 5,108 observed purchases.

Figure 2: Example distribution of own-price elasticities for 4 products



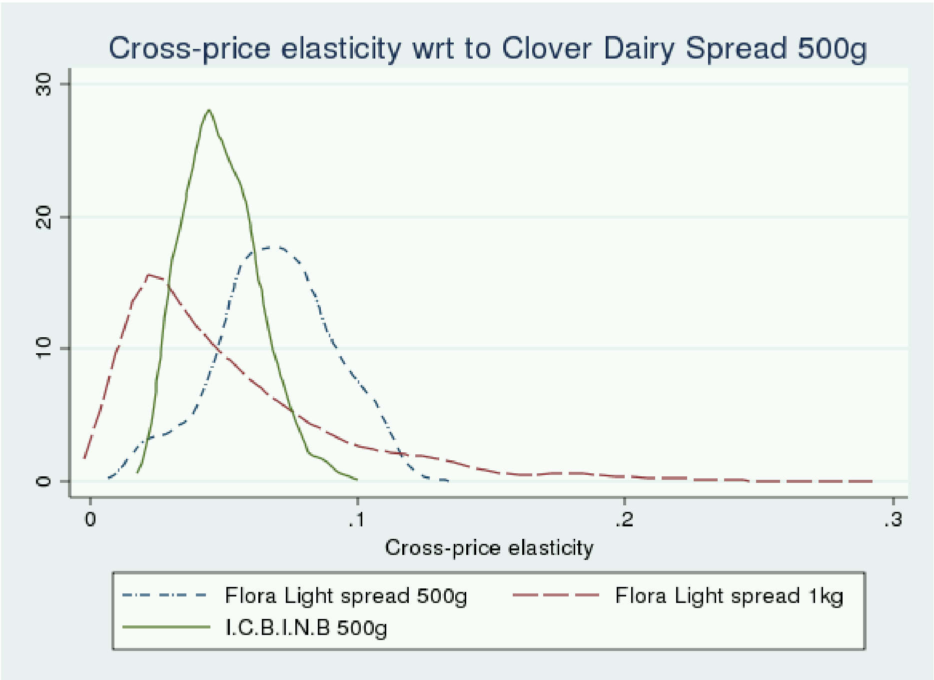
Note: The first three products are the ones with the largest market shares, the last one has the highest own price elasticity. Distribution is of own-price elasticity across households.

Figure 3a: Example distribution of cross-price elasticities



Note: Distribution is of cross-price elasticity across households.

Figure 3b: Example distribution of cross-price elasticities



Note: Distribution is of cross-price elasticity across households.

