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Demand drivers and changes in food-related emissions in the UK: A decomposition approach

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Abstract

UK food-related greenhouse gas emissions have substantially decreased over the last two decades in response to changes in the household food baskets. The evolution of diets depends on a combination of driving forces, not necessarily acting in the same direction. We propose a decomposition of household food choices which separates changes in tastes and consumer preferences from the effects of prices, household budgets, and socio-demographic trends. More specifically, we explore to what extent these drivers facilitate or hinder the adoption of sustainable food choices. Our decomposition strategy is grounded on a theory-consistent demand system to account for substitution effects across food groups. We find that the decline in UK food-related emissions is primarily driven by reductions in household food budgets and evolving food preferences. Relative price dynamics and demographic trends act in the opposite direction, but their effect is small. Our evidence suggests that policy interventions aiming to shape consumer preferences towards more sustainable choices could be a valid instrument to further reduce food-related emissions in the UK.

JEL classification: D12, Q18, Q51

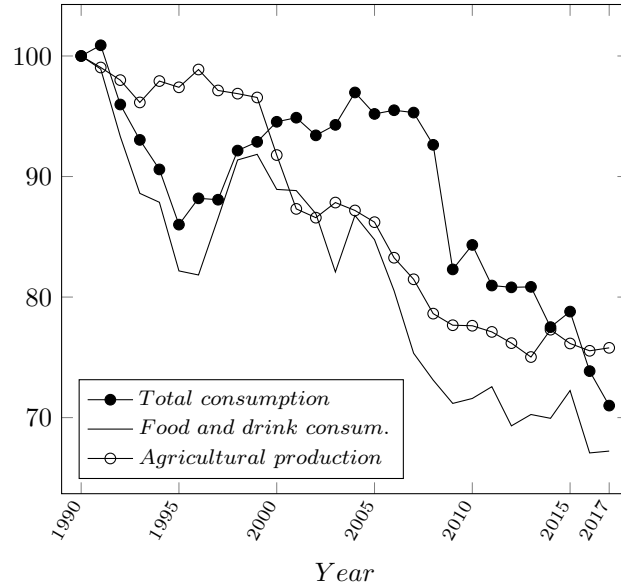
Keywords: Greenhouse Gas Emission; Food Choices; Preference; Price; Sustainability; Food Policy.

1 Introduction

Between 2000 and 2019 total domestic (territorial) greenhouse gas emissions (GHGEs) in the United Kingdom (UK) have fallen by 36.8%, and the decrease in per capita emissions is even larger (-44.3%), given the UK population growth over the same period ([National Statistics, 2021](#)). In absolute terms, this corresponds to a per capita reduction of 5.4 tonnes of carbon dioxide equivalent (CO₂e) per year, a major achievement if one considers that in 2015 UK GHGEs accounted for 1.14% of global emissions ([Crippa et al., 2019](#)). UK carbon footprints estimates of total food and drink consumption also indicate a reduction in GHGEs between 2000 and 2017 (-24.4%, [DEFRA, 2020](#)). Per capita emissions from food and drink consumption were about 1.19 tonnes CO₂e per year in 2017, or 12.7% of total consumption emissions. One key difference exists between territorial GHGEs and carbon footprints, as the former only accounts for domestic emissions (including those for exported goods), whereas the latter refers to estimates of emissions associated with UK food consumption, whatever the food origin. Regardless of the production or consumption perspective, the UK has been successful in reducing food-related GHGEs over the last two decades.

Figure 1 shows per capita GHGE trends (indexed at 1990=100) for (a) total emissions from human consumption (any good); (b) emissions from food and drink consumption; and (c) agriculture-related GHGEs. Estimates show that UK consumption-related GHGEs have declined faster for food and drinks, not only relative to the overall consumer basket, but also with respect to production-related agriculture GHGEs. On the other hand, the 2008 financial crisis has generated a steep decline in overall consumption-related emissions which was

Figure 1: Per capita consumption-driven GHGEs¹ (total vs food and drinks) and agricultural production-driven GHGEs²: 1990-2017 UK trends (1990=100)



¹ Department for Environment, Food & Rural Affairs (DEFRA, 2020)

² National Statistics (National Statistics, 2021)

1 still ongoing in 2017, whereas the decline in food-related emissions has become
2 slower after 2012. More specifically, total per capita consumption-related emis-
3 sions have fallen by 23.3% between 2008 and 2017, against a decrease of 8% for
4 food and drinks. Thus, a key question is whether there is still room for policies
5 to further reduce emissions from food and drink consumption. Answering such
6 question requires an exploration of the drivers of food and drink consumption.
7 The present study aims at exploring the determinants of the changes in UK food-
8 related GHGEs. More specifically, our goal is the decomposition of changes in
9 total food-related GHGEs into different components associated with evolving
10 consumer preferences, price dynamics, changes in household food budgets, and
11 demographic trends. The innovation in our approach lies in the explicit con-
12 sideration of changes in consumer preferences. For the empirical analysis, our
13 study takes into account GHGEs from food and drink purchased in the UK over

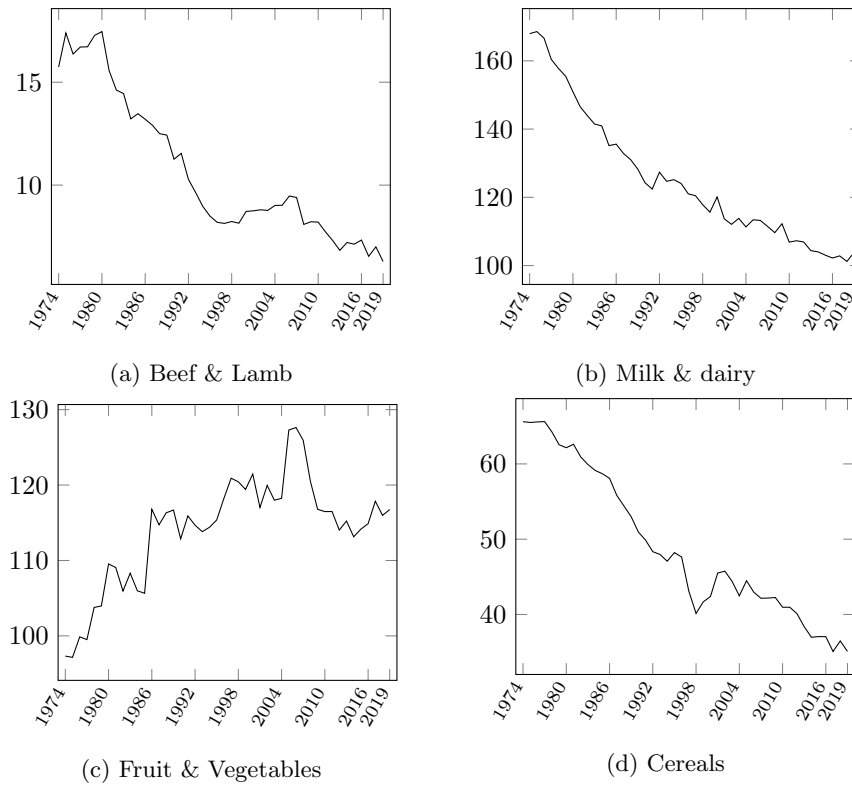
1 the years between 2001 and 2015.
2 Understanding how the considered factors contribute to the observed reduction
3 in diet-related emissions supports the adoption of effective policies, and improves
4 coordination between nutrition and sustainability targets. Many aspects (often
5 competing) need to be considered when designing interventions to influence food
6 choices (Lang and Mason, 2018; Zhang and Wang, 2017). For example, informa-
7 tion and education measures promoting more sustainable choices act through
8 changes in consumer preferences and attitudes. However, if the cost of sustain-
9 able food baskets is higher, sustainable choices may be discouraged, especially
10 for low income households. In this case, well calibrated policies changing rela-
11 tive prices or targeted income support actions would be effective. In fact, we
12 aim to test whether the evolution of relative prices may have favoured the choice
13 of less sustainable food and drink products.

14 **2 Trends in UK food and drink purchases and** 15 **their determinants**

16 The major structural changes observed in food and drink purchases over time
17 have a major impact on the evolution of the UK food carbon footprint. Figure
18 2 displays the trends in per capita purchases of selected food groups between
19 1974 and 2019. Beef and lamb purchases have declined since the Eighties, and
20 the 2019 consumption levels were slightly above one third of those observed in
21 1980. Milk and dairy products have also undergone a regular reduction, with
22 a steep descent until the 1990s and a slower but regular one afterwards. The
23 decrease in consumption of animal products is only partially compensated by

1 growing consumption in other categories. Fruit and vegetable purchases have
 2 increased by 31% between 1974 and 2006, then decreased by 8.5% since then.
 3 Consumption of cereal products has also steadily declined, and the 2019 levels
 4 are almost half of those of 1974. Indeed, considering the most recent DEFRA
 5 (2020) family food statistics, the total quantity of purchased foods was 11.2%
 6 lower in 2019 relative to 1974.

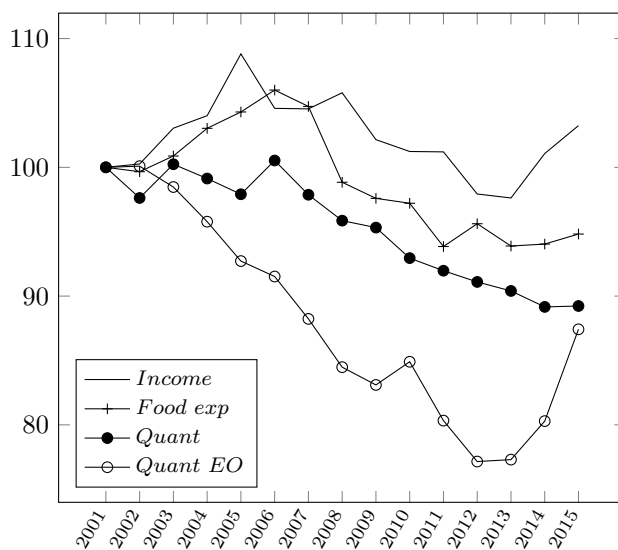
Figure 2: Trends in per capita consumption of specific foods, ($\text{kg person}^{-1} \text{ year}^{-1}$) (DEFRA, 2020)



7 The fact that UK residents are eating less – or wasting less – food at home
 8 had been observed before (see e.g. Griffith et al., 2016), together with some
 9 evidence that this decrease is not explained with substitution with out-of-home
 10 food consumption. Figure 3 displays trends in real household income, food
 11 expenditure, and food purchases for home and eating out consumption, over

1 the period 2001-2015. Before the onset of the 2008 financial crisis, purchases for
 2 home consumption and household income have followed similar patterns. From
 3 2008, the crisis has reduced purchases, whereas the effects on incomes become
 4 visible with a year delay. Furthermore, the impact is much stronger on real
 5 food budgets compared to income: in 2007, both measures were 5% higher
 6 than their 2001 value, in 2015 household income had recovered to a level which
 7 was 3% higher than 2001, whereas real food expenditure was still 5% lower.
 8 Estimates on eating out quantities show a regular decline until 2009, then they
 9 closely follow income changes, with a sharper fall during the recession years,
 10 and a recovery towards the end of the period.

