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

Published Version:
Beatrice Biondi, C.C. (2021). Demand drivers and changes in food-related emissions in the UK: A decomposition approach. ECOLOGICAL ECONOMICS, 188(October), 1-15 [10.1016/j.ecolecon.2021.107114].

Availability:
This version is available at: https://hdl.handle.net/11585/821946 since: 2021-06-14

Published:
DOI: http://doi.org/10.1016/j.ecolecon.2021.107114

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

Beatrice Biondi[1], Concetta Castiglione[2], and Mario Mazzocchi[3]

[1] *Department of Statistical Sciences, University of Bologna, b.biondi@unibo.it*
[2] *Department of Economics, Statistics and Finance, University of Calabria, concetta.castiglione@unical.it*
[3] *Department of Statistical Sciences, University of Bologna, m.mazzocchi@unibo.it*

July 9, 2021

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.

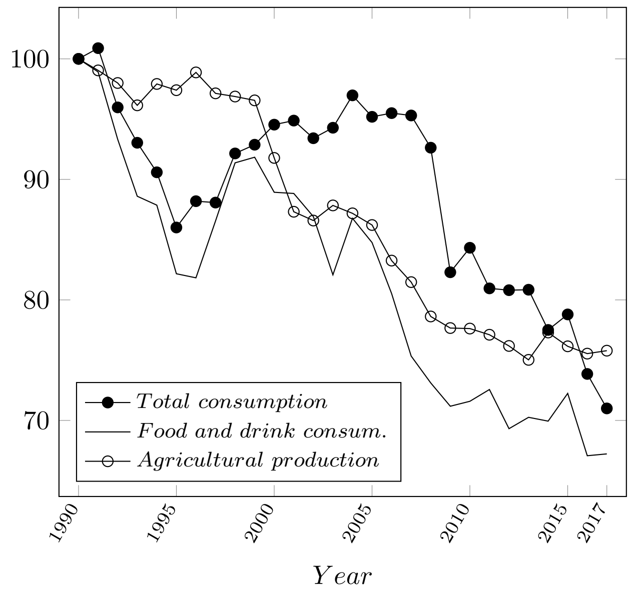
JEL classification: D12, Q18, Q51
Keywords: Greenhouse Gas Emission; Food Choices; Preference; Price; Sustainability; Food Policy.

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 (CO_2e) 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 CO_2e 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 GHGEs[1] (total vs food and drinks) and agricultural production-driven GHGEs[2]: 1990-2017 UK trends (1990=100)



[1] Department for Environment, Food & Rural Affairs (DEFRA, 2020)
[2] National Statistics (National Statistics, 2021)

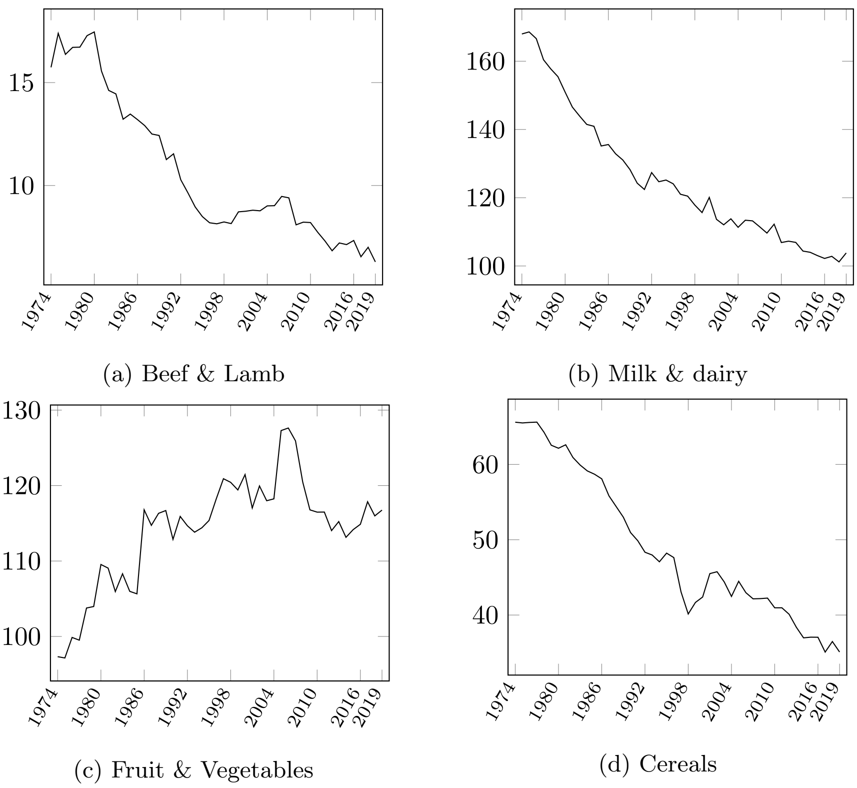
still ongoing in 2017, whereas the decline in food-related emissions has become slower after 2012. More specifically, total per capita consumption-related emissions have fallen by 23.3% between 2008 and 2017, against a decrease of 8% for food and drinks. Thus, a key question is whether there is still room for policies to further reduce emissions from food and drink consumption. Answering such question requires an exploration of the drivers of food and drink consumption. The present study aims at exploring the determinants of the changes in UK food-related GHGEs. More specifically, our goal is the decomposition of changes in total food-related GHGEs into different components associated with evolving consumer preferences, price dynamics, changes in household food budgets, and demographic trends. The innovation in our approach lies in the explicit consideration of changes in consumer preferences. For the empirical analysis, our study takes into account GHGEs from food and drink purchased in the UK over the years between 2001 and 2015.