Figure 4: Change in market shares from a 10p tax on 100g saturated fat

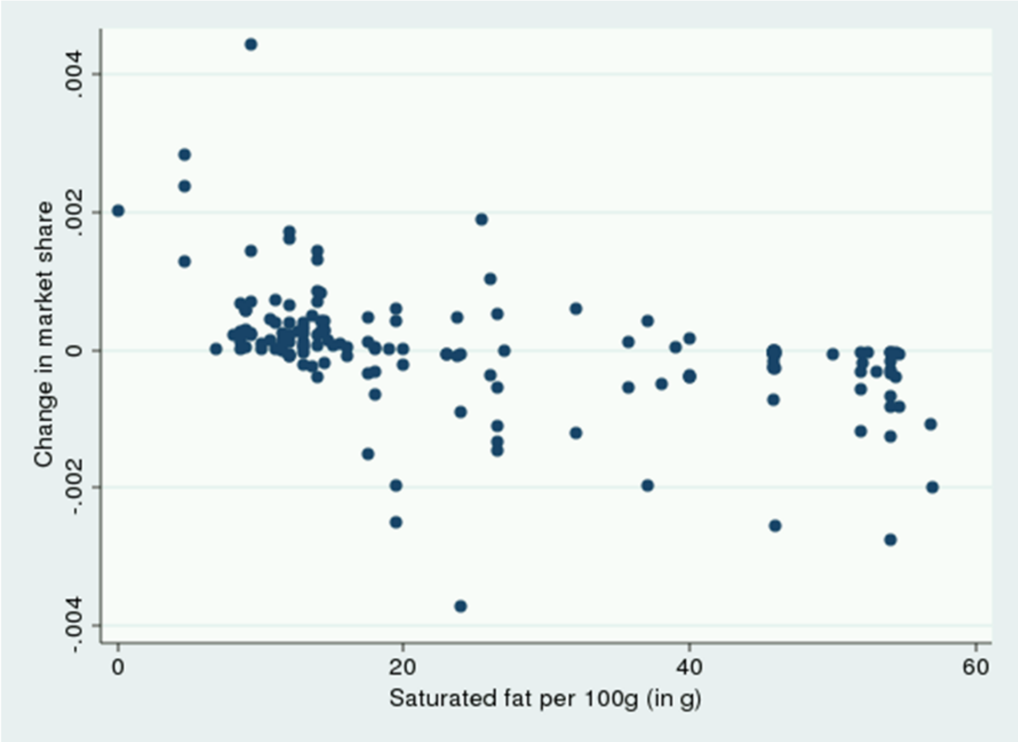
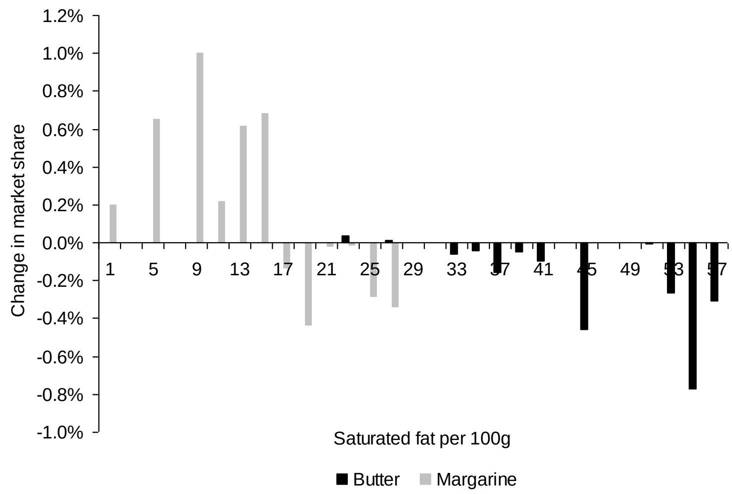
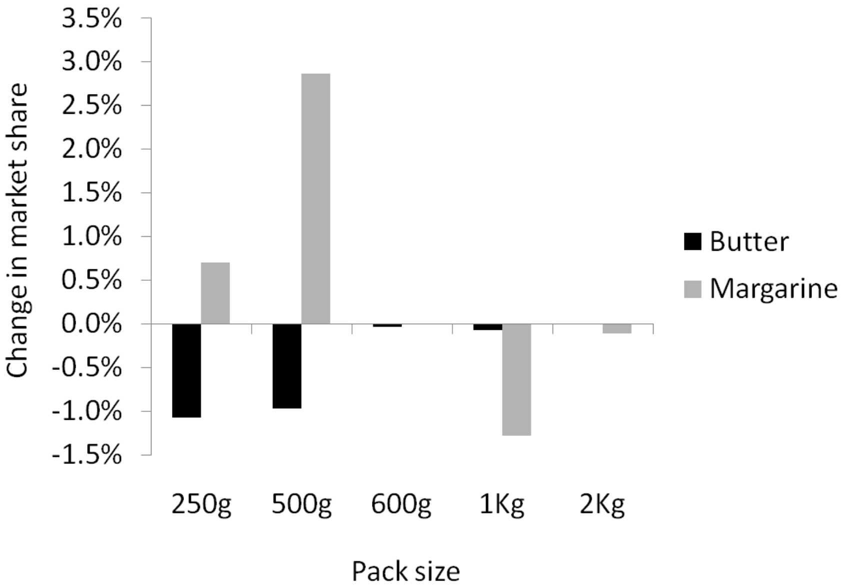