Figure 3: Household income¹ deflated by general CPI²; Food expenditure¹ deflated by food CPI²; Food quantity purchased per household¹; Food quantity per capita eaten out¹ (2001=100)



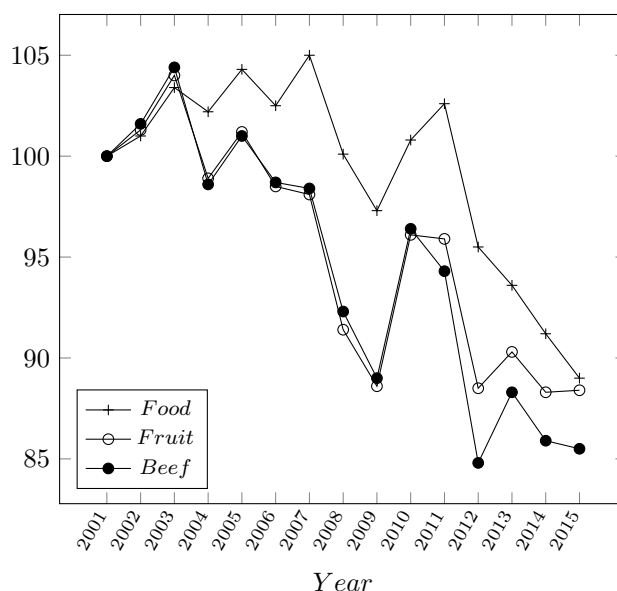
¹ Our estimates using Expenditure and Food Survey, and Living Cost and Food Survey data (DEFRA, 2019);

² Office for National Statistics

11 Thus, the evidence points towards reduced emissions because of lower overall
 12 consumption. Over the last two decades this trend seems to be closely associated

1 with the evolution of purchasing powers. It remains an open question whether
 2 and how other forces like prices, consumer preferences and demographic changes
 3 have acted on food-related emissions.
 4 Figure 4 shows the evolution of the real price indices for food as a whole, fruit
 5 and beef. Relative to the overall index, food has been more expensive until 2012,
 6 with a single exception in 2009. Between 2012 and 2015, average food prices
 7 have sharply declined. What especially matters to substitutions, however, is the
 8 relative price of individual foods. For example, beef and fruit retail prices have
 9 moved simultaneously until 2010 and they have been systematically cheaper
 10 than the average food. In 2011 the two price indices have started to diverge,
 11 with fruit becoming relatively more expensive. In our study we explore to
 12 what extent changes in relative prices have influenced substitutions within the
 13 food basket, which in this specific case would favour more emission-intensive
 14 consumption.

Figure 4: Real retail price indexes (2001=100)^a



^a Source: ONS UK; Food, Fruits and Beef RPI are expressed in relative terms, with respect to the all-items RPI.

1 **3 Methodology**

2 The identification of components and drivers of changes in emission sources has
3 been the subject of study especially in the energy economics field (see [Wang](#)
4 [et al., 2017](#)). Fewer studies look at the decomposition of food-related emis-
5 sions (see e.g. [Hawkins et al., 2018](#)), and to the best of our knowledge they
6 are not based explicitly on demand modelling. Regardless of the sustainability
7 focus, several studies have looked at the relative contribution of prices and in-
8 comes, and less frequently demographics, in explaining changes in demand for
9 specific goods. These studies generally assume constant consumer preferences
10 (i.e. constant model parameters) over the considered time span. For example,
11 [Heien and Wessells \(1988\)](#) assume constant elasticities to decompose changes
12 in US demand for dairy products over the period 1948-1984. Similarly, [Nelson](#)
13 [\(1997\)](#) explores the relative weight of prices, income and demographics in ex-
14 plaining the evolution of US alcohol consumption between 1980 and 1990, again
15 assuming a constant-parameter demand model over the decade¹. A more com-
16 prehensive modelling strategy is proposed in [Karagiannis and Velentzas \(2004\)](#),
17 who quantify the contribution of price, income and habits to changes in con-
18 sumer demand for five very aggregate consumption categories, using a dynamic
19 demand system. Again, their decomposition is obtained by assuming constant
20 coefficient models, so that elasticities depend on expenditure shares, but prefer-
21 ences are held constant. The possibility of evolving preferences is considered in
22 [Selvanathan and Selvanathan \(2004\)](#) who allow for a linear trend in a demand
23 model for Australian alcohol consumption. Indeed, even with this simple time-

¹The study actually allows for some basic structural change in the demand model over a longer time window – a shift in the intercept – but makes no attempt to relate these changes to those in the economic and demographic determinants

1 changing intercept, they find preference effects to be significant and substantial.

2 A closer attempt to allow for time-varying preferences is the study by [Okrent](#)
3 [and Macewan \(2014\)](#) on the demand for non-alcoholic beverages in the US. They
4 consider advertising expenditure as an additional factor in the demand model,
5 consistently with the idea that preferences and tastes can be influenced by in-
6 formation and promotion actions. However, when simulating demand changes
7 over two sub-samples to capture relative contributions before and after the 2008
8 recession, this study also assumes constant (average) elasticities.

9 The assumption of constant demand coefficients simplifies the identification of
10 the various drivers, but it is also a major limitation. While one might assume
11 that preference changes are fully captured by demographics, this is hardly credi-
12 ble over long periods of time where tastes are known to evolve, also as a result of
13 information and advertising, or to adjust to policy changes. We propose a strat-
14 egy which allows all model coefficients to evolve over different time windows,
15 and we explicitly account for this preference change at the decomposition stage.

16 Our decomposition is grounded on microeconomic theory. Greenhouse gas food-
17 related emissions are broken down into determinants directly related to social,
18 economic and demographic factors. Utility-maximising consumers make their
19 food and drink choices based on tastes and preferences, including attitudes to-
20 wards their environmental sustainability, but their final allocation also depends
21 on market prices and is subject to budget constraints. We exploit variation in
22 choices across households and over time to estimate the relative contribution of
23 the different forces driving food-related emissions.

1 **3.1 Decomposing demand change into preference and socio-** 2 **economic determinants**

The decomposition follows an empirical comparative statics approach. Consider a generic demand function:

$$C = \alpha + \beta X \tag{1}$$

3 where C is the consumption level and $X = [P, Y, D]$ is the set of socio-economic
4 determinants, i.e. prices (P), income (Y) and demographics (D). The coefficient
5 vector $\Theta = [\alpha, \beta]$ stems from a consumer preference structure (i.e. tastes), as
6 represented by her utility function. Consumers change their food and drink
7 choices over time not only as a result of changing tastes, but also in response to
8 variations in other determinants. If we consider two time periods, consumption
9 in each period is the outcome of different values of Θ and X :

$$10 \quad C_1 = \alpha_1 + \beta_1 X_1 \tag{2}$$

$$11 \quad C_0 = \alpha_0 + \beta_0 X_0 \tag{3}$$

12 Let us define ΔC as the change in consumption between the two time periods:

$$13 \quad \Delta C = C_1 - C_0 = \alpha_1 - \alpha_0 + \beta_1 X_1 - \beta_0 X_0 \tag{4}$$

14 We can decompose ΔC into two main effects: (a) change in preferences Θ , and
15 (b) change in the socio-economic determinants X . By adding and subtracting

1 $\beta_1 X_0$ on the right-hand side of (4), the equation can be rewritten as:

$$2 \quad \Delta C = \underbrace{\alpha_1 - \alpha_0 + X_0(\beta_1 - \beta_0)}_{\text{preference change effect}} + \underbrace{\beta_1(X_1 - X_0)}_{\text{determinants change effect}} \quad (5)$$

3 Equation (5) shows that the preference change reflects the difference in the
 4 coefficients, while holding constant the set of determinants at their value at
 5 time 0. Instead, the contribution of the changing determinants towards the new
 6 level of consumption C_1 depends on the coefficients β at time 1².

7 **3.2 Decomposition using the AIDS specification**

8 We decompose evolving demand based on the flexible specification of the Almost
 9 Ideal Demand System (AIDS, [Deaton and Muellbauer, 1980](#)), which consists in a
 10 set of related Marshallian demand equations and allows to consider substitutions
 11 across foods and drinks in response to changing preferences and consumption
 12 determinants.

13 The generic demand equation $w_i(\mathbf{p}_t, x_t, P_t, \mathbf{d}_t | \Theta_t)$ for a good i in a basket of N
 14 goods, based on consumer preferences at time t with data on $t = 1, \dots, T$ time
 15 periods, is specified as follows:

$$16 \quad w_{it} = \tilde{\alpha}_{it} + \sum_j \gamma_{ijt} \ln p_{jt} + \beta_{it} \ln \frac{x_t}{P_t} \quad (6)$$

17 where $w_{it} = \frac{p_{it} \cdot q_{it}}{x_t}$ is the share of household food and drink budget devoted
 18 to the i -th good; x_t is the total food and drink budget; $\mathbf{p}_t = [p_{jt}]_{j=1, \dots, N}$ is
 19 a vector containing the prices of the N goods at time t ; q_{it} is the quantity of

²The choice of the reference point has to be explicit, as one might instead consider the set of determinants at time 1 by adding and subtracting $\beta_0 X_1$.

1 good i purchased at time t . Demographic variables enter the model through the
 2 following intercept specification³:

$$3 \quad \tilde{\alpha}_{it} = \alpha_{it} + \lambda_{it} \mathbf{d}_t \quad (7)$$

4 where \mathbf{d}_t is a vector of socio-demographic household characteristics. The price
 5 index P_t is defined as follows:

$$6 \quad \ln P_t = \alpha_0 + \sum_k \tilde{\alpha}_{kt} \ln p_{kt} + \frac{1}{2} \sum_j \sum_k \gamma_{kjt} \ln p_{kt} \ln p_{jt} \quad (8)$$

7 Note that socio-demographic characteristics and their coefficients also appear in
 8 the non-linear price index through $\tilde{\alpha}_{kt}$. Considering estimates for all N goods
 9 in the system, the matrix of coefficient vectors $\Theta_t = [\alpha_t, \beta_t, \gamma_t, \lambda_t]$ represents
 10 the household preference structure at time t .

11 Changes over time in the budget shares of each good in the AIDS model in (6)
 12 can be decomposed into a preference effect and individual effects for each deter-
 13 minant (prices, total budget and socio-demographics) as described by Equation
 14 5. Considering two time periods ($t = 0, 1$), and following the AIDS specification,
 15 these effects can be expressed as follows:

$$16 \quad \begin{aligned} E_{price,i} &= w_i(\mathbf{p}_1, x_1, P_1, \mathbf{d}_1 | \Theta_1) - w_i(\mathbf{p}_0, x_1, P_0, \mathbf{d}_1 | \Theta_1) \\ &= \underbrace{\sum_j \gamma_{ij1} (\ln p_{j1} - \ln p_{j0})}_{\text{substitution effect}} + \underbrace{\beta_{i1} (\ln P_{0,\Theta_1} - \ln P_{1,\Theta_1})}_{\text{income effect}} \end{aligned} \quad (9)$$

³As discussed in Alston et al. (2001) augmenting the AIDS intercept with shifters potentially violates closure under unit scaling, i.e. coefficient estimates may vary depending on the units of measurement. We show in Section 4.5 that our decomposition is empirically robust to changes in the measurement unit.

1 where $\mathbf{p}_t = [p_{jt}, j = 1, \dots, N]$ is the vector of prices of all goods observed in
 2 period t , x_t is the total household food and drink budget, \mathbf{d}_t is the vector
 3 containing the household socio-demographic characteristics, and P_{s, Θ_t} is the
 4 non-linear price index defined in (8), computed using price data at time s and
 5 the household preference structure at time t .