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

2 Trends in UK food and drink purchases and their determinants

The major structural changes observed in food and drink purchases over time have a major impact on the evolution of the UK food carbon footprint. Figure 2 displays the trends in per capita purchases of selected food groups between 1974 and 2019. Beef and lamb purchases have declined since the Eighties, and the 2019 consumption levels were slightly above one third of those observed in 1980. Milk and dairy products have also undergone a regular reduction, with a steep descent until the 1990s and a slower but regular one afterwards. The decrease in consumption of animal products is only partially compensated by growing consumption in other categories. Fruit and vegetable purchases have increased by 31% between 1974 and 2006, then decreased by 8.5% since then. Consumption of cereal products has also steadily declined, and the 2019 levels are almost half of those of 1974. Indeed, considering the most recent DEFRA (2020) family food statistics, the total quantity of purchased foods was 11.2% lower in 2019 relative to 1974.

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



(a) Beef & Lamb

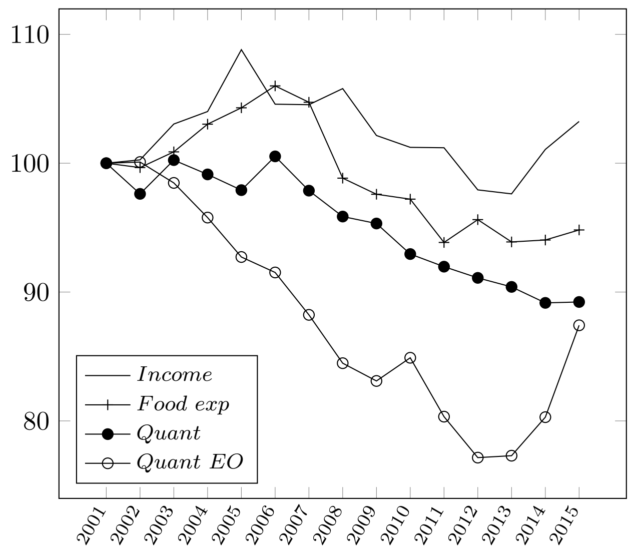
(b) Milk & dairy

(c) Fruit & Vegetables

(d) Cereals

The fact that UK residents are eating less – or wasting less – food at home had been observed before (see e.g. Griffith et al., 2016), together with some evidence that this decrease is not explained with substitution with out-of-home food consumption. Figure 3 displays trends in real household income, food expenditure, and food purchases for home and eating out consumption, over the period 2001-2015. Before the onset of the 2008 financial crisis, purchases for home consumption and household income have followed similar patterns. From 2008, the crisis has reduced purchases, whereas the effects on incomes become visible with a year delay. Furthermore, the impact is much stronger on real food budgets compared to income: in 2007, both measures where 5% higher than their 2001 value, in 2015 household income had recovered to a level which was 3% higher than 2001, whereas real food expenditure was still 5% lower. Estimates on eating out quantities show a regular decline until 2009, then they closely follow income changes, with a sharper fall during the recession years, and a recovery towards the end of the period.

Figure 3: Household income[1] deflated by general CPI[2]; Food expenditure[1] deflated by food CPI[2]; Food quantity purchased per household[1]; Food quantity per capita eaten out[1] (2001=100)

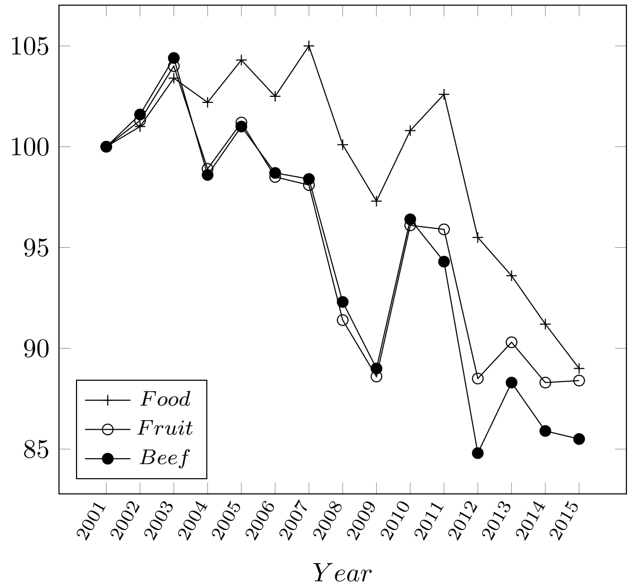


[1] Our estimates using Expenditure and Food Survey, and Living Cost and Food Survey data (DEFRA, 2019);
[2] Office for National Statistics

Thus, the evidence points towards reduced emissions because of lower overall consumption. Over the last two decades this trend seems to be closely associated with the evolution of purchasing powers. It remains an open question whether and how other forces like prices, consumer preferences and demographic changes have acted on food-related emissions.

Figure 4 shows the evolution of the real price indices for food as a whole, fruit and beef. Relative to the overall index, food has been more expensive until 2012, with a single exception in 2009. Between 2012 and 2015, average food prices have sharply declined. What especially matters to substitutions, however, is the relative price of individual foods. For example, beef and fruit retail prices have moved simultaneously until 2010 and they have been systematically cheaper than the average food. In 2011 the two price indices have started to diverge, with fruit becoming relatively more expensive. In our study we explore to what extent changes in relative prices have influenced substitutions within the food basket, which in this specific case would favour more emission-intensive 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.