Figure 5: Change in market shares from a 10p tax on 100g saturated fat



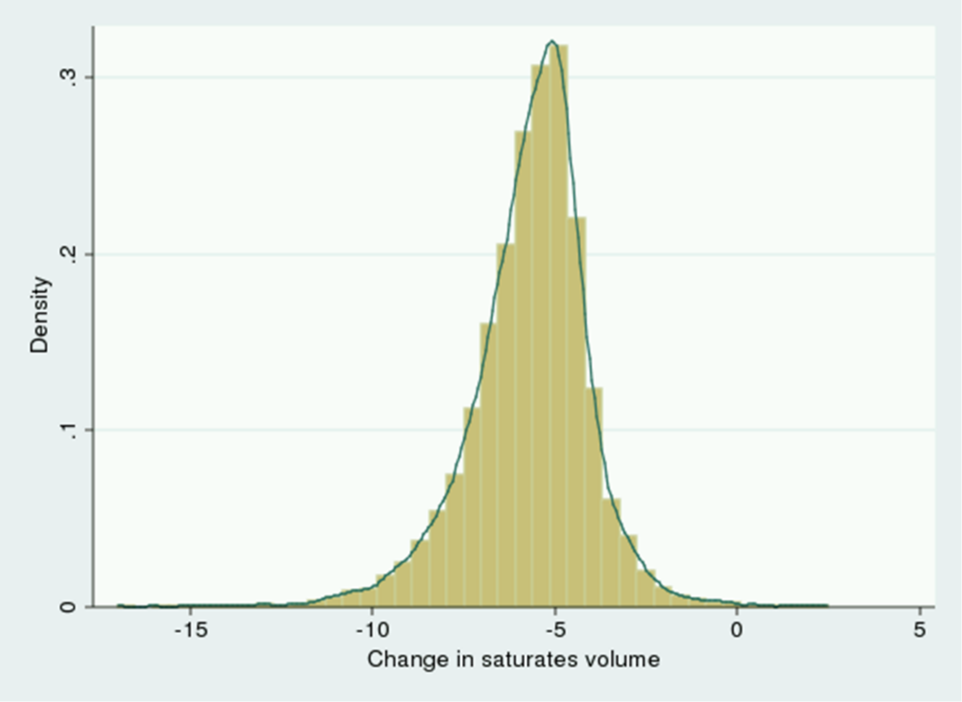
Notes: Market shares are based on predicted values from the estimated model for the 15,746 households in our sample. Market shares are the average of the predicted probability of purchasing that product using predicted values from estimated coefficients reported in Table 4.

Figure 5: Change in market shares of butter and margarine, by pack size



Notes: Market shares are based on predicted values from the estimated model for the 15,746 households in our sample. Market shares

Figure 6: Change in saturated fat purchased across households



Notes: Figures are based on predicted values from the estimated model for the 15,746 households in our sample.

Table 1: Mean values of product characteristics

Product characteristic		Butter	Margarine
Price	(price)	1.07	1.09
		(0.63)	(0.67)
Unit price	(per kg)	3.07	1.88
		(0.734)	(1.34)
Saturated volume	(saturates)	140.45	97.64
		(49.03)	(63.44)
Sodium volume	(sodium)	1.54	3.77
		(0.72)	(1.89)
Pack size 250g	(sz1)	0.71	0.08
		(0.46)	(0.27)
Pack size 500g	(sz2)	0.26	0.64
		(0.44)	(0.48)
Pack size 600g	(sz3)	0.01	0.00
		(0.08)	(0.00)
Pack size 1Kg	(sz4)	0.02	0.27
		(0.15)	(0.45)
Pack size 2Kg	(sz5)	0.00	0.01
		(0.00)	(0.08)
PUFA margarine	(pufa)		0.31
			(0.46)
Healthy margarine	(healthy)		0.25
			(0.43)
Standard margarine	(standard)		0.45
			(0.50)
Budget brand	(budg)	0.24	0.05
		(0.42)	(0.22)
Number of products		58	96

Notes: All means are sales weighted. Standard deviations are in parenthesis.