6 More simply put, the price effect is quantified by taking the difference between
 7 the budget share evaluated with data and preferences at time 1 and the same
 8 budget share, but with prices held fixed at time 0. The interpretation is straight-
 9 forward, as the price effect captures the difference between the budget share at
 10 time 1 and the budget share that would have been observed at time 1 had the
 11 prices remained constant at their level at time 0. The two addends in (9) reflect
 12 the two different effects of a price change under the law of demand. The change
 13 in relative prices (first term) leads to substitution effects across goods (here-
 14 inafter $E_{price,i}^{subs}$). Nevertheless, changes in price levels, as captured by the price
 15 index in (8), also affect household purchasing powers (income effect, $E_{price,i}^{inc}$).

16 Using the same strategy, we derive nominal expenditure and socio-demographics
 17 determinants as:

$$\begin{aligned}
 E_{expen,i}^{nominal} &= w_i(\mathbf{p}_1, x_1, P_1, \mathbf{d}_1 | \Theta_1) - w_i(\mathbf{p}_1, x_0, P_1, \mathbf{d}_1 | \Theta_1) = \beta_{i1}(\ln x_1 - \ln x_0) \\
 E_{demo,i} &= w_i(\mathbf{p}_1, x_1, P_1, \mathbf{d}_1 | \Theta_1) - w_i(\mathbf{p}_1, x_1, P_1, \mathbf{d}_0 | \Theta_1) = \lambda_{i1}(\mathbf{d}_1 - \mathbf{d}_0)
 \end{aligned}
 \tag{10}$$

19 The expressions in (10) reflect the difference between the budget share at time 1
 20 and what would have been observed at time 1 had nominal expenditure (socio-
 21 demographic variables) remained constant at their level at time 0. Combining
 22 the nominal expenditure effect in (10) and the income effect of price changes in

1 (9) returns the overall effect of changes in household purchasing powers:

$$2 \quad E_{expen,i}^{real} = E_{expen,i}^{nominal} + E_{price,i}^{inc} = \beta_{i1} \left(\ln \frac{x_1}{P_{1,\Theta_1}} - \ln \frac{x_0}{P_{0,\Theta_1}} \right) \quad (11)$$

3 Finally, we define the effect of changes in the preference structure as follows:

$$4 \quad \begin{aligned} E_{pref,i} &= w_i(\mathbf{p}_0, x_0, P_0, \mathbf{d}_0 | \Theta_1) - w_i(\mathbf{p}_0, x_0, P_0, \mathbf{d}_0 | \Theta_0) \\ &= \alpha_{i1} - \alpha_{i0} + \ln p_{j0} \sum_j (\gamma_{ij1} - \gamma_{ij0}) + \ln x_0 (\beta_{i1} - \beta_{i0}) \\ &\quad - \beta_{i1} \ln P_{0,\Theta_1} + \beta_{i0} \ln P_{0,\Theta_0} + \mathbf{d}_0 (\lambda_{i1} - \lambda_{i0}) \end{aligned} \quad (12)$$

5 Consistently with Equation 5, the evaluation of the preference effect is obtained
6 by holding data on all determinants constant at time 0, and letting the pref-
7 erence structure change from Θ_0 to Θ_1 ⁴. Thus, the preference effect $E_{pref,i}$
8 captures the difference in the budget share caused by the shift in the preference
9 structure between time 0 and time 1. In order to isolate the preference effect
10 as captured by the coefficient changes, a reference time for the socio-economic
11 determinants must be chosen. For a given preference structure, consumption
12 depends on period-specific price, demographics and budget values. As shown in
13 Appendix A.1, using time 0 as the reference period for the data on determinants
14 ensures that the following equality holds:

$$15 \quad \begin{aligned} \Delta w_i = w_{i1} - w_{i0} &= E_{price,i} + E_{expen,i}^{nominal} + E_{demo,i} + E_{pref,i} \\ &= E_{price,i}^{subs} + E_{expen,i}^{real} + E_{demo,i} + E_{pref,i} \end{aligned} \quad (13)$$

⁴Once more, it is worth noting that the price index P_{t,Θ_t} also includes socio-demographic variables and their coefficients and must be treated accordingly, i.e. P_{0,Θ_1} includes demographics at time 0 and demographic coefficients at time 1

1 3.3 From share effects to quantity and emission effects

2 The AIDS is an allocative model, as it reflects the optimal (utility-maximizing)
3 allocation of household budget to the various goods in the basket. Therefore,
4 the decomposition in (13) is defined in budget shares, and some further passages
5 are needed to translate these effects into quantities. Purchased quantities for
6 a good i at a given time t are obtained as $q_{it} = w_{it} \frac{x_t}{p_{it}}$ under the assumption
7 of homogeneous quality⁵ (see Appendix A.2). Adopting the usual notation, the
8 quantity change between period 0 and period 1 can be expressed as:

$$\begin{aligned}
 \Delta q_i &= w_{i1} \frac{x_1}{p_{i1}} - w_{i0} \frac{x_0}{p_{i0}} \\
 &= \Delta w_i \frac{x_1}{p_{i1}} + w_{i0} \left(\frac{x_1}{p_{i1}} - \frac{x_0}{p_{i0}} \right)
 \end{aligned}
 \tag{14}$$

10 Hence, by combining (13) and (14), the decomposition of Δq becomes:

$$\begin{aligned}
 \Delta q_i &= E_{price,i} \frac{x_1}{p_{i1}} + E_{expen,i}^{nominal} \frac{x_1}{p_{i1}} + E_{demo,i} \frac{x_1}{p_{i1}} + E_{pref,i} \frac{x_1}{p_{i1}} \\
 &\quad + w_{i0} \left(\frac{x_1}{p_{i1}} - \frac{x_0}{p_{i0}} \right)
 \end{aligned}
 \tag{15}$$

12 In Equation 15, the previous decomposition of Δw_i is translated into quan-
13 tity changes by considering the current (at time 1) budget and prices. This
14 transformation depends on the choice of the reference period required to iden-
15 tify the preference change effects $E_{pref,i}$ in Equation 12. Here, we evaluate
16 preference changes with reference to data at the baseline period, but nothing
17 prevents to take a different reference time. Whatever the reference period, an
18 adjustment to account for potentially different purchasing powers is required to
19 ensure that the decomposition identity holds. Here, the adjustment is the last

⁵This also implies that the composition of food aggregates is stable over time (Nelson, 1991)

1 term in (15)⁶. For each good, this adjustment factor is a function of the expen-
 2 diture share at the baseline period and the change over the two time periods in
 3 the ratio between total expenditure and the price for the same good. This ratio
 4 measures the quantity of each good that a consumer could buy by spending all
 5 her budget on it. The adjustment is positive when it is possible to buy a higher
 6 quantity of the good at time 1 relative to time 0 and vice versa. In other words,
 7 it is positive (negative) when a consumer purchasing power for that good has
 8 become higher (lower). The expenditure share at the baseline period weighs
 9 the importance of that good for the consumer. Given this interpretation, this
 10 adjustment factor is used to obtain the real expenditure effect along with the
 11 income effect of price changes.
 12 In summary, we can define the quantity effects in relation to the budget share
 13 effects as follows:

$$\begin{aligned}
 E_{price,i}^{Q,subs} &= E_{price,i}^{subs} \frac{x_1}{p_{i1}} \\
 E_{price,i}^{Q,inc} &= E_{price,i}^{inc} \frac{x_1}{p_{i1}} \\
 E_{expen,i}^{Q,nominal} &= E_{expen,i}^{nominal} \frac{x_1}{p_{i1}} \\
 14 \quad E_{demo,i}^Q &= E_{demo,i} \frac{x_1}{p_{i1}} \tag{16} \\
 E_{pref,i}^Q &= E_{pref,i} \frac{x_1}{p_{i1}} \\
 E_{PP}^Q &= w_{i0} \left(\frac{x_1}{p_{i1}} - \frac{x_0}{p_{i0}} \right) \\
 E_{expen,i}^{Q,real} &= E_{expen,i}^{Q,nominal} + E_{price,i}^{Q,inc} + E_{PP}^Q
 \end{aligned}$$

15 Therefore, the same equality in (13) holds for changes in purchased quantities,

⁶See the proof in Appendix A.2.

1 too:

$$2 \quad \Delta q_i = E_{price,i}^{Q,subs} + E_{expen,i}^{Q,real} + E_{demo,i}^Q + E_{pref,i}^Q \quad (17)$$

3 Finally, the translation of changes in purchased quantities into changes in
4 CO₂e greenhouse gas emissions is straightforward, and simply requires multi-
5 plication by the appropriate emission factor f_i for each good:

$$6 \quad \Delta GHGE_i = \Delta q_i f_i \quad (18)$$

7 **3.4 Data & estimation procedure**

8 Within the framework of UK household budget survey (currently named as
9 the Living Costs and Food Survey, LCF), the UK Office for National Statistics
10 (ONS) and the Department for Environment, Food and Rural Affairs (DEFRA),
11 run a yearly module to collect data about household food and drink purchases
12 (DEFRA, 2019). This survey consists in three questionnaires, administered to a
13 representative sample of more than 5000 households every year. The household
14 questionnaire collects household-level information, such as family structure, em-
15 ployment details, ownership of household durables, regular payments, etc. The
16 individual questionnaire collects income-related person-level variables for each
17 adult member in the household, such as income from employment, and personal
18 assets. Lastly, each individual in the household aged 16 years and over records
19 her daily purchases in a diary for two weeks.

20 Micro-data on purchased quantities and expenditures on each food and drink
21 item – classified according to the five-level EUROSTAT Classification of Indi-

1 vidual Consumption by Purpose (ECOICOP) – are published at the household
2 level. This classification is available for food and drink items purchased for home
3 consumption, and data on purchased quantities are not available for eating out
4 expenditures, hence our study does not cover that portion of food purchases⁷.
5 Per-capita values for quantities, expenditures and incomes are obtained con-
6 sidering an adjusted household size measure based on the OECD equivalence
7 scale (OECD, 2009). Purchase unit values are obtained for each household as
8 the ratio between expenditure and purchased quantities for each food and drink.
9 Unit values reflect both shelf prices and a quality component, as different house-
10 holds may choose different quality levels and pay different prices for the same
11 goods (e.g. different types of strawberries). This is especially true when work-
12 ing with composite goods (e.g. fruit) that reflect different compositions across
13 households, e.g. variation in the proportion of strawberries and apples within
14 fruit. As the use of unit values leads to bias in estimates (Deaton, 1988), some
15 procedure is needed to obtain quality-adjusted prices. A widely used approach
16 is the definition of prices as the average unit values across households by month
17 and government office region, under the common assumption that households
18 in the same area and time period face the same prices.
19 A second issue to be considered when working with LCF data is the high fre-
20 quency of non-purchases that mainly depends on the relatively short time win-
21 dow covered by the household diary. This is another well-known source of bias
22 in the estimation of demand parameters (see e.g. Deaton, 1986, pp. 1807-1810).
23 A variety of solutions has been proposed, but they often generate diverging re-
24 sults, with no consensus on their ability to solve the problem without generating

⁷In 2015 eating out expenditure of UK households represented 31.1% of the overall food budget (DEFRA, 2017).

1 further biases⁸. To address the problem, we proceed by changing the unit of
2 analysis into an artificial aggregated household by geographical region, month
3 of the survey and income quartile.