3 Methodology

The identification of components and drivers of changes in emission sources has been the subject of study especially in the energy economics field (see Wang et al., 2017). Fewer studies look at the decomposition of food-related emissions (see e.g. Hawkins et al., 2018), and to the best of our knowledge they are not based explicitly on demand modelling. Regardless of the sustainability focus, several studies have looked at the relative contribution of prices and incomes, and less frequently demographics, in explaining changes in demand for specific goods. These studies generally assume constant consumer preferences (i.e. constant model parameters) over the considered time span. For example, Heien and Wessells (1988) assume constant elasticities to decompose changes in US demand for dairy products over the period 1948-1984. Similarly, Nelson (1997) explores the relative weight of prices, income and demographics in explaining the evolution of US alcohol consumption between 1980 and 1990, again assuming a constant-parameter demand model over the decade[1]. A more comprehensive modelling strategy is proposed in Karagiannis and Velentzas (2004), who quantify the contribution of price, income and habits to changes in consumer demand for five very aggregate consumption categories, using a dynamic demand system. Again, their decomposition is obtained by assuming constant coefficient models, so that elasticities depend on expenditure shares, but preferences are held constant. The possibility of evolving preferences is considered in Selvanathan and Selvanathan (2004) who allow for a linear trend in a demand model for Australian alcohol consumption. Indeed, even with this simple time-

[1] The 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

changing intercept, they find preference effects to be significant and substantial. A closer attempt to allow for time-varying preferences is the study by Okrent and Macewan (2014) on the demand for non-alcoholic beverages in the US. They consider advertising expenditure as an additional factor in the demand model, consistently with the idea that preferences and tastes can be influenced by information and promotion actions. However, when simulating demand changes over two sub-samples to capture relative contributions before and after the 2008 recession, this study also assumes constant (average) elasticities.

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

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

3.1 Decomposing demand change into preference and socio-economic determinants

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

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

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

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

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

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

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

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

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

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

Equation (5) shows that the preference change reflects the difference in the coefficients, while holding constant the set of determinants at their value at time 0. Instead, the contribution of the changing determinants towards the new level of consumption C_1 depends on the coefficients β at time 1[2].

3.2 Decomposition using the AIDS specification

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

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 goods, based on consumer preferences at time t with data on $t = 1, ..., T$ time periods, is specified as follows:

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

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

[2] The 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 $\beta_0 X_1$.

good i purchased at time t. Demographic variables enter the model through the following intercept specification[3]:

$$\tilde{\alpha}_{it} = \alpha_{it} + \lambda_{it}\mathbf{d_t} \tag{7}$$

where $\mathbf{d_t}$ is a vector of socio-demographic household characteristics. The price index P_t is defined as follows:

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

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

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

$$\begin{aligned} E_{price,i} &= w_i(\mathbf{p_1}, x_1, P_1, \mathbf{d_1}|\Theta_1) - w_i(\mathbf{p_0}, x_1, P_0, \mathbf{d_1}|\Theta_1) \\ &= \underbrace{\sum_j \gamma_{ij1}(\ln p_{j1} - \ln p_{j0})}_{\text{substitution effect}} + \underbrace{\beta_{i1}(\ln P_{0,\Theta_1} - \ln P_{1,\Theta_1})}_{\text{income effect}} \end{aligned} \tag{9}$$

[3]As 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.

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

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

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

$$\begin{aligned} E^{nominal}_{expen,i} &= w_i(\mathbf{p_1}, x_1, P_1, \mathbf{d_1}|\Theta_1) - w_i(\mathbf{p_1}, x_0, P_1, \mathbf{d_1}|\Theta_1) = \beta_{i1}(\ln x_1 - \ln x_0) \\ E_{demo,i} &= w_i(\mathbf{p_1}, x_1, P_1, \mathbf{d_1}|\Theta_1) - w_i(\mathbf{p_1}, x_1, P_1, \mathbf{d_0}|\Theta_1) = \lambda_{i1}(\mathbf{d_1} - \mathbf{d_0}) \end{aligned} \tag{10}$$

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

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

$$E^{real}_{expen,i} = E^{nominal}_{expen,i} + E^{inc}_{price,i} = \beta_{i1}(\ln \frac{x_1}{P_{1,\Theta_1}} - \ln \frac{x_0}{P_{0,\Theta_1}}) \tag{11}$$

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

$$\begin{aligned} E_{pref,i} &= w_i(\mathbf{p_0}, x_0, P_0, \mathbf{d_0}|\Theta_1) - w_i(\mathbf{p_0}, x_0, P_0, \mathbf{d_0}|\Theta_0) \\ &= \alpha_{i1} - \alpha_{i0} + \ln p_{j0} \sum_j (\gamma_{ij1} - \gamma_{ij0}) + \ln x_0(\beta_{i1} - \beta_{i0}) \\ &- \beta_{i1} \ln P_{0,\Theta_1} + \beta_{i0} \ln P_{0,\Theta_0} + \mathbf{d_0}(\lambda_{i1} - \lambda_{i0}) \end{aligned} \tag{12}$$

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

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

[4]Once 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

3.3 From share effects to quantity and emission effects

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

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

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

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

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

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

term in (15)[6]. For each good, this adjustment factor is a function of the expenditure share at the baseline period and the change over the two time periods in the ratio between total expenditure and the price for the same good. This ratio measures the quantity of each good that a consumer could buy by spending all her budget on it. The adjustment is positive when it is possible to buy a higher quantity of the good at time 1 relative to time 0 and vice versa. In other words, it is positive (negative) when a consumer purchasing power for that good has become higher (lower). The expenditure share at the baseline period weighs the importance of that good for the consumer. Given this interpretation, this adjustment factor is used to obtain the real expenditure effect along with the income effect of price changes.