Table 2: Mean household characteristics, by household type

Household characteristic		Couple with children (cokids)	Single parent (sikids)	Household without children (nokids)	Pensioner household (pens)	Total
Income < £10,000pa	(i1)	0.04	0.36	0.10	0.30	0.13
		(0.20)	(0.48)	(0.30)	(0.46)	(0.34)
£10,000pa < Income < £20,000pa	(i2)	0.20	0.42	0.25	0.46	0.28
		(0.40)	(0.49)	(0.43)	(0.50)	(0.45)
£20,000pa < Income < £30,000pa	(i3)	0.27	0.13	0.25	0.16	0.23
		(0.44)	(0.34)	(0.43)	(0.37)	(0.42)
£30,000pa < Income < £40,000pa	(i4)	0.21	0.06	0.17	0.05	0.15
		(0.41)	(0.24)	(0.37)	(0.22)	(0.36)
Income > £40,000pa	(i5)	0.27	0.03	0.24	0.03	0.20
		(0.45)	(0.17)	(0.43)	(0.16)	(0.40)
Household size	(hhsize)	4.06	2.60	2.14	1.52	2.65
		(0.95)	(0.77)	(0.88)	(0.50)	(1.30)
Main shopper not overweight	(bmi12)	0.43	0.50	0.35	0.34	0.38
		(0.49)	(0.50)	(0.48)	(0.47)	(0.49)
Main shopper overweight	(bmi3)	0.50	0.45	0.60	0.62	0.57
		(0.50)	(0.50)	(0.49)	(0.48)	(0.50)
Main shopper bmi not reported	(bmim)	0.07	0.05	0.06	0.03	0.06
		(0.26)	(0.22)	(0.23)	(0.18)	(0.23)
Household is in south of UK	(south)	0.43	0.48	0.42	0.47	0.43
		(0.49)	(0.50)	(0.49)	(0.50)	(0.50)
Household in social classes A, B or C1		0.48	0.32	0.52	0.36	0.47
		(0.50)	(0.47)	(0.50)	(0.48)	(0.50)
Number of households		4949	623	7211	2981	15764

Notes: Standard deviations are in parenthesis. Whether or not the main shopper is overweight is inferred from self reported measures of height and weight. If the individual's body mass index, equal to weight (in Kg) over height (in m) squared, is over 25 we classify them as being overweight. Since this is self reported we have some missing values in our data. If a household is in the government administrative regions East of England, South East, South West or London we classify it as being in the south of the United Kingdom. Social class is A (upper middle class - higher managerial, administrative or professional), B (middle class - intermediate managerial, administrative or professional) C1 (lower middle class - supervisory or clerical, junior managerial, administrative or professional); the omitted category is C2 (skilled working class - skilled manual workers) D (working class - semi and unskilled manual workers) and E (those at lowest level of subsistence - state pensioners or widows (no other earner), casual or lowest grade workers).