4 For the purpose of the present study, we exploit LCF data for the years from
5 2001 to 2015⁹. We consider eighteen food groups and a residual category (mis-
6 cellaneous food). We follow food group classification and emission factors used
7 in [Castiglione and Mazzocchi \(2019\)](#)¹⁰. These emission factors by food group
8 are UK estimates derived from the disaggregated emission factors provided in
9 [Hoolohan et al. \(2013\)](#). They account for all the production phases, indepen-
10 dently from the country of origin of the food: from field to farm gate, transport
11 from farm to processing and/or distribution centres, processing, packaging, stor-
12 age and supermarket operations, including transport to store, and are based on
13 a number of studies carried out between 2003 and 2010 ([Hoolohan et al., 2013](#)).
14 The full dataset spanning over 15 years consists of nearly 87,000 observations,
15 which become 8,443 after aggregation of households¹¹. We split the dataset into
16 four periods: (i) 2001-2004, i.e. the *baseline* period; (ii) 2005-2008, or period
17 1; (iii) period 2 from 2009 to 2012 and (iv) period 3 from 2013 to 2015. The
18 procedure to estimate and decompose the changes in food demand that have
19 occurred over the 15 years of analysis consists in the following steps:

20 1. Estimate the AIDS model in (6) in each of the four sub-samples s , to obtain

⁸For example, some methods do not automatically satisfy the adding-up restriction of demand systems, and trade-offs between consistency and efficiency may be large ([Tauchmann, 2005](#)).

⁹LCF 2015 is the latest year for which the food diary data has been distributed at the date of the present study. The LCF survey went through several changes switching between calendar and financial twice during the covered time span; therefore, we combined the fifteen surveys in a single dataset and henceforth we refer to the calendar years.

¹⁰The set of emission factors is shown in Table 1 of [Castiglione and Mazzocchi \(2019\)](#).

¹¹Descriptive from the raw data-set, together with the proportion of non-purchases before and after aggregation are provided as Supplemental Material, sheet A. Estimates from the raw data-set are also provided for comparison purposes, see Section 4.5

- 1 the four sets of preference structures $w_i(\mathbf{p}, x, P, \mathbf{d}|\Theta_s)$ with $s = 0, \dots, 3$,
2 where $s = 0$ indicates the baseline period. The system is estimated via
3 Iterated Linear Least Squares (Blundell and Robin, 1999);
- 4 2. Use the previous coefficient estimates to obtain the budget share decom-
5 position in (13) according to equations (9), (10) and (12);
 - 6 3. Translate the decomposition into quantity effects by applying Equation
7 16;
 - 8 4. Estimate the emission effects in terms of changes in carbon dioxide equiv-
9 alent GHG emissions for each food product using Equation 18.

10 Thus, our final decompositions all refer to changes with respect to the same
11 baseline period 2001-2004. Table 1 displays summary statistics of the key vari-
12 ables for each of the four time windows¹².

13 There are some clear patterns in the data. First, there is a progressive reduc-
14 tion in the amount of food and drinks purchased by UK households, especially
15 over the last two periods. Considering the difference between the last period
16 and the baseline period, yearly per capita purchases of food and drinks have
17 decreased by about 78.8 kg, or 10.5%. This has also resulted in a decrease in
18 food-related emissions by 182 kg CO₂e per year, or -8.2%.

19 Relative to the baseline period, we observe that the onset of the financial crisis
20 (i.e. period 2) has major effects on a variety of dimensions. Beyond the expected
21 clear reduction in real incomes and the rise in unemployment rates, we observe
22 that the food budget falls sharply, especially in the last period. Total purchased
23 quantities decline sharply after a long period of relative stability (2001-2008),

¹²Descriptive statistics on shares, prices, quantities and emissions at the food group level are available as online Supplemental Material, sheet B.

Table 1. Descriptive statistics per period.

Periods	Baseline	1	2	3
Number of households	25,818	24,792	21,550	14,869
Sample size	2,151	2,299	2,283	1,710
Purchased food & drinks quantity (kg person ⁻¹ year ⁻¹)	747.5 (129.9)	732.3 (131.1)	700.2 (148.2)	668.7 (146.2)
Food-related GHGEs (tons CO ₂ e person ⁻¹ year ⁻¹)	2.22 (0.41)	2.20 (0.41)	2.13 (0.47)	2.04 (0.47)
Av. real food&drinks price (£/kg)	2.38 (0.36)	2.43 (0.38)	2.52 (0.45)	2.53 (0.51)
Food & drinks expenditure (£ person ⁻¹ year ⁻¹)	1332.4 (357.2)	1437.3 (367.1)	1613.3 (470.4)	1685.8 (521.2)
Real food & drinks expenditure (£ person ⁻¹ year ⁻¹)	1,775.0	1,771.5	1,766.3	1,694.5
Income (£ person ⁻¹ year ⁻¹)	17,888.8 (12,543.1)	17,770.1 (10,501.2)	17,856.7 (10,159.7)	18,019.4 (10,246.4)
Real Income (£ person ⁻¹ year ⁻¹)	23,843.8	21,904.7	19,542.2	18,110.0
Food & drinks expend. share on total expend.	8.7% (2.7)	9.6% (3.9)	10.3% (3.3)	10.3% (3.4)
Male	67.2% (18.8)	58.1% (19.7)	56.1% (21.1)	53.1% (22.7)
Married	61.5% (19.3)	60.0% (19.7)	62.6% (21.1)	63.2% (22.7)
Single	14.0% (12.8)	14.6% (13.8)	14.3% (14.6)	14.6% (15.9)
Retired	22.8% (18.8)	26.6% (20.5)	28.1% (20.6)	29.6% (21.6)
Unemployed	2.0% (4.6)	2.3% (5.9)	4.8% (10.5)	4.1% (10.5)
HH with children	31.4% (17.2)	31.0% (17.5)	30.6% (19.5)	31.4% (21.3)
Age	50.5 (6.5)	52.1 (7.0)	52.8 (7.2)	53.7 (7.6)
OECD equivalence scale	1.86 (0.27)	1.85 (0.28)	1.84 (0.31)	1.87 (0.37)

Source: Our processing on Expenditure and Food Survey, and Living Cost and Food Survey data (DEFRA, 2019).

Notes: Baseline period: 2001-2004; Period 1: 2005-2008; Period 2: 2009-2012; Period 3: 2013-2015. Real food expenditure: base year=2015. Demographic information refers to the household reference person. Shares of retired people refer to retired and unoccupied people over minimum National Insurance age. Standard deviations in parentheses.

1 and we observe an increase in the food budget share, which indicates a decline
2 in household resources, as expected in recession times, in line with Engel's Law.
3 Our estimates of total food-related emissions also show that the decline in per
4 capita emission has started in period 2, which suggests that economic dynamics
5 during the financial crisis may have played a major role. The reduction in emis-
6 sions seems to be strongly related to the overall decline in total food and drink
7 quantities, rather than to a re-allocation across foods. The reduction in pur-
8 chased quantities is unlikely to depend on absolute price levels, as the changes
9 in real food and drink prices over the four time periods are small. This does not
10 rule out that relative price changes may have influenced the consumer basket.
11 The proposed decomposition strategy also considers the contribution of demo-
12 graphic changes, and some clear and regular trends emerge from Table 1. Over
13 time, we observe a substantial reduction in the proportion of male household
14 reference persons (HRP) from 67.2% in the baseline period to 53.1% in the final
15 period, a slight increase in the proportion of married HRP, a regular increase
16 in the average age of HRP (+3.2 years between the baseline period and the
17 last period). This latter trend also results in an increase in the proportion of
18 households with retired HRP. How these changes affect food-related emissions
19 depends on the association between demographics and food consumption bas-
20 kets, as captured by demographic scaling in the demand system.

21 **4 Results and Discussion**

22 We analyse the changes in the UK food basket over the period 2001-2015 under
23 three different dimensions: (a) changes in the food budget allocation (budget

1 shares); (b) changes in purchased quantities; (c) changes in GHGEs. The de-
2 composition strategy described in Section 3 is applied to all three dimensions.
3 Here we report the key findings on the relative contribution of changes in pref-
4 erences, prices, real expenditures and socio-demographics. Here we focus on
5 quantity and emission effects, but the full set of decomposition estimates for
6 each of the above dimensions, across the three time windows and for each indi-
7 vidual food group is provided as Supplemental Material.

8 Table 2 shows the actual evolution of expenditure shares, purchased quantities
9 and GHGEs by product between the baseline period and the last period (2013-
10 2015)¹³. The reduction in emissions are mostly generated by a significant fall
11 in purchases of animal products, mostly meat (especially beef and lamb) and
12 dairy products (especially milk and yoghurt). Other food groups contribute to
13 the reduction to a lesser extent, including drinks (especially soft drinks), confec-
14 tionery and fruit and vegetables. For some products, larger budget shares are
15 associated with lower purchased quantities and emissions. *It is the case of fruit
16 and vegetables, cheese and other dairy products, whose prices have risen more
17 than other food prices, leading to expenditure increases despite lower purchased
18 quantities.*

19 **4.1 Changes in the preference structure**

20 The first question is to what extent the observed changes in purchased quanti-
21 ties and the associated emissions can be explained by the evolution of consumer
22 preferences and tastes, possibly in response to increased sensitivity to nutritional
23 and sustainability issues, and information and education measures. Table 3 re-

¹³Data for the other two periods are available as Supplemental Material, sheet C.

Table 2. Observed changes in period 3 (2013-2015) relative to the baseline period (2001-2004).

	Budget share %	Purchased quant. kg p ⁻¹ y ⁻¹	GHGEs kg CO ₂ e p ⁻¹ y ⁻¹
Fruit & vegetables	0.71*** (0.15)	-6.04*** (1.49)	-11.18*** (3.25)
<i>Fruit</i>	0.28** (0.09)	-4.20*** (0.82)	-5.91*** (1.15)
<i>Vegetables</i>	0.43*** (0.09)	-1.84* (0.85)	-5.27* (2.44)
Cereals	0.58*** (0.08)	-5.93*** (0.62)	-11.16*** (1.17)
Meat	-0.08 (0.14)	-5.74*** (0.69)	-81.42*** (9.52)
<i>Beef & Lamb</i>	-0.05 (0.09)	-2.24*** (0.30)	-50.36*** (6.70)
<i>Chicken</i>	0.10 (0.07)	-1.33*** (0.32)	-5.37*** (1.29)
<i>Pork</i>	-0.42*** (0.06)	-0.86*** (0.21)	-8.88*** (2.12)
<i>Other meats</i>	0.28*** (0.06)	-1.32*** (0.23)	-16.80*** (2.95)
Fish	-0.09 (0.06)	-0.98*** (0.14)	-2.88*** (0.40)
Dairy & eggs	0.22* (0.09)	-5.85*** (1.41)	-18.56*** (5.37)
<i>Milk & yoghurt</i>	-0.39*** (0.08)	-6.72*** (1.31)	-21.99*** (4.28)
<i>Butter, cheese & dairy</i>	0.32*** (0.04)	-0.13 (0.18)	-1.47 (2.05)
<i>Eggs</i>	0.29*** (0.02)	1.00*** (0.13)	4.90*** (0.62)
Oils & fats	0.23*** (0.03)	0.38* (0.16)	0.98* (0.42)
Confectionery	0.01 (0.08)	-3.26*** (0.49)	-12.22*** (1.82)
Crisps & snacks	0.04 (0.03)	-0.29*** (0.07)	-0.08*** (0.02)
Potatoes	-0.06 (0.03)	-9.85*** (0.77)	-3.33*** (0.26)
Composite dishes	-0.02 (0.10)	0.23 (0.38)	1.28 (2.10)
Miscellaneous food	0.28*** (0.07)	0.18 (0.17)	0.18 (0.17)
Foods	1.82*** (0.25)	-37.14*** (3.77)	-138.39*** (16.73)
Alcoholic drinks	-1.35*** (0.25)	-8.33*** (1.31)	-15.02*** (2.36)
Non-alcoholic drinks	-0.47*** (0.08)	-33.50*** (1.93)	-30.09*** (1.74)
Drinks	-1.82*** (0.25)	-41.84*** (2.43)	-45.11*** (3.05)
Total	0.00 (0.00)	-78.98*** (4.89)	-183.50*** (17.87)

Notes: Bootstrapped standard errors in parentheses. Drink quantities are expressed in Lt p⁻¹ y⁻¹. Asterisks refer to estimates' significance at 0.001 (***), 0.01 (**) and 0.05 (*) level.