In summary, we can define the quantity effects in relation to the budget share effects as follows:

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

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

[6] See the proof in Appendix A.2.

too:

$$\Delta q_i = E^{Q,subs}_{price,i} + E^{Q,real}_{expen,i} + E^{Q}_{demo,i} + E^{Q}_{pref,i} \tag{17}$$

Finally, the translation of changes in purchased quantities into changes in CO_2e greenhouse gas emissions is straightforward, and simply requires multiplication by the appropriate emission factor f_i for each good:

$$\Delta GHGE_i = \Delta q_i \ f_i \tag{18}$$

3.4 Data & estimation procedure

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

Micro-data on purchased quantities and expenditures on each food and drink item – classified according to the five-level EUROSTAT Classification of Individual Consumption by Purpose (ECOICOP) – are published at the household level. This classification is available for food and drink items purchased for home consumption, and data on purchased quantities are not available for eating out expenditures, hence our study does not cover that portion of food purchases[7]. Per-capita values for quantities, expenditures and incomes are obtained considering an adjusted household size measure based on the OECD equivalence scale (OECD, 2009). Purchase unit values are obtained for each household as the ratio between expenditure and purchased quantities for each food and drink. Unit values reflect both shelf prices and a quality component, as different households may choose different quality levels and pay different prices for the same goods (e.g. different types of strawberries). This is especially true when working with composite goods (e.g. fruit) that reflect different compositions across households, e.g. variation in the proportion of strawberries and apples within fruit. As the use of unit values leads to bias in estimates (Deaton, 1988), some procedure is needed to obtain quality-adjusted prices. A widely used approach is the definition of prices as the average unit values across households by month and government office region, under the common assumption that households in the same area and time period face the same prices.

A second issue to be considered when working with LCF data is the high frequency of non-purchases that mainly depends on the relatively short time window covered by the household diary. This is another well-known source of bias in the estimation of demand parameters (see e.g. Deaton, 1986, pp. 1807-1810). A variety of solutions has been proposed, but they often generate diverging results, with no consensus on their ability to solve the problem without generating

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

further biases[8]. To address the problem, we proceed by changing the unit of analysis into an artificial aggregated household by geographical region, month of the survey and income quartile.

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

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

[8] For 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).

[9] LCF 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.

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

[11] Descriptive 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

the four sets of preference structures $w_i(\mathbf{p}, x, P, \mathbf{d}|\Theta_s)$ with $s = 0, ..., 3$, where $s = 0$ indicates the baseline period. The system is estimated via Iterated Linear Least Squares (Blundell and Robin, 1999);

2. Use the previous coefficient estimates to obtain the budget share decomposition in (13) according to equations (9), (10) and (12);

3. Translate the decomposition into quantity effects by applying Equation 16;

4. Estimate the emission effects in terms of changes in carbon dioxide equivalent GHG emissions for each food product using Equation 18.

Thus, our final decompositions all refer to changes with respect to the same baseline period 2001-2004. Table 1 displays summary statistics of the key variables for each of the four time windows[12].

There are some clear patterns in the data. First, there is a progressive reduction in the amount of food and drinks purchased by UK households, especially over the last two periods. Considering the difference between the last period and the baseline period, yearly per capita purchases of food and drinks have decreased by about 78.8 kg, or 10.5%. This has also resulted in a decrease in food-related emissions by 182 kg CO_2e per year, or -8.2%.

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

[12] Descriptive 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	732.3	700.2	668.7
	(129.9)	(131.1)	(148.2)	(146.2)
Food-related GHGEs (tons CO_2e person^{-1} year^{-1})	2.22	2.20	2.13	2.04
	(0.41)	(0.41)	(0.47)	(0.47)
Av. real food&drinks price (£/kg)	2.38	2.43	2.52	2.53
	(0.36)	(0.38)	(0.45)	(0.51)
Food & drinks expenditure (£ person^{-1} year^{-1})	1332.4	1437.3	1613.3	1685.8
	(357.2)	(367.1)	(470.4)	(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	17,770.1	17,856.7	18,019.4
	(12,543.1)	(10,501.2)	(10,159.7)	(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%	9.6%	10.3%	10.3%
	(2.7)	(3.9)	(3.3)	(3.4)
Male	67.2%	58.1%	56.1%	53.1%
	(18.8)	(19.7)	(21.1)	(22.7)
Married	61.5%	60.0%	62.6%	63.2%
	(19.3)	(19.7)	(21.1)	(22.7)
Single	14.0%	14.6%	14.3%	14.6%
	(12.8)	(13.8)	(14.6)	(15.9)
Retired	22.8%	26.6%	28.1%	29.6%
	(18.8)	(20.5)	(20.6)	(21.6)
Unemployed	2.0%	2.3%	4.8%	4.1%
	(4.6)	(5.9)	(10.5)	(10.5)
HH with children	31.4%	31.0%	30.6%	31.4%
	(17.2)	(17.5)	(19.5)	(21.3)
Age	50.5	52.1	52.8	53.7
	(6.5)	(7.0)	(7.2)	(7.6)
OECD equivalence scale	1.86	1.85	1.84	1.87
	(0.27)	(0.28)	(0.31)	(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.

and we observe an increase in the food budget share, which indicates a decline in household resources, as expected in recession times, in line with Engel's Law. Our estimates of total food-related emissions also show that the decline in per capita emission has started in period 2, which suggests that economic dynamics during the financial crisis may have played a major role. The reduction in emissions seems to be strongly related to the overall decline in total food and drink quantities, rather than to a re-allocation across foods. The reduction in purchased quantities is unlikely to depend on absolute price levels, as the changes in real food and drink prices over the four time periods are small. This does not rule out that relative price changes may have influenced the consumer basket.