Table 3: Estimated coefficients

	mean	variance	i2	i3	i4	i5	hhsize	cokids	sikids	pens	bmi3	bmim	south	upper
price	**-2.1799**	**1.0277**	**0.3042**	**0.4907**	**0.6488**	**0.8342**	**-0.1545**	-0.0500	0.1988	**0.1754**	0.0827	0.0385	-0.0307	-0.0322
	(0.2172)	*(0.0845)*	*(0.1280)*	*(0.1380)*	*(0.1507)*	*(0.1498)*	*(0.0416)*	*(0.0982)*	*(0.1861)*	*(0.0890)*	*(0.0641)*	*(0.1426)*	*(0.0597)*	*(0.0631)*
saturates	**-0.0103**	0.0000	0.0033	0.0031	0.0005	0.0025	0.0003	-0.0021	-0.0002	0.0002	-0.0003	-0.0007	0.0005	0.0014
	(0.0021)	*(0.0014)*	*(0.0018)*	*(0.0019)*	*(0.0021)*	*(0.0021)*	*(0.0005)*	*(0.0015)*	*(0.0026)*	*(0.0014)*	*(0.0010)*	*(0.0021)*	*(0.0010)*	*(0.0010)*
sodium	-0.0740		-0.0962	**-0.1210**	-0.0494	**-0.2111**	0.0093	**0.1146**	0.0502	**-0.1529**	**0.0732**	**0.1868**	-0.0259	**-0.0643**
	(0.0878)		*(0.0532)*	*(0.0568)*	*(0.0621)*	*(0.0649)*	*(0.0198)*	*(0.0451)*	*(0.0821)*	*(0.0457)*	*(0.0314)*	*(0.0629)*	*(0.0297)*	*(0.0322)*
small							**-0.1910**							
							(0.0436)							
large							**0.2334**							
							(0.0608)							
butter			-0.0822	-0.0536	0.3448	0.1903	0.0599	0.1606	-0.4383	-0.0104	0.1194	0.4578	-0.1450	-0.0228
			(0.2036)	*(0.2176)*	*(0.2414)*	*(0.2462)*	*(0.0704)*	*(0.1817)*	*(0.3225)*	*(0.1739)*	*(0.1217)*	*(0.2543)*	*(0.1169)*	*(0.1251)*
pufa			0.1102	0.0013	0.1034	0.2114	-0.0522	-0.2701	-0.3461	0.1273	0.0088	0.2451	-0.1330	0.0631
			(0.1441)	*(0.1585)*	*(0.1771)*	*(0.1855)*	*(0.0474)*	*(0.1416)*	*(0.2392)*	*(0.1332)*	*(0.0937)*	*(0.1930)*	*(0.0925)*	*(0.0995)*
healthy			0.0929	-0.0068	-0.0657	0.0638	0.0037	-0.1691	-0.4954	-0.0270	0.0461	-0.1625	0.0486	0.1178
			(0.1939)	*(0.2111)*	*(0.2363)*	*(0.2424)*	*(0.0647)*	*(0.1813)*	*(0.3194)*	*(0.1750)*	*(0.1198)*	*(0.2703)*	*(0.1157)*	*(0.1258)*
budget			-0.2630	**-0.5383**	**-0.4191**	**-0.8868**	0.0718							
			(0.1538)	*(0.1665)*	*(0.1817)*	*(0.1852)*	*(0.0390)*							
Pack size	**2.1231**													
500g	*(0.1716)*													
Pack size	0.5340													
600g	*(0.3479)*													
Pack size	**3.3933**													
1Kg	*(0.4107)*													
Pack size	**7.3559**													
2Kg	*(0.8905)*													

Notes: Standard errors are in parenthesis. Coefficients in bold are significant at 5% level. The coefficient in the "mean" column is identified from within brand variation, the "variance" column reports the variance of the random effect. The definitions for the product and household characteristics are given in Tables 2 and 3, expect for "butter" (denotes a butter product), small (pack size 250g) and large (pack size 1kg or 2kg). Fixed effects for 104 brands are included in the regression but are not reported (available from authors on request).

Table 4: Own-price elasticities

Product	Mean	Standard deviation
Morr Soft Marg 2Kg	-2.062	0.348
Asda Soft Marg Tub 2Kg	-2.061	0.353
Tesco Soft Npufa Marg 2Kg	-2.061	0.350
Morr Rdft Sprdble Danish 500Gm	-2.059	0.376
Tesco Spreadable 500Gm	-2.050	0.346
Tsco Olve Gld Rd Ft Spd 1Kg	-2.049	0.385
Pure Org Rdcd Fat Spread 500Gm	-2.046	0.347
Sains Olive Gld Rd Ft Spd 1Kg	-2.045	0.390
Anchr New Zealand 500Gm	-2.041	0.352
Cty.L Spreadable 500Gm	-2.034	0.381
St Ivel Utrly Btrly Dry Spd1Kg	-2.012	0.353
Aldi Spreadable Danish S/S500G	-2.010	0.306
Lrpak S/S Danish 500Gm	-2.008	0.407
Anchr Lghtr Sprdbl Nw Zlnd500G	-2.002	0.407
Anchr Sprdbl Nw Zealand 500Gm	-1.990	0.392
Ob Blended 250Gm	-1.988	0.313
Kerrygold Sprdble Irish 500Gm	-1.988	0.417
Flora Pufa 1Kg	-1.985	0.414
I.C.B.I.N.B Dairy Spread 1Kg	-1.981	0.325
Morrs Better By Far Sprd 1Kg	-1.980	0.298
Lrpak S/S Sprdbl Danish 600Gm	-1.972	0.433
Sains Butterlicious 1Kg	-1.966	0.285
Lrpak Lgtr S/S Sprdb Dan 500Gm	-1.957	0.413
Flora Light Lw Ft Spread 1Kg	-1.955	0.388
Asda Youd Bttr Blv It D/S 1Kg	-1.948	0.277
Lrpak S/S Sprdbl Danish 500Gm	-1.947	0.416
Tesco Butter Me Up Sprd 1Kg	-1.944	0.275
Flora Proactiv Lw Ft Spd 250Gm	-1.936	0.448
Sains Org English Unsltd 250Gm	-1.935	0.272
Smrfld Olive Rdft Sprd 500Gm	-1.930	0.292
Bertolli Olivio Rd Ft Spd500Gm	-1.922	0.299
Yeo Valley Blended Orgnc 250Gm	-1.920	0.293
Tesco Fnst English 250Gm	-1.899	0.261
Gold Omega 3 Light 500Gm	-1.889	0.327
Tesco H/L Light Olive Spd500Gm	-1.875	0.257
Clover Dairy Spread 500Gm	-1.867	0.311
Tesco Fnst French 250Gm	-1.863	0.255
Tesco Sunflower Pufa 1Kg	-1.855	0.271
Sains Sunflwr Pufa 1Kg	-1.855	0.277
Tesco H/L S/Fl Lf/Spd 1Kg	-1.854	0.270
Sains Bgty Olive Gold 500Gm	-1.847	0.275
Mathws Wot Not Btr Sprd 1Kg	-1.837	0.251