1 ports estimates of the effects of changes in the preference structure, considering
2 the last period of analysis (2013-2015) with respect to the baseline period (2001-
3 2004). The interpretation of these estimates is straightforward: as preferences
4 change over time, what would be the expenditure shares, purchased quantities
5 and GHGEs in period 3 had prices, food budgets and socio-demographic vari-
6 ables remained constant at the baseline level?

7 The comparison between the effects of preference-driven changes and the ac-
8 tual changes in purchased quantities shows some interesting differences. For
9 example, the evolution of preferences would lead to higher purchases of fruit
10 and vegetables (+7 kg per person per year), whereas observed quantities have
11 reduced by 6 kg per person per year¹⁴. This conflicting outcome is consis-
12 tent with evidence that the UK 5-a-day program and other promotion policies
13 have succeeded in lifting potential demand, while actual consumption has been
14 constrained by lower budgets and price increases (Castiglione and Mazzocchi,
15 2019). Considering animal products, the reduction in purchases of pork, milk
16 and yoghurt corresponds to a lower preference towards these foods. This is not
17 the case for beef, where estimates show stable preferences relative to the base-
18 line period. Other relevant changes in preferences suggest that ceteris paribus,
19 households would consumer higher quantities of chicken, eggs and to a lesser
20 extent butter and cheese, and lower quantities of confectionery and soft drinks.
21 In general, the evolution in the preference structure seems in line with nutri-
22 tional recommendations. The total net effect of preference changes on GHGEs
23 is negative and highly significant.

¹⁴The decomposition expressed in percentages relative to the baseline values of purchases is reported as Supplemental Material, sheet E

Table 3. Effects of changes in the preference structure in period 3 (2013-2015) relative to the baseline period (2001-2004).

	Budget share %	Purchased quant. kg p ⁻¹ y ⁻¹	GHGEs kg CO ₂ e p ⁻¹ y ⁻¹
Fruit & vegetables	0.90*** (0.26)	7.06*** (2.06)	14.59** (4.63)
<i>Fruit</i>	0.51** (0.16)	3.87** (1.21)	5.44** (1.69)
<i>Vegetables</i>	0.39* (0.16)	3.19* (1.32)	9.15* (3.80)
Cereals	0.35* (0.15)	2.45* (1.08)	4.61* (2.03)
Meat	-0.41 (0.30)	-0.89 (0.79)	-18.82 (10.84)
<i>Beef & Lamb</i>	0.01 (0.18)	0.03 (0.39)	0.57 (8.71)
<i>Chicken</i>	0.42** (0.13)	1.39** (0.43)	5.61** (1.75)
<i>Pork</i>	-0.66*** (0.17)	-1.78*** (0.45)	-18.36*** (4.67)
<i>Other meats</i>	-0.19 (0.15)	-0.52 (0.40)	-6.64 (5.11)
Fish	-0.04 (0.12)	-0.06 (0.17)	-0.18 (0.51)
Dairy & eggs	-0.13 (0.17)	-9.70*** (2.48)	-23.44** (8.59)
<i>Milk & yoghurt</i>	-0.68*** (0.13)	-12.43*** (2.43)	-40.66*** (7.96)
<i>Butter, cheese & dairy</i>	0.20* (0.10)	0.57* (0.28)	6.60* (3.26)
<i>Eggs</i>	0.34*** (0.06)	2.17*** (0.38)	10.63*** (1.88)
Oils & fats	0.17* (0.08)	0.95* (0.45)	2.44* (1.14)
Confectionery	-0.60*** (0.17)	-3.19*** (0.93)	-11.99*** (3.50)
Crisps & snacks	0.03 (0.08)	0.08 (0.19)	0.02 (0.06)
Potatoes	-0.18* (0.08)	-3.17* (1.45)	-1.07* (0.49)
Composite dishes	-0.33 (0.22)	-1.18 (0.78)	-6.47 (4.27)
Miscellaneous food	0.51* (0.21)	1.33* (0.55)	1.34* (0.55)
Foods	0.27 (0.41)	-6.33 (3.96)	-38.97** (14.16)
Alcoholic drinks	0.13 (0.39)	0.49 (1.40)	0.88 (2.52)
Non-alcoholic drinks	-0.40* (0.17)	-9.50* (4.11)	-8.53* (3.69)
Drinks	-0.27 (0.41)	-9.02* (4.22)	-7.66 (4.27)
Total	0.00 (0.00)	-15.34*** (4.55)	-46.62*** (12.43)

Notes: Bootstrapped standard errors in parentheses. Drink quantities are expressed in Lt p⁻¹ y⁻¹. Asterisks refer to estimates' significance at 0.001 (***), 0.01 (**) and 0.05 (*) level.

1 4.2 Changes in real food budget and relative prices

2 Tables 4 and 5 show the full decomposition of changes between the last period
3 and the baseline period in purchased quantities and emissions, respectively¹⁵.

4 The real expenditure component is obtained by combining the effects of nom-
5 inal expenditure, the income effect of price changes, and the adjustment in
6 purchasing powers required by the decomposition approach (see Section 3.3).

7 The remaining price effect refers to substitutions induced by changes in relative
8 prices and is purged from any income effect.

9 Our estimates clearly point out at a major impact of the economic recession.

10 The impact of the reduction in food budgets is much larger than any other
11 effect, and accounts for 76% of the total reduction in quantities and 90% of
12 the total reduction in emissions. The loss of purchasing powers has especially
13 hit fruit and vegetables, leading to a reduction of almost 11 kg per person per
14 year, which completely offsets the higher demand prompted by preferences (+7
15 kg). Drink purchases also responded heavily to the fall in real budgets, with an
16 estimated reduction of 16.9 litres and 8.8 litres per person per year in soft and
17 alcoholic drinks, respectively. For all food groups, including staple foods like
18 potatoes or cereals, we estimate a major reduction in purchases and emissions
19 in response to the decline in real food budgets, with the only exception of milk
20 and yoghurt and composite dishes, whose quantities show a significant increase.
21 As discussed earlier, there is a sharp decline in preferences towards milk and
22 yoghurt, also reflected in a decrease in real prices. This made milk a source of
23 relatively cheaper animal proteins, resulting in a positive real expenditure effect.

24 This is consistent with the positive effect of real expenditure on purchases of

¹⁵The same decomposition expressed in percentages relative to the baseline values is reported in Appendix A.3

1 composite dishes and the non-negative effect on pork purchases, the two other
2 and only food groups characterised by a decrease in real prices between the two
3 periods.

4 While these tendencies reflect the weight of prices on a household budget, the
5 allocation to the various foods also depends on change in relative prices. The
6 overall impact of the substitution effects is close to zero and non-significant in
7 terms of total quantities, but positive and significant – albeit very small – in
8 terms of GHGEs, with an increase of 12.9 kg CO₂e per capita per year, or 0.58%
9 of the baseline emissions level. This very small impact is almost exclusively re-
10 lated to an increase in emissions from purchases of other meats, whose price
11 has risen in real terms less than half of the increase in beef and lamb prices.
12 Overall, the role played by changes in relative prices on purchases and emissions
13 is negligible.

14 **4.3 Demographic trends**

15 Like relative prices, changes in the socio-demographic factors (mainly ageing,
16 rising unemployment and an increase in female-led households) are not large
17 enough to impact purchased quantities in a meaningful way. Overall, the effect
18 on quantities is non-significant, whereas there is a slight increase in terms of
19 emissions (15.4 kg CO₂e per person per year). The food groups that emerge as
20 more sensitive to socio-demographic trends are confectionery, other meats and
21 potatoes, all characterised by a positive effect on purchased quantities (hence
22 emissions)¹⁶. Purchases for all three groups appear to be strongly increasing
23 with age, and these significant increases are mainly an outcome of ageing popu-

¹⁶The full set of coefficient estimates is available as Supplemental Material, sheet H

Table 4. Decomposition of quantities in food choice determinants, period 3 vs baseline (kg person⁻¹ year⁻¹).

	Real expenditure	Price subs.	Demo.	Preference	Total
Fruit & vegetables	-10.95*** (1.23)	0.46 (1.38)	-1.71 (1.14)	7.06*** (2.06)	-5.15*** (1.47)
<i>Fruit</i>	-5.84*** (0.67)	-0.36 (0.76)	-1.19 (0.68)	3.87** (1.21)	-3.52*** (0.85)
<i>Vegetables</i>	-5.11*** (0.72)	0.82 (1.04)	-0.52 (0.78)	3.19* (1.32)	-1.63 (0.88)
Cereals	-7.36*** (0.57)	-0.22 (0.69)	-0.13 (0.53)	2.45* (1.08)	-5.26*** (0.80)
Meat	-6.54*** (0.59)	0.60 (0.52)	0.48 (0.43)	-0.89 (0.79)	-6.34*** (0.71)
<i>Beef & Lamb</i>	-2.75*** (0.31)	0.00 (0.23)	0.17 (0.27)	0.03 (0.39)	-2.55*** (0.37)
<i>Chicken</i>	-1.94*** (0.24)	-0.58 (0.38)	-0.31 (0.24)	1.39** (0.43)	-1.44*** (0.34)
<i>Pork</i>	0.09 (0.14)	0.49 (0.28)	0.18 (0.24)	-1.78*** (0.45)	-1.03*** (0.21)
<i>Other meats</i>	-1.94*** (0.16)	0.69* (0.32)	0.45** (0.17)	-0.52 (0.40)	-1.32*** (0.26)
Fish	-1.10*** (0.17)	0.06 (0.10)	0.02 (0.09)	-0.06 (0.17)	-1.08*** (0.18)
Dairy & eggs	4.62*** (1.28)	-0.71 (1.64)	1.54 (1.25)	-9.70*** (2.48)	-4.24* (2.11)
<i>Milk & yoghurt</i>	6.20*** (1.18)	-0.28 (1.59)	1.36 (1.22)	-12.43*** (2.43)	-5.16** (1.97)
<i>Butter, cheese & dairy</i>	-0.97*** (0.13)	0.09 (0.24)	0.15 (0.12)	0.57* (0.28)	-0.16 (0.19)
<i>Eggs</i>	-0.61*** (0.12)	-0.53 (0.35)	0.04 (0.15)	2.17*** (0.38)	1.08*** (0.18)
Oils & fats	-1.01*** (0.13)	-0.11 (0.36)	0.22 (0.23)	0.95* (0.45)	0.04 (0.19)
Confectionery	-1.72** (0.53)	0.61 (0.56)	1.60*** (0.44)	-3.19*** (0.93)	-2.71*** (0.64)
Crisps & snacks	-0.30*** (0.06)	-0.06 (0.15)	-0.03 (0.08)	0.08 (0.19)	-0.32*** (0.10)
Potatoes	-7.69*** (0.70)	-0.53 (1.02)	1.83** (0.59)	-3.17* (1.45)	-9.57*** (0.90)
Composite dishes	0.74** (0.28)	0.29 (0.61)	0.42 (0.40)	-1.18 (0.78)	0.27 (0.45)
Miscellaneous food	-0.16 (0.19)	-0.33 (0.23)	-0.30 (0.31)	1.33* (0.55)	0.54* (0.22)
Foods	-31.48*** (3.95)	0.07 (1.78)	3.93 (2.10)	-6.33 (3.96)	-33.81*** (4.82)
Alcoholic drinks	-8.77*** (1.10)	-1.07** (0.37)	-1.20 (0.78)	0.49 (1.40)	-10.55*** (1.57)
Non-alcoholic drinks	-16.91*** (2.21)	1.08 (2.40)	-5.20 (2.75)	-9.50* (4.11)	-30.53*** (2.50)
Drinks	-25.68*** (2.65)	0.01 (2.36)	-6.40* (2.71)	-9.02* (4.22)	-41.08*** (2.96)
Total	-57.16*** (5.71)	0.08 (2.53)	-2.47 (2.89)	-15.34*** (4.55)	-74.89*** (5.88)