The proposed decomposition strategy also considers the contribution of demographic changes, and some clear and regular trends emerge from Table 1. Over time, we observe a substantial reduction in the proportion of male household reference persons (HRP) from 67.2% in the baseline period to 53.1% in the final period, a slight increase in the proportion of married HRP, a regular increase in the average age of HRP (+3.2 years between the baseline period and the last period). This latter trend also results in an increase in the proportion of households with retired HRP. How these changes affect food-related emissions depends on the association between demographics and food consumption baskets, as captured by demographic scaling in the demand system.

4 Results and Discussion

We analyse the changes in the UK food basket over the period 2001-2015 under three different dimensions: (a) changes in the food budget allocation (budget shares); (b) changes in purchased quantities; (c) changes in GHGEs. The decomposition strategy described in Section 3 is applied to all three dimensions. Here we report the key findings on the relative contribution of changes in preferences, prices, real expenditures and socio-demographics. Here we focus on quantity and emission effects, but the full set of decomposition estimates for each of the above dimensions, across the three time windows and for each individual food group is provided as Supplemental Material.

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

4.1 Changes in the preference structure

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

[13] Data 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_2e p^{-1} y^{-1}
Fruit & vegetables	0.71***	-6.04***	-11.18***
	(0.15)	(1.49)	(3.25)
Fruit	*0.28***	*-4.20****	*-5.91****
	(0.09)	*(0.82)*	*(1.15)*
Vegetables	*0.43****	*-1.84**	*-5.27**
	(0.09)	*(0.85)*	*(2.44)*
Cereals	0.58***	-5.93***	-11.16***
	(0.08)	(0.62)	(1.17)
Meat	-0.08	-5.74***	-81.42***
	(0.14)	(0.69)	(9.52)
Beef & Lamb	*-0.05*	*-2.24****	*-50.36****
	(0.09)	*(0.30)*	*(6.70)*
Chicken	*0.10*	*-1.33****	*-5.37****
	(0.07)	*(0.32)*	*(1.29)*
Pork	*-0.42****	*-0.86****	*-8.88****
	(0.06)	*(0.21)*	*(2.12)*
Other meats	*0.28****	*-1.32****	*-16.80 ****
	(0.06)	*(0.23)*	*(2.95)*
Fish	-0.09	-0.98***	-2.88***
	(0.06)	(0.14)	(0.40)
Dairy & eggs	0.22*	-5.85***	-18.56***
	(0.09)	(1.41)	(5.37)
Milk & yoghurt	*-0.39****	*-6.72****	*-21.99****
	(0.08)	*(1.31)*	*(4.28)*
Butter, cheese & dairy	*0.32****	*-0.13*	*-1.47*
	(0.04)	*(0.18)*	*(2.05)*
Eggs	*0.29****	*1.00****	*4.90****
	(0.02)	*(0.13)*	*(0.62)*
Oils & fats	0.23***	0.38*	0.98*
	(0.03)	(0.16)	(0.42)
Confectionery	0.01	-3.26***	-12.22***
	(0.08)	(0.49)	(1.82)
Crisps & snacks	0.04	-0.29***	-0.08***
	(0.03)	(0.07)	(0.02)
Potatoes	-0.06	-9.85***	-3.33***
	(0.03)	(0.77)	(0.26)
Composite dishes	-0.02	0.23	1.28
	(0.10)	(0.38)	(2.10)
Miscellaneous food	0.28***	0.18	0.18
	(0.07)	(0.17)	(0.17)
Foods	**1.82*****	**-37.14*****	**-138.39*****
	(0.25)	**(3.77)**	**(16.73)**
Alcoholic drinks	-1.35***	-8.33***	-15.02***
	(0.25)	(1.31)	(2.36)
Non-alcoholic drinks	-0.47***	-33.50***	-30.09***
	(0.08)	(1.93)	(1.74)
Drinks	**-1.82*****	**-41.84*****	**-45.11*****
	(0.25)	**(2.43)**	**(3.05)**
Total	0.00	-78.98***	-183.50***
	(0.00)	(4.89)	(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.