Product	Mean	Standard deviation
Flora Proactiv Lf Olvspd 250Gm	-1.837	0.479
Kerrygold Sprdble Irish 250Gm	-1.807	0.237
Pure Sunflower Spread 500Gm	-1.805	0.245
Anchr Lghtr Sprdbl Nw Zlnd250G	-1.800	0.239
Lrpak Lgtr S/S Sprdb Dan 250Gm	-1.793	0.236
Flora Pufa U/S 500Gm	-1.793	0.247
President Frnch Unsalted 250Gm	-1.791	0.239
Lrpak S/S Sprdbl Danish 250Gm	-1.790	0.236
Morr Sunflower Pufa 1Kg	-1.786	0.246
Bertolli Olivio Rd Ft Spd 1Kg	-1.785	0.479
Morr Olve Rdft Sprd 500G	-1.784	0.256
Lrpak U/S Danish 250Gm	-1.784	0.236
Flora Diet 500Gm	-1.783	0.240
Clover Dairy Spread 250Gm	-1.776	0.241
Obpl Blended 250Gm	-1.773	0.234
Flora Buttery 500Gm	-1.771	0.244
Flora Pufa 500Gm	-1.770	0.246
Lrpak S/S Danish 250Gm	-1.769	0.230
Cty.L Spreadable 250Gm	-1.766	0.232
Netto Olive Rd Ft Spd 500Gm	-1.761	0.386
Anchr Sprdbl Nw Zealand 250Gm	-1.758	0.243
Asda Nat Snflwr Pufa Tub 1Kg	-1.742	0.254
Lrpak Sprdbl Danish U/S 250Gm	-1.742	0.268
Stork Sb Tub Marg 1Kg	-1.729	0.220
Sains Olive Gld Rd Ft Spd500Gm	-1.716	0.226
Asda Orgnc English S/S 250Gm	-1.716	0.215
Flora Light Lw Ft Spread 500Gm	-1.714	0.237
Tsc Organic Danish 250G	-1.705	0.214
Tsco Olve Gld Rd Ft Spd 500Gm	-1.699	0.222
Coop Buttery Spread 500Gm	-1.699	0.239
Clover Dairy Spread 1Kg	-1.694	0.519
Willow Dairy Spread 2X250Gm	-1.691	0.225
Asda Olive Gold Rd Ft Spd500Gm	-1.689	0.225
Ob English 250Gm	-1.663	0.236
Gold Light 500Gm	-1.616	0.270
Smrfld English S/S 250Gm	-1.606	0.200
Bertolli Olivio Rd Ft Spd250Gm	-1.599	0.201
Smrfld U/S English 250Gm	-1.597	0.237
Gold Lowest Extra Light 500Gm	-1.597	0.283
Sains English Unsalted 250Gm	-1.597	0.194
Anchr New Zealand 250Gm	-1.593	0.204
Cty.L Standard Unsalted 250Gm	-1.590	0.200