Notes: Bootstrapped standard errors in parentheses. Drink quantities are expressed in Lt p⁻¹ y⁻¹. Asterisks refer to estimates' significance at 0.001 (***), 0.01 (**) and 0.05 (*) level.

Table 5. Decomposition of diet-related GHGEs in food choice determinants, period 3 vs baseline (kg CO₂e person⁻¹ year⁻¹).

	Real expenditure	Price subs.	Demo.	Preference	Total
Fruit & vegetables	-22.88*** (2.71)	1.84 (3.33)	-3.17 (2.62)	14.59** (4.63)	-9.62** (3.25)
<i>Fruit</i>	-8.21*** (0.95)	-0.50 (1.06)	-1.68 (0.95)	5.44** (1.69)	-4.95*** (1.19)
<i>Vegetables</i>	-14.68*** (2.08)	2.35 (2.98)	-1.49 (2.24)	9.15* (3.80)	-4.67 (2.53)
Cereals	-13.85*** (1.06)	-0.41 (1.29)	-0.25 (1.00)	4.61* (2.03)	-9.90*** (1.51)
Meat	-93.46*** (8.52)	11.56 (6.53)	10.08 (6.88)	-18.82 (10.84)	-90.64*** (10.35)
<i>Beef & Lamb</i>	-61.78*** (6.88)	0.03 (5.19)	3.82 (6.16)	0.57 (8.71)	-57.36*** (8.21)
<i>Chicken</i>	-7.85*** (0.98)	-2.34 (1.52)	-1.26 (0.99)	5.61** (1.75)	-5.84*** (1.38)
<i>Pork</i>	0.93 (1.43)	5.01 (2.91)	1.81 (2.52)	-18.36*** (4.67)	-10.60*** (2.11)
<i>Other meats</i>	-24.76*** (2.09)	8.86* (4.10)	5.71** (2.12)	-6.64 (5.11)	-16.84*** (3.28)
Fish	-3.22*** (0.49)	0.18 (0.30)	0.06 (0.26)	-0.18 (0.51)	-3.16*** (0.53)
Dairy & eggs	6.05 (4.94)	-2.39 (5.88)	6.32 (4.41)	-23.44** (8.59)	-13.45 (7.74)
<i>Milk & yoghurt</i>	20.27*** (3.87)	-0.91 (5.20)	4.44 (4.00)	-40.66*** (7.96)	-16.86** (6.45)
<i>Butter, cheese & dairy</i>	-11.24*** (1.52)	1.09 (2.82)	1.69 (1.40)	6.60* (3.26)	-1.87 (2.24)
<i>Eggs</i>	-2.97*** (0.61)	-2.57 (1.70)	0.20 (0.76)	10.63*** (1.88)	5.27*** (0.88)
Oils & fats	-2.60*** (0.33)	-0.28 (0.91)	0.55 (0.60)	2.44* (1.14)	0.11 (0.48)
Confectionery	-6.47** (1.99)	2.30 (2.11)	6.00*** (1.66)	-11.99*** (3.50)	-10.15*** (2.40)
Crisps & snacks	-0.09*** (0.02)	-0.02 (0.04)	-0.01 (0.02)	0.02 (0.06)	-0.09*** (0.03)
Potatoes	-2.60*** (0.24)	-0.18 (0.34)	0.62** (0.20)	-1.07* (0.49)	-3.24*** (0.31)
Composite dishes	4.05** (1.55)	1.62 (3.33)	2.29 (2.19)	-6.47 (4.27)	1.49 (2.48)
Miscellaneous food	-0.16 (0.19)	-0.34 (0.24)	-0.30 (0.31)	1.34* (0.55)	0.54* (0.22)
Foods	-135.23*** (16.19)	13.89* (6.53)	22.20** (7.76)	-38.97** (14.16)	-138.11*** (19.34)
Alcoholic drinks	-15.81*** (1.98)	-1.93** (0.67)	-2.16 (1.40)	0.88 (2.52)	-19.02*** (2.84)
Non-alcoholic drinks	-15.18*** (1.98)	0.97 (2.15)	-4.67 (2.47)	-8.53* (3.69)	-27.41*** (2.24)
Drinks	-30.99*** (3.06)	-0.96 (2.14)	-6.83** (2.60)	-7.66 (4.27)	-46.44*** (3.62)
Total	-166.22*** (17.96)	12.93* (6.13)	15.37* (6.75)	-46.62*** (12.43)	-184.55*** (20.17)

Notes: Bootstrapped standard errors in parentheses. Drink quantities are expressed in Lt p⁻¹ y⁻¹. Asterisks refer to estimates' significance at 0.001 (***), 0.01 (**) and 0.05 (*) level.

1 lation. For potatoes, the effect is reinforced by the increase in retirement rates
2 and unemployment rates. The proportion of children in the household is also a
3 major determinant of demand for most food groups, but this indicator has been
4 very stable over the time window covered by the study. In general, demographic
5 factors have played a minor role in driving food-related emissions.

6 **4.4 Overall emission effects**

7 The summary findings from our decomposition strategy are displayed in Table
8 [6¹⁷](#). Real expenditure is clearly the main determinant of changes in diet-related
9 GHGEs, and acts towards reducing emissions. The effect has become larger
10 over time, especially after the onset of the economic recession. The mechanism
11 is relatively trivial, households have progressively allocated less budget to food
12 in real terms, because they demand less food (in terms of quantities), but es-
13 pecially – over the last two periods – because of the loss in purchasing powers
14 driven by recession.

15 Over the first time period, the emission-reducing effect of real expenditure has
16 been counterbalanced by emission-increasing demographic and preference effects
17 (i.e. increased demand for some emission-intensive foods like meat and dairy
18 products), so that on balance no meaningful change in GHGEs is observed.

19 The reduction in food-related emissions becomes substantial in period 2, due to
20 the contraction of real budget caused by the financial crisis. Socio-demographic
21 patterns have had a compensating effect towards higher emissions, but as de-
22 mographic factors change slowly and regularly, their impact remains stable and
23 relatively small. Furthermore, the preference shift is neutral on aggregate, but

¹⁷Details for all periods and individual food groups available as Supplemental Material, sheet D

1 changes happen at the individual food level. For example, preferences in period
2 2 lean towards higher purchases of cereals, dairy products, chicken and other
3 meats, and lower purchases of beef, pork, composite dishes and confectionery.
4 During the last period, the effects of real expenditure are reinforced. The re-
5 sulting lower emissions are further magnified by a sharp switch in preferences
6 towards more sustainable choices, and only partially contrasted by substitutions
7 driven by changes in relative prices and demographic trends.

Table 6. Change in diet-related GHG emissions with respect to benchmark period (per capita kg CO₂e/year) - Breakdown by effects.

Periods	1	2	3
Real expenditure	-42.49*** (12.55)	-100.92*** (13.92)	-166.22*** (17.96)
Price Sub	-5.27 (2.77)	-7.92 (4.79)	12.93* (6.13)
Demographics	12.20*** (2.87)	14.74*** (4.42)	15.37* (6.75)
Preference	15.62* (6.88)	3.77 (10.19)	-46.62*** (12.43)
Total	-19.93 (13.90)	-90.33*** (15.44)	-184.55*** (20.17)

Notes: Bootstrapped standard errors in parentheses. Asterisks refer to estimates' significance at 0.001 (***), 0.01 (**) and 0.05 (*) level.

8 4.5 Decomposition diagnostics and robustness checks

9 Since the AIDS model predicts exact shares at the sample mean, our decompo-
10 sition strategy is also exact on average, as changes in both the coefficients and
11 socio-economic determinants are accounted for. Thus, when comparing the sum
12 of the individual components to the observed changes in expenditure shares,
13 i.e. the dependent variables of the demand systems, we expect the difference to
14 be negligible, as any discrepancy would simply depend on rounding effects and

1 non-linearities in the iterative estimation procedures.

2 In principle, the translation of the expenditure share decomposition into quan-
3 tity and emission effects is also exact at the sample mean. However, while
4 theoretically (16) also yields identities at the sample mean, it implies the pos-
5 sibility of observing share changes for each household in the sample. Since our
6 data-set is not longitudinal, we cannot observe individual household-level share
7 changes. Empirically, we must rely on an approximation, i.e. we refer to the
8 representative (average) household in each time period. As the transformation
9 in (16) is non-linear, this approximation is not exact and some error is expected.
10 Table 7 compares the estimated change in shares and emissions¹⁸ to the observed
11 change, together with a t-test on the difference.

12 As expected, the error from the expenditure share decomposition is negligible
13 (the highest margin being 0.22%) and never significantly different from zero.
14 The approximation to obtain GHGE estimates holds quite well, too. First, the
15 directions of all estimated changes are fully consistent with those of the observed
16 changes. Second, only two food groups (oils and fats and miscellaneous foods)
17 return a significant error, and their emission levels only change by less than 1
18 Kg CO₂e per person per year. Finally, the error is slightly larger for the two
19 drink groups (significant at the 5% level, but not at the 1% level), but again
20 there is a high consistency in terms of direction and total effect size.

21 As our strategy rests on consistent estimation of the AIDS model coeffi-
22 cients, and there is a rich literature on potential estimation biases, we ran a set
23 of robustness checks. The estimation biases we consider are: (a) demographic
24 scaling and measurement units; (b) endogeneity of total food expenditure; (c)

¹⁸Comparisons for quantity changes are available as Supplemental Material, sheet G

Table 7. Differences in estimated and observed change in budget shares and GHGEs.