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

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

[14]The 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_2e p^{-1} y^{-1}
Fruit & vegetables	0.90***	7.06***	14.59**
	(0.26)	(2.06)	(4.63)
Fruit	*0.51***	*3.87***	*5.44***
	(0.16)	*(1.21)*	*(1.69)*
Vegetables	*0.39**	*3.19**	*9.15**
	(0.16)	*(1.32)*	*(3.80)*
Cereals	0.35*	2.45*	4.61*
	(0.15)	(1.08)	(2.03)
Meat	-0.41	-0.89	-18.82
	(0.30)	(0.79)	(10.84)
Beef & Lamb	*0.01*	*0.03*	*0.57*
	(0.18)	*(0.39)*	*(8.71)*
Chicken	*0.42***	*1.39***	*5.61***
	(0.13)	*(0.43)*	*(1.75)*
Pork	*-0.66****	*-1.78****	*-18.36****
	(0.17)	*(0.45)*	*(4.67)*
Other meats	*-0.19*	*-0.52*	*-6.64*
	(0.15)	*(0.40)*	*(5.11)*
Fish	-0.04	-0.06	-0.18
	(0.12)	(0.17)	(0.51)
Dairy & eggs	-0.13	-9.70***	-23.44**
	(0.17)	(2.48)	(8.59)
Milk & yoghurt	*-0.68****	*-12.43****	*-40.66****
	(0.13)	*(2.43)*	*(7.96)*
Butter, cheese & dairy	*0.20**	*0.57**	*6.60**
	(0.10)	*(0.28)*	*(3.26)*
Eggs	*0.34****	*2.17****	*10.63****
	(0.06)	*(0.38)*	*(1.88)*
Oils & fats	0.17*	0.95*	2.44*
	(0.08)	(0.45)	(1.14)
Confectionery	-0.60***	-3.19 ***	-11.99 ***
	(0.17)	(0.93)	(3.50)
Crisps & snacks	0.03	0.08	0.02
	(0.08)	(0.19)	(0.06)
Potatoes	-0.18*	-3.17*	-1.07*
	(0.08)	(1.45)	(0.49)
Composite dishes	-0.33	-1.18	-6.47
	(0.22)	(0.78)	(4.27)
Miscellaneous food	0.51*	1.33*	1.34*
	(0.21)	(0.55)	(0.55)
Foods	**0.27**	**-6.33**	**-38.97** **
	(0.41)	**(3.96)**	**(14.16)**
Alcoholic drinks	0.13	0.49	0.88
	(0.39)	(1.40)	(2.52)
Non-alcoholic drinks	-0.40*	-9.50*	-8.53*
	(0.17)	(4.11)	(3.69)
Drinks	**-0.27**	**-9.02***	**-7.66**
	(0.41)	**(4.22)**	**(4.27)**
Total	0.00	-15.34***	-46.62***
	(0.00)	(4.55)	(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.

4.2 Changes in real food budget and relative prices

Tables 4 and 5 show the full decomposition of changes between the last period and the baseline period in purchased quantities and emissions, respectively[15]. The real expenditure component is obtained by combining the effects of nominal expenditure, the income effect of price changes, and the adjustment in purchasing powers required by the decomposition approach (see Section 3.3). The remaining price effect refers to substitutions induced by changes in relative prices and is purged from any income effect.

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

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

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

While these tendencies reflect the weight of prices on a household budget, the allocation to the various foods also depends on change in relative prices. The overall impact of the substitution effects is close to zero and non-significant in terms of total quantities, but positive and significant – albeit very small – in terms of GHGEs, with an increase of 12.9 kg CO_2e per capita per year, or 0.58% of the baseline emissions level. This very small impact is almost exclusively related to an increase in emissions from purchases of other meats, whose price has risen in real terms less than half of the increase in beef and lamb prices. Overall, the role played by changes in relative prices on purchases and emissions is negligible.

4.3 Demographic trends

Like relative prices, changes in the socio-demographic factors (mainly ageing, rising unemployment and an increase in female-led households) are not large enough to impact purchased quantities in a meaningful way. Overall, the effect on quantities is non-significant, whereas there is a slight increase in terms of emissions (15.4 kg CO_2e per person per year). The food groups that emerge as more sensitive to socio-demographic trends are confectionery, other meats and potatoes, all characterised by a positive effect on purchased quantities (hence emissions)[16]. Purchases for all three groups appear to be strongly increasing with age, and these significant increases are mainly an outcome of ageing popu-

[16]The 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***	0.46	-1.71	7.06***	-5.15***
	(1.23)	(1.38)	(1.14)	(2.06)	(1.47)
Fruit	*-5.84****	*-0.36*	*-1.19*	*3.87***	*-3.52****
	(0.67)	*(0.76)*	*(0.68)*	*(1.21)*	*(0.85)*
Vegetables	*-5.11****	*0.82*	*-0.52*	*3.19**	*-1.63*
	(0.72)	*(1.04)*	*(0.78)*	*(1.32)*	*(0.88)*
Cereals	-7.36***	-0.22	-0.13	2.45*	-5.26***
	(0.57)	(0.69)	(0.53)	(1.08)	(0.80)
Meat	-6.54***	0.60	0.48	-0.89	-6.34***
	(0.59)	(0.52)	(0.43)	(0.79)	(0.71)
Beef & Lamb	*-2.75****	*0.00*	*0.17*	*0.03*	*-2.55****
	(0.31)	*(0.23)*	*(0.27)*	*(0.39)*	*(0.37)*
Chicken	*-1.94****	*-0.58*	*-0.31*	*1.39***	*-1.44****
	(0.24)	*(0.38)*	*(0.24)*	*(0.43)*	*(0.34)*
Pork	*0.09*	*0.49*	*0.18*	*-1.78****	*-1.03****
	(0.14)	*(0.28)*	*(0.24)*	*(0.45)*	*(0.21)*
Other meats	*-1.94****	*0.69**	*0.45***	*-0.52*	*-1.32****
	(0.16)	*(0.32)*	*(0.17)*	*(0.40)*	*(0.26)*
Fish	-1.10***	0.06	0.02	-0.06	-1.08***
	(0.17)	(0.10)	(0.09)	(0.17)	(0.18)
Dairy & eggs	4.62***	-0.71	1.54	-9.70***	-4.24*
	(1.28)	(1.64)	(1.25)	(2.48)	(2.11)
Milk & yoghurt	*6.20****	*-0.28*	*1.36*	*-12.43****	*-5.16***
	(1.18)	*(1.59)*	*(1.22)*	*(2.43)*	*(1.97)*
Butter, cheese & dairy	*-0.97****	*0.09*	*0.15*	*0.57**	*-0.16*
	(0.13)	*(0.24)*	*(0.12)*	*(0.28)*	*(0.19)*
Eggs	*-0.61****	*-0.53*	*0.04*	*2.17****	*1.08****
	(0.12)	*(0.35)*	*(0.15)*	*(0.38)*	*(0.18)*
Oils & fats	-1.01***	-0.11	0.22	0.95*	0.04
	(0.13)	(0.36)	(0.23)	(0.45)	(0.19)
Confectionery	-1.72**	0.61	1.60***	-3.19***	-2.71***
	(0.53)	(0.56)	(0.44)	(0.93)	(0.64)
Crisps & snacks	-0.30***	-0.06	-0.03	0.08	-0.32***
	(0.06)	(0.15)	(0.08)	(0.19)	(0.10)
Potatoes	-7.69***	-0.53	1.83**	-3.17*	-9.57***
	(0.70)	(1.02)	(0.59)	(1.45)	(0.90)
Composite dishes	0.74**	0.29	0.42	-1.18	0.27
	(0.28)	(0.61)	(0.40)	(0.78)	(0.45)
Miscellaneous food	-0.16	-0.33	-0.30	1.33*	0.54*
	(0.19)	(0.23)	(0.31)	(0.55)	(0.22)
Foods	**-31.48***	**0.07**	**3.93**	**-6.33**	**-33.81***
	(3.95)	**(1.78)**	**(2.10)**	**(3.96)**	**(4.82)**
Alcoholic drinks	-8.77***	-1.07**	-1.20	0.49	-10.55***
	(1.10)	(0.37)	(0.78)	(1.40)	(1.57)
Non-alcoholic drinks	-16.91***	1.08	-5.20	-9.50*	-30.53***
	(2.21)	(2.40)	(2.75)	(4.11)	(2.50)
Drinks	**-25.68***	**0.01**	**-6.40***	**-9.02***	**-41.08***
	(2.65)	**(2.36)**	**(2.71)**	**(4.22)**	**(2.96)**
Total	-57.16***	0.08	-2.47	-15.34***	-74.89***
	(5.71)	(2.53)	(2.89)	(4.55)	(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 CO_2e person^{-1} year^{-1}).