Product	Mean	Standard deviation
Co-Op Creamery Blended 250Gm	-1.587	0.198
Morrs Better By Far Sprd 500Gm	-1.586	0.197
Pure Soya Spread 500Gm	-1.585	0.199
Sains Butterlicious 500Gm	-1.585	0.203
Yorkshire English 250Gm	-1.574	0.210
Ob Scottish 250Gm	-1.569	0.188
Asda Youd Bttr Blv It D/S500Gm	-1.565	0.203
Tesco Butter Me Up Sprd 500Gm	-1.556	0.209
I.C.B.I.N.B Dairy Spread 500Gm	-1.554	0.266
Waitrose English 250Gm	-1.554	0.185
Vitalite Pufa 500Gm	-1.547	0.193
Kerrygold Std Irish 250Gm	-1.528	0.189
St Ivel Utrly Btrly D/Spd500Gm	-1.527	0.236
Benecol Veg Spread 250Gm	-1.520	0.544
Cty.L Standard 250Gm	-1.482	0.183
Lidl Olive Gold Rd Ft Spd500Gm	-1.466	0.172
Aldi Olive Gold Rd Ft Spd500Gm	-1.466	0.171
Lidl Sprdable English S/S 250G	-1.464	0.170
Flora Pufa 250Gm	-1.459	0.186
Flora Light Lw Ft Spread 250Gm	-1.414	0.196
Mntn Maid Blended 250Gm	-1.405	0.164
Sains Blended S/S 250Gm	-1.389	0.158
Aldi Beautifully Btrflly 500Gm	-1.382	0.166
Lidl Veg Spread 500Gm	-1.380	0.167
Morrs English 250Gm	-1.324	0.167
Sains Olive Gld Rd Ft Spd250Gm	-1.314	0.154
Ob Danish 250Gm	-1.312	0.147
Willow Dairy Spread 250Gm	-1.292	0.151
Asda Creamery Blended 250Gm	-1.285	0.143
Tesco Creamery Blended 250Gm	-1.282	0.142
Tsco Olve Gld Rd Ft Spd 250Gm	-1.282	0.154
Tesco Lw Chlstrl Snflwr 500Gm	-1.274	0.173
Sains Ble Lbl Pkt Marg 500Gm	-1.273	0.144
Morr Pkt Marg 500Gm	-1.271	0.145
Tesco H/L S/Flw L.F.Spd 500Gm	-1.269	0.167

Product	Mean	Standard deviation
Sains Sunflwr Pufa 500Gm	-1.267	0.177
Tesco Baking Pkt Marg 500Gm	-1.267	0.155
Sains Bgty Snflw Lt Rd Fs 500G	-1.243	0.181
Sains Butterlicious 250Gm	-1.240	0.196
Aldi Blended 250Gm	-1.207	0.133
Lidl Slghtly Sltd German 250Gm	-1.207	0.131
Hollybush English 250Gm	-1.203	0.133
Morr Btr For You Sflwr Sp500Gm	-1.201	0.152
Morr Sunflower Pufa 500Gm	-1.200	0.153
Morrs Bttby English 250Gm	-1.196	0.130
Sains Bsc English 250Gm	-1.193	0.130
Asda Sp Oth Blended 250Gm	-1.177	0.127
Asda Gfy Lf Snflower Spd 500Gm	-1.153	0.163
Asda Nat Snflwr Pufa Tub 500Gm	-1.150	0.163
Tesco Value Blended 250Gm	-1.141	0.128
Asda Best For Bkng Mrg Tb500Gm	-1.128	0.160
Tesco Value Npufa Sft Spd 1Kg	-1.118	0.116
Stork Sb Npufa Marg 500Gm	-1.083	0.121
Lidl Snflwr Low Fat Sprd 500Gm	-1.046	0.122
Morr Soft Marg 500Gm	-0.998	0.108
Aldi Sl Snflwr Lw Ft Spd 500Gm	-0.945	0.098
Lidl Gldn Sn Snflw Lw Ft 500Gm	-0.942	0.098
Tesco Value Snflwr Pufa 500Gm	-0.921	0.097
Netto Snflwr Lw Ft Spd 500Gm	-0.861	0.114
Stork Pkt Marg 250Gm	-0.751	0.086
Bttaby Soft Spread 500Gm	-0.683	0.082
Netto Veg Spread 500Gm	-0.619	0.061
Sains Bsc R/Ft Sft Sprd 500Gm	-0.618	0.061
Asda Sp Rdcd Ft Sprd 500Gm	-0.614	0.061
Lrpak S/S Sprdbl Danish 1Kg	0.008	0.641
Lrpak Lgtr S/S Sprdb Dan 1Kg	0.022	0.659
Flora Proactiv Lw Ft Spd 500Gm	0.106	0.606
Benecol Light Spread 500Gm	0.788	0.657
Flora Proactiv Lf Olvspd 500Gm	0.942	0.968
Benecol Olive Spread 500Gm	0.969	0.717