	Share (Est %)	Share (Obs %)	Diff	GHGEs (Est)	GHGEs (Obs)	Diff
Fruit & vegetables	0.71	0.71	0.00	-9.62	-11.18	1.56
<i>Fruit</i>	<i>0.28</i>	<i>0.28</i>	<i>0.00</i>	<i>-4.95</i>	<i>-5.91</i>	<i>0.95</i>
<i>Vegetables</i>	<i>0.44</i>	<i>0.43</i>	<i>-0.01</i>	<i>-4.67</i>	<i>-5.27</i>	<i>0.60</i>
Cereals	0.62	0.58	-0.04	-9.90	-11.16	1.26
Meat	-0.08	-0.08	0.00	-90.64	-81.42	-9.22
<i>Beef & Lamb</i>	<i>-0.07</i>	<i>-0.05</i>	<i>0.02</i>	<i>-57.36</i>	<i>-50.36</i>	<i>-7.00</i>
<i>Chicken</i>	<i>0.10</i>	<i>0.10</i>	<i>0.00</i>	<i>-5.84</i>	<i>-5.37</i>	<i>-0.47</i>
<i>Pork</i>	<i>-0.41</i>	<i>-0.42</i>	<i>0.00</i>	<i>-10.60</i>	<i>-8.88</i>	<i>-1.72</i>
<i>Other meats</i>	<i>0.31</i>	<i>0.28</i>	<i>-0.02</i>	<i>-16.84</i>	<i>-16.80</i>	<i>-0.04</i>
Fish	-0.10	-0.09	0.01	-3.16	-2.88	-0.28
Dairy & eggs	0.29	0.22	-0.08	-13.45	-18.56	5.11
<i>Milk & yoghurt</i>	<i>-0.32</i>	<i>-0.39</i>	<i>-0.07</i>	<i>-16.86</i>	<i>-21.99</i>	<i>5.13</i>
<i>Butter, cheese & dairy</i>	<i>0.32</i>	<i>0.32</i>	<i>0.00</i>	<i>-1.87</i>	<i>-1.47</i>	<i>-0.39</i>
<i>Eggs</i>	<i>0.30</i>	<i>0.29</i>	<i>-0.01</i>	<i>5.27</i>	<i>4.90</i>	<i>0.38</i>
Oils & fats	0.24	0.23	-0.01	0.11	0.98	-0.87**
Confectionery	0.05	0.01	-0.04	-10.15	-12.22	2.06
Crisps & snacks	0.04	0.04	0.00	-0.09	-0.08	-0.01
Potatoes	-0.04	-0.06	-0.01	-3.24	-3.33	0.10
Composite dishes	0.00	-0.02	-0.02	1.49	1.28	0.20
Miscellaneous food	0.30	0.28	-0.02	0.54	0.18	0.36**
Foods	2.03	1.82	-0.21	-138.11	-138.39	0.28
Alcoholic drinks	-1.57	-1.35	0.22	-19.02	-15.02	-4.00*
Non-alcoholic drinks	-0.46	-0.47	0.00	-27.41	-30.09	2.67*
Drinks	-2.03	-1.82	0.21	-46.44	-45.11	-1.33
Total	0.00	0.00	0.00	-184.55	-183.50	-1.05

Notes: Asterisks refer to estimates' significance at 0.001 (***), 0.01 (**) and 0.05 (*) level.

1 aggregation to control for non-purchases and zero expenditure biases. A com-
2 parison between the various specification is provided in Table 8
3 First, as discussed in Section 3.2, our demographic scaling approach is known
4 not to be closed under unit scaling (CUUS), which means that a change in the
5 measurement units could potentially affect the coefficient estimates. We empir-
6 ically check the extent of the problem by replicating our estimates on a data-set
7 where prices are expressed in pence per hectogram instead of £per kilogram,
8 and total expenditure is also expressed in pences rather than £. The compar-
9 ison between our benchmark model (1) and the model on rescaled prices and
10 expenditure (2) is shown in Table 8. Estimates are almost identical, and this
11 finding is robust to other scaling choices for monetary values.

1 Second, total food expenditure on the right-hand side of the AIDS equations
2 is endogenous, which would bias estimates in each time period. While instru-
3 menting total expenditure with exogenous variables (household income being
4 the typical instrument) allows to improve the consistency of the estimated co-
5 efficients, it has a major drawback for our decomposition strategy. Our aim is
6 to analyse the changes in actual household expenditure and not those in the
7 artificial (instrumented) expenditure, but the decomposition on instrumented
8 coefficients has a poorer fit with the actual data. This is clear from Table
9 8 when comparing the benchmark model (1) to the instrumented model (3).
10 When instrumenting, the difference between the estimated and the observed
11 change in total emissions becomes much larger and - as expected - estimates
12 are less efficient. While estimates of the individual effects are in line with those
13 of model (1), model (3) systematically underestimates the contribution of each
14 component except demographics.

15 Third, our approach rests on aggregation of households by region, survey month
16 and income quartile to address the censoring bias, as discussed in Section 3.4.
17 The differences with estimates obtained on the raw data-set, i.e. including ze-
18 roes (model 4) are more conspicuous. Using raw data, the overall change in
19 emissions is lower (-129.4 versus -183.5 kg CO_2e per person per year). Model (4)
20 does a good job in replicating the actual change in emissions, but the balance
21 between the various components, especially real expenditure and preferences,
22 is different from the decomposition from model (1). This suggests that biases
23 in coefficient estimates indeed matter to quantification, although the finding
24 that real expenditure and preferences are the key contributors to the observed
25 emission changes remains valid.

Table 8. Models comparison in estimating the observed GHGEs decomposition.

	(1)	(2)	(3)	(4)
Real expenditure	-166.22 (17.96)	-167.73 (16.77)	-151.26 (18.43)	-76.20 (22.88)
Price Sub	12.93 (6.13)	14.30 (5.90)	8.85 (8.21)	9.84 (4.94)
Demographics	15.37 (6.75)	15.42 (6.47)	15.03 (7.15)	13.84 (1.84)
Preference	-46.62 (12.43)	-43.59 (14.14)	-28.58 (33.61)	-79.35 (7.48)
Delta Emissions	-184.55 (20.17)	-181.60 (17.88)	-155.96 (39.72)	-131.87 (21.44)
Delta (Obs)	-183.50 (17.87)	-183.50 (15.63)	-183.50 (16.09)	-129.39 (10.89)
Difference	-1.05 (7.93)	1.89 (9.52)	27.53 (35.28)	-2.49 (18.77)

Notes: Model 1: aggregate household data
Model 2: aggregate household data, prices and expenditures rescaled
Model 3: aggregate household data, food expenditure instrumented by income
Model 4: raw household data (includes zero purchases)
None of the estimates in the row "Difference" is significantly different from 0 at the 10% level

1 4.6 Limitations and further results

2 The proposed decomposition approach necessarily rests on some assumptions
3 and is constrained by the available data. First, estimating structural changes
4 with demand models is a non-trivial exercise, and identification of changes in
5 parameters may result from specification errors rather than actual preference
6 changes (Chalfant and Alston, 1988). Thus, our findings are thus conditional
7 on the adopted, albeit standard, demand model specification.
8 Second, we compare purchases of composite food groups across different time
9 periods, but their composition and quality also changes over time. We address
10 the unit value estimation bias and quality variation within the same time period
11 by using average prices, but we have insufficient information to test whether the

1 assumption of homogenous food groups holds over time.

2 More generally, a necessary assumption of the present study is that all relevant
3 factors not explicitly considered in the decomposition are constant over time.
4 This holds for the emission conversion factors, assumed to be constant over the
5 study time span. Increased agricultural productivity and other technical miti-
6 gation options may have contributed to reduce GHGEs per unit of food ([Burney
7 et al., 2010](#); [Herrero et al., 2016](#)). Identification of the demand-side components
8 requires to leave out changes in food supply and technology. The decomposition
9 of changes in purchased quantities remains valid, while detailed information on
10 the evolution of emission factors would allow to consider a further supply-side
11 component on the decomposition of changes in GHGEs. Most importantly, a
12 comprehensive set of time-varying conversion factors accounting for technology
13 and production advancements over time is not yet available¹⁹.

14 Third, a potential extension of the present study concerns the distinction be-
15 tween domestic and foreign food-related GHGEs. An in-depth analysis requires
16 to combine consumption, production and trade information at the food group
17 level. We provide some exploratory results in [Table 9](#) which reports the share of
18 consumption from domestic products in baseline period and in the last period
19 of our study, and changes in GHGEs between the two periods. UK levels of
20 self-sufficiency have evolved heterogeneously across food groups. For example
21 the domestic share of beef and lamb, other meats and fish has become larger,
22 while the UK is increasingly relying on imports has for milk and yoghurt, con-
23 fectionery, and vegetables. This translates in some hidden effects in terms of
24 territorial GHGEs, for example food consumption GHGEs for vegetables have

¹⁹DEFRA publishes yearly conversion factors by food group to allow estimates of supply chain emissions by year and company reporting, but these refer to sales (monetary) values rather than production quantities

1 decreased by nearly 5 kg CO₂e per person per year over the study time window,
2 but domestic agriculture GHGEs have decreased to a greater extent (-21.2 kg
3 CO₂e per person per year), because the UK imports less. On balance, the to-
4 tal reduction in domestic GHGEs is larger than the total food-related GHGEs
5 (-260.51 kg CO₂e per person per year), as there as been an increase in exported
6 emissions, especially for milk and yoghurt whose domestic share has decreased
7 from 76% to less than 50%.

Table 9. Domestic share of GHGEs in baseline period (2001-2004) and period 3 (2013-2015) and total, domestic and foreign change in GHGEs between period 3 and baseline.

	Baseline	Period 3	GHGEs change	GHGEs domestic	GHGEs foreign
Fruit	5.91%	4.75%	-5.91	-1.16	-4.75
Vegetables	47.98%	38.37%	-5.27	-21.19	15.92
Cereals	97.80%	98.66%	-11.16	-9.95	-1.21
Beef & Lamb	62.34%	73.75%	-50.36	-7.06	-43.30
Chicken	88.00%	79.51%	-5.37	-9.92	4.55
Pork	50.91%	50.96%	-8.88	-4.48	-4.40
Other meats	77.83%	90.54%	-16.80	9.83	-26.63
Fish	39.68%	55.23%	-2.88	0.67	-3.55
Milk & yoghurt	76.06%	49.79%	-21.99	-122.14	100.15
Butter, cheese & dairy	67.14%	61.17%	-1.47	-8.16	6.69
Eggs	92.40%	87.66%	4.90	2.78	2.11
Oils & fats	47.32%	53.68%	0.98	2.02	-1.04
Alcoholic drinks	93.31%	80.52%	-15.02	-24.29	9.27
Non-alcoholic drinks ^a	95.09%	93.65%	-30.09	-30.13	0.05
Confectionery	96.98%	80.78%	-12.22	-37.31	25.10
Crisps & snacks	80.80%	84.63%	-0.08	-0.02	-0.07
Miscellaneous food	47.79%	79.11%	0.18	3.98	-3.79
Potatoes	82.72%	73.49%	-3.33	-3.97	0.64
Total			-184.78	-260.51	75.73

Notes: ^aJuice excluded due to missing values; composite dishes not available; GHGEs expressed in kg CO₂e p⁻¹ y⁻¹.

Sources: Authors computation on Eurostat and FAO data

1 **5 Conclusion**

2 Our decomposition allows to break down the driving forces that led to a reduc-
3 tion in UK diet-related emissions between 2001 and 2015. As household food
4 and drink purchases are the result of a complex set of determinants that may act
5 in different directions, we exploit a theory-based allocative consumer demand
6 model to identify substitution patterns and estimate the relative contribution
7 of various economics and demographic drivers. We also account for evolving
8 preferences, a dimension which has been overlooked in previous demand decom-
9 position studies.