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

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

4.4 Overall emission effects

The summary findings from our decomposition strategy are displayed in Table 6[17]. Real expenditure is clearly the main determinant of changes in diet-related GHGEs, and acts towards reducing emissions. The effect has become larger over time, especially after the onset of the economic recession. The mechanism is relatively trivial, households have progressively allocated less budget to food in real terms, because they demand less food (in terms of quantities), but especially – over the last two periods – because of the loss in purchasing powers driven by recession.

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

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

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

changes happen at the individual food level. For example, preferences in period 2 lean towards higher purchases of cereals, dairy products, chicken and other meats, and lower purchases of beef, pork, composite dishes and confectionery. During the last period, the effects of real expenditure are reinforced. The resulting lower emissions are further magnified by a sharp switch in preferences towards more sustainable choices, and only partially contrasted by substitutions 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***	-100.92***	-166.22***
	(12.55)	(13.92)	(17.96)
Price Sub	-5.27	-7.92	12.93*
	(2.77)	(4.79)	(6.13)
Demographics	12.20***	14.74***	15.37*
	(2.87)	(4.42)	(6.75)
Preference	15.62*	3.77	-46.62***
	(6.88)	(10.19)	(12.43)
Total	-19.93	-90.33***	-184.55***
	(13.90)	(15.44)	(20.17)

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

4.5 Decomposition diagnostics and robustness checks

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

In principle, the translation of the expenditure share decomposition into quantity and emission effects is also exact at the sample mean. However, while theoretically (16) also yields identities at the sample mean, it implies the possibility of observing share changes for each household in the sample. Since our data-set is not longitudinal, we cannot observe individual household-level share changes. Empirically, we must rely on an approximation, i.e. we refer to the representative (average) household in each time period. As the transformation in (16) is non-linear, this approximation is not exact and some error is expected. Table 7 compares the estimated change in shares and emissions[18] to the observed change, together with a t-test on the difference.

As expected, the error from the expenditure share decomposition is negligible (the highest margin being 0.22%) and never significantly different from zero. The approximation to obtain GHGE estimates holds quite well, too. First, the directions of all estimated changes are fully consistent with those of the observed changes. Second, only two food groups (oils and fats and miscellaneous foods) return a significant error, and their emission levels only change by less than 1 Kg CO_2e per person per year. Finally, the error is slightly larger for the two drink groups (significant at the 5% level, but not at the 1% level), but again there is a high consistency in terms of direction and total effect size.

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

[18] Comparisons 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
Fruit	*0.28*	*0.28*	*0.00*	*-4.95*	*-5.91*	*0.95*
Vegetables	*0.44*	*0.43*	*-0.01*	*-4.67*	*-5.27*	*0.60*
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
Beef & Lamb	*-0.07*	*-0.05*	*0.02*	*-57.36*	*-50.36*	*-7.00*
Chicken	*0.10*	*0.10*	*0.00*	*-5.84*	*-5.37*	*-0.47*
Pork	*-0.41*	*-0.42*	*0.00*	*-10.60*	*-8.88*	*-1.72*
Other meats	*0.31*	*0.28*	*-0.02*	*-16.84*	*-16.80*	*-0.04*
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
Milk & yoghurt	*-0.32*	*-0.39*	*-0.07*	*-16.86*	*-21.99*	*5.13*
Butter, cheese & dairy	*0.32*	*0.32*	*0.00*	*-1.87*	*-1.47*	*-0.39*
Eggs	*0.30*	*0.29*	*-0.01*	*5.27*	*4.90*	*0.38*
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.

aggregation to control for non-purchases and zero expenditure biases. A comparison between the various specification is provided in Table 8

First, as discussed in Section 3.2, our demographic scaling approach is known not to be closed under unit scaling (CUUS), which means that a change in the measurement units could potentially affect the coefficient estimates. We empirically check the extent of the problem by replicating our estimates on a data-set where prices are expressed in pence per hectogram instead of £per kilogram, and total expenditure is also expressed in pences rather than £. The comparison between our benchmark model (1) and the model on rescaled prices and expenditure (2) is shown in Table 8. Estimates are almost identical, and this finding is robust to other scaling choices for monetary values.