Table 5: Average effect of tax across all households

	Initial value	Absolute change	Standard deviation	Percentage change
Intensity				
Saturated fat (in g)	27.13	-1.03	0.23	-3.8%
Sodium (in g)	0.55	-0.001	0.001	- 0.2%
Volume				
Saturated fat (in g)	114.23	-5.68	1.61	-5.0%
Sodium (in g)	2.83	-0.06	0.05	-2.0%
Expenditure (in p)	1.08	0.09	0.01	+ 8.8%

Notes: We calculate the predicted nutrient intensity and volume and expenditure for each of the 15,764 households in our sample, prior to and following the imposition of the 'fat tax'. Column one presents the initial values based on the pre-tax prediction and the remaining columns present summary statistics for the change in these values across all households in response to the tax.

Table 6: Average effect on nutrient intensity, by household type

Household characteristic	**Saturates intensity**			**Sodium intensity**			**Number of households**
	Initial value	**Absolute change**	**Std. dev.**	**Initial value**	**Absolute change**	**Std. dev.**	
Household income							
Inc <10k	26.58	-1.20	0.23	0.57	0.00	0.00	2048
10k<Inc <20k	27.01	-1.08	0.22	0.56	0.00	0.00	4451
20k<Inc <30k	26.93	-1.00	0.20	0.56	0.00	0.00	3684
30k<Inc <40k	27.27	-0.93	0.20	0.55	0.00	0.00	2419
Inc>40k	27.77	-0.96	0.21	0.53	0.00	0.00	3162
Family type							
Couple with children	26.25	-0.98	0.20	0.57	0.00	0.00	4949
Single parent	24.83	-0.85	0.18	0.58	0.00	0.00	623
Household without children	27.41	-1.03	0.23	0.55	0.00	0.00	7211
Pensioner household	28.36	-1.12	0.24	0.53	0.00	0.00	2981

Notes: Table shows effect of fat tax on nutrient intensity by household type.

Table 7: Average effect on nutrient volume, by household type

Household characteristic	**Saturates volume**			**Sodium volume**			**Number of households**
	Initial value	**Absolute change**	**Std. dev.**	**Initial value**	**Absolute change**	**Std. dev.**	
Household income							
Inc <10k	104.72	-5.56	1.38	2.76	-0.05	0.05	2048
10k<Inc <20k	113.28	-5.98	1.72	2.86	-0.06	0.05	4451
20k<Inc <30k	116.77	-6.09	1.66	2.94	-0.07	0.05	3684
30k<Inc <40k	117.02	-5.43	1.42	2.92	-0.06	0.04	2419
Inc>40k	116.62	-5.04	1.38	2.66	-0.04	0.02	3162
Family type							
Couple with children	120.72	-6.98	1.61	3.23	-0.10	0.05	4949
Single parent	116.93	-6.14	1.36	3.26	-0.10	0.04	623
Household without children	112.74	-5.26	1.20	2.71	-0.04	0.02	7211
Pensioner household	106.48	-4.46	0.84	2.39	-0.02	0.01	2981

Notes: Table shows effect of fat tax on nutrient volume by household type.