10 The proposed modelling strategy allows to identify a few clear patterns behind
11 the evolution of UK household food and drink choices, and the resulting reduc-
12 tion in diet-related emissions. According to our estimates from LCF data, food
13 purchases of UK household have decreased by about 10.5% between the baseline
14 period (2001-2004) and the latest study period (2013-2015), which translates in
15 a reduction of GHGEs by 8.3%.

16 Three key findings can be extrapolated from our estimates. First, the evolution
17 of (real) food budgets over time has led to food baskets with lower emissions.
18 This tendency has become stronger over time, not least because of the effects
19 of the economic recession which has reduced the average real food budget by
20 4%. This is certainly the strongest driver behind the change in emissions, as it
21 accounts for about 90% of the observed reduction.

22 Second, we disentangle the impact of changing household preferences. Had
23 budgets, prices and demographics remained the same, UK household would still
24 have reduced their emissions, albeit to a lower extent. We estimate that the
25 preference shift would have reduced emissions by 25.2%.

1 Third, relative prices and demographics have acted towards an increase in emis-
2 sions, but their impact on diets is much smaller relative to the other factors.
3 Ageing of the population, together with rising unemployment rates, are asso-
4 ciated with relatively higher emissions. Over the study period these patterns
5 have been regular, but in the last study period the emission-increasing impact
6 of socio-demographic trends was less than one third of the emissions saved be-
7 cause of more sustainable preferences. Similarly, the evolution of relative prices
8 has only led to a minor increase in emissions, and more generally prices do not
9 seem to act in a clear direction and univocal in terms of aggregate emissions, as
10 they were not significantly different from zero over the first two period of our
11 analysis. [This small price effect suggests that taxes inducing minor changes in](#)
12 [relative prices are unlikely to significantly reduce emissions, although they may](#)
13 [have a signalling effect and therefore reach their objective through preferences.](#)
14 This study contributes to the evidence base for developing consumer targeted
15 emission-reducing food policies. Our methodology is based on average food and
16 drink choices, but it could be applied to identify patterns in relevant population
17 sub-groups, or even adapted to consider the full distribution. A better under-
18 standing of the heterogeneity and time patterns in food purchases can help to
19 generate a meaningful impact in reducing food-related greenhouse gas emis-
20 sions. Our findings point out at the relevance of food preferences and tastes,
21 and emphasise that they have become more sustainable over time. Education
22 and information measures, or more generally awareness of sustainability issue,
23 could become even more relevant during times of economic expansion. We also
24 find that the income effect of price changes (i.e. their influence on household
25 purchasing powers) is far more important than substitution effects linked to

1 relative prices. If food assistance programs or fiscal policies such as subsidies
2 and taxes are to be considered for nutritional and/or environmental goals, it is
3 crucial to account for their heterogeneous effect across food groups.

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5 A Appendix

6 A.1 Decomposition of changes in budget share from the 7 AIDS model

Based on the AIDS model specification in (6) and using the same notation as
in the main article, Equation 13 can be written explicitly as:

$$\begin{aligned}
\Delta w &= E_{price,i} + E_{expen,i}^{nominal} + E_{demo,i} + E_{pref,i} \\
&= \sum_j \gamma_{ij1} (\ln p_{j1} - \ln p_{j0}) + \beta_{i1} (\ln P_{0,\Theta_1} - \ln P_{1,\Theta_1}) \\
&\quad + \beta_{i1} (\ln x_1 - \ln x_0) + \lambda_{i1} (\mathbf{d}_1 - \mathbf{d}_0) + \alpha_{i1} - \alpha_{i0} \\
&\quad + \ln p_{j0} \sum_j (\gamma_{ij1} - \gamma_{ij0}) + \ln x_0 (\beta_{i1} - \beta_{i0}) \\
&\quad - \beta_{i1} \ln P_{0,\Theta_1} + \beta_{i0} \ln P_{0,\Theta_0} + \mathbf{d}_0 (\lambda_{i1} - \lambda_{i0})
\end{aligned} \tag{A.1}$$

After some algebra, (A.1) becomes:

$$\begin{aligned}
\Delta w_i &= \alpha_{i1} - \alpha_{i0} + \sum_j \gamma_{ij1} \ln p_{j1} - \sum_j \gamma_{ij0} \ln p_{j0} \\
&\quad + \beta_{i1} \ln \frac{x_1}{P_1} - \beta_{i0} \ln \frac{x_0}{P_0} + \lambda_{i1} \mathbf{d}_1 - \lambda_{i0} \mathbf{d}_0
\end{aligned} \tag{A.2}$$

1 which corresponds to writing $\Delta w = w_i(\mathbf{p}_1, x_1, P_1, \mathbf{d}_1 | \Theta_1) - w_i(\mathbf{p}_0, x_0, P_0, \mathbf{d}_0 | \Theta_0)$,
 2 or in short $w_{i1} - w_{i0}$ as in (13).

3 **A.2 From budget shares to quantities**

In order to translate the decomposition of budget share variation into the corresponding breakdown for purchased quantities, we start from the equality $q_{it} = w_{it} \frac{x_t}{p_{it}}$. This equality is valid under the assumption that a composite food group i is homogeneous over time and across households, i.e. there are no quality adjustments and its relative composition is also constant. When detailed information on the individual foods within the composite food group is available, it could be possible to relax this assumption (see Nelson, 1991, pag. 1208). Hence, the following equation holds for the difference between two periods 0 and 1:

$$\Delta q_i = w_{i1} \frac{x_1}{p_{i1}} - w_{i0} \frac{x_0}{p_{i0}} \quad (\text{A.3})$$

4 where x_t is the total food and drink expenditure and p_{it} is the price for good i
 5 at time t . In order to decompose Δq_i , we want to isolate the effects of changes
 6 in prices, demographics, expenditure and preferences on purchased quantities,
 7 consistently with the budget share decomposition in (13).

By subtracting and adding $w_{i0} \frac{x_1}{p_{i1}}$ from the right hand side of (A.3), after some simple passages we obtain:

$$\Delta q_i = \Delta w_i \frac{x_1}{p_{i1}} + w_{i0} \left(\frac{x_1}{p_{i1}} - \frac{x_0}{p_{i0}} \right) \quad (\text{A.4})$$

By replacing Δw_i with its components from (13) one can express the observed

change in quantities as a function of the previously obtained components:

$$\Delta q_i = (E_{price,i}^{subs} + E_{price,i}^{inc} + E_{expen,i}^{nominal} + E_{demo,i} + E_{pref,i}) \frac{x_1}{p_{i1}} + E_{PP}^Q \quad (\text{A.5})$$

where the last term is defined as:

$$E_{PP}^Q = w_{i0} \left(\frac{x_1}{p_{i1}} - \frac{x_0}{p_{i0}} \right) \quad (\text{A.6})$$

This term is an adjustment required to account for the change in purchasing powers between the two periods.

All terms between brackets in the right hand side of (A.5) are components of the expenditure share change. By multiplying these components by $\frac{x_1}{p_{i1}}$, we obtain quantities at time 1. Thus, the decomposition of quantities can be made explicit:

$$\begin{aligned} E_{price,i}^{Q,subs} &= E_{price,i}^{subs} r_{i1} = \sum_j \gamma_{ij1} (\ln p_{j1} - \ln p_{j0}) r_{i1} \\ E_{price,i}^{Q,inc} &= E_{price,i}^{inc} r_{i1} = \beta_{i1} (\ln P_{0,\Theta_1} - \ln P_{1,\Theta_1}) r_{i1} \\ E_{expen,i}^{Q,nominal} &= E_{expen,i}^{nominal} r_{i1} = \beta_{i1} (\ln x_1 - \ln x_0) r_{i1} \\ E_{demo,i}^Q &= E_{demo,i} r_{i1} = \lambda_{i1} (\mathbf{d}_1 - \mathbf{d}_0) r_{i1} \\ E_{pref,i}^Q &= E_{pref,i} r_{i1} = [\alpha_{i1} - \alpha_{i0} + \ln p_{j0} \sum_j (\gamma_{ij1} - \gamma_{ij0}) + \\ &\quad + \ln x_0 (\beta_{i1} - \beta_{i0}) - \beta_{i1} \ln P_{0,\Theta_1} + \beta_{i0} \ln P_{0,\Theta_0} + \mathbf{d}_0 (\lambda_{i1} - \lambda_{i0})] r_{i1} \end{aligned} \quad (\text{A.7})$$

where $r_{it} = \frac{x_t}{p_{it}}$ is the ratio between total expenditure and the price of good i at time t . In order to evaluate the expenditure effect in real terms, one must consider both the income effect of price changes, and the adjustment factor which control

for purchasing power changes relative to the chosen reference period. Hence:

$$E_{expen,i}^{Q,real} = E_{expen,i}^{Q,nominal} + E_{price,i}^{Q,inc} + E_{PP}^Q \quad (\text{A.8})$$

1 A.3 Additional Results

Table A1. Percentage variation decomposition in period 3 (2013-2015) relative to observed quantities in the baseline period (2001-2004).

	Quantity kg p ⁻¹ y ⁻¹	Real exp.(%)	Price sub.(%)	Demo (%)	Pref. (%)	Total (%)
Fruit & vegetables	122.57	-6.47	0.31	1.59	6.72	2.14
<i>Fruit</i>	53.85	-0.95	1.72	2.13	3.85	6.76
<i>Vegetables</i>	68.72	-10.80	-0.80	1.16	8.96	-1.48
Cereals	65.08	-14.80	0.12	-0.29	1.02	-13.95
Meat	51.35	-8.53	0.80	0.24	-2.80	-10.29
<i>Beef & Lamb</i>	11.48	-16.87	1.16	1.11	-5.47	-20.06
<i>Chicken</i>	15.77	-5.59	-2.58	-1.19	6.10	-3.27
<i>Pork</i>	8.78	1.58	1.51	1.20	-13.69	-9.40
<i>Other meats</i>	15.32	-11.09	3.60	0.50	-3.72	-10.70
Fish	5.00	-20.62	1.20	1.01	-1.67	-20.08
Dairy & eggs	147.67	10.72	-0.18	2.30	-14.50	-1.66
<i>Milk & yoghurt</i>	130.64	12.75	0.19	2.48	-18.09	-2.67
<i>Butter, cheese & dairy</i>	10.33	-3.31	-2.34	0.97	9.16	4.48
<i>Eggs</i>	6.69	-7.18	-3.95	0.71	19.14	8.72
Oils & fats	9.20	-13.80	-6.10	-0.20	15.37	-4.73
Confectionery	45.78	-1.82	0.02	2.19	-5.84	-5.45
Crisps & snacks	4.55	1.03	0.31	-1.78	1.67	1.23
Potatoes	49.47	-16.66	-3.24	1.39	-6.62	-25.13
Composite dishes	28.55	4.29	2.19	-1.43	2.53	7.59
Miscellaneous food	11.98	7.28	-2.71	0.76	4.40	9.74
Food	541.22	-2.83	-0.22	1.22	-3.18	-5.02
Alcoholic drinks	48.29	0.12	-0.31	-1.98	4.19	2.02
Non-alcoholic drinks	139.95	-11.22	0.68	-4.91	-6.49	-21.94
Drinks	188.24	-8.31	0.42	-4.16	-3.75	-15.80
Total	729.46	-4.25	-0.05	-0.17	-3.33	-7.80

Notes: Drink quantities are expressed in Lt p⁻¹ y⁻¹.