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

Third, our approach rests on aggregation of households by region, survey month and income quartile to address the censoring bias, as discussed in Section 3.4. The differences with estimates obtained on the raw data-set, i.e. including zeroes (model 4) are more conspicuous. Using raw data, the overall change in emissions is lower (-129.4 versus -183.5 kg co_2e per person per year). Model (4) does a good job in replicating the actual change in emissions, but the balance between the various components, especially real expenditure and preferences, is different from the decomposition from model (1). This suggests that biases in coefficient estimates indeed matter to quantification, although the finding that real expenditure and preferences are the key contributors to the observed emission changes remains valid.

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

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

4.6 Limitations and further results

The proposed decomposition approach necessarily rests on some assumptions and is constrained by the available data. First, estimating structural changes with demand models is a non-trivial exercise, and identification of changes in parameters may result from specification errors rather than actual preference changes (Chalfant and Alston, 1988). Thus, our findings are thus conditional on the adopted, albeit standard, demand model specification.

Second, we compare purchases of composite food groups across different time periods, but their composition and quality also changes over time. We address the unit value estimation bias and quality variation within the same time period by using average prices, but we have insufficient information to test whether the assumption of homogenous food groups holds over time.

More generally, a necessary assumption of the present study is that all relevant factors not explicitly considered in the decomposition are constant over time. This holds for the emission conversion factors, assumed to be constant over the study time span. Increased agricultural productivity and other technical mitigation options may have contributed to reduce GHGEs per unit of food (Burney et al., 2010; Herrero et al., 2016). Identification of the demand-side components requires to leave out changes in food supply and technology. The decomposition of changes in purchased quantities remains valid, while detailed information on the evolution of emission factors would allow to consider a further supply-side component on the decomposition of changes in GHGEs. Most importantly, a comprehensive set of time-varying conversion factors accounting for technology and production advancements over time is not yet available[19].

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

[19]DEFRA 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

decreased by nearly 5 kg CO_2e per person per year over the study time window, but domestic agriculture GHGEs have decreased to a greater extent (-21.2 kg CO_2e per person per year), because the UK imports less. On balance, the total reduction in domestic GHGEs is larger than the total food-related GHGEs (-260.51 kg CO_2e per person per year), as there as been an increase in exported emissions, especially for milk and yoghurt whose domestic share has decreased 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: [a]Juice excluded due to missing values; composite dishes not available; GHGEs expressed in kg CO_2e p^{-1} y^{-1}.
Sources: Authors computation on Eurostat and FAO data

5 Conclusion

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

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

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

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

Third, relative prices and demographics have acted towards an increase in emissions, but their impact on diets is much smaller relative to the other factors. Ageing of the population, together with rising unemployment rates, are associated with relatively higher emissions. Over the study period these patterns have been regular, but in the last study period the emission-increasing impact of socio-demographic trends was less than one third of the emissions saved because of more sustainable preferences. Similarly, the evolution of relative prices has only led to a minor increase in emissions, and more generally prices do not seem to act in a clear direction and univocal in terms of aggregate emissions, as they were not significantly different from zero over the first two period of our analysis. This small price effect suggests that taxes inducing minor changes in relative prices are unlikely to significantly reduce emissions, although they may have a signalling effect and therefore reach their objective through preferences. This study contributes to the evidence base for developing consumer targeted emission-reducing food policies. Our methodology is based on average food and drink choices, but it could be applied to identify patterns in relevant population sub-groups, or even adapted to consider the full distribution. A better understanding of the heterogeneity and time patterns in food purchases can help to generate a meaningful impact in reducing food-related greenhouse gas emissions. Our findings point out at the relevance of food preferences and tastes, and emphasise that they have become more sustainable over time. Education and information measures, or more generally awareness of sustainability issue, could become even more relevant during times of economic expansion. We also find that the income effect of price changes (i.e. their influence on household purchasing powers) is far more important than substitution effects linked to relative prices. If food assistance programs or fiscal policies such as subsidies and taxes are to be considered for nutritional and/or environmental goals, it is crucial to account for their heterogeneous effect across food groups.

References

Alston, J.M., Chalfant, J.A., Piggott, N.E., 2001. Incorporating demand shifters in the Almost Ideal demand system. Economics Letters 70, 73–78. doi:10.1016/S0165-1765(00)00322-0.

Blundell, R., Robin, J.M., 1999. Estimation in large and disaggregated demand systems: An estimator for conditionally linear systems. Journal of Applied Econometrics 14, 209–232.

Burney, J.A., Davis, S.J., Lobell, D.B., 2010. Greenhouse gas mitigation by agricultural intensification. Proceedings of the national Academy of Sciences 107, 12052–12057.

Castiglione, C., Mazzocchi, M., 2019. Ten years of five-a-day policy in the UK: Nutritional outcomes and environmental effects. Ecological Economics 157, 185–194. URL: https://doi.org/10.1016/j.ecolecon.2018.11.016, doi:10.1016/j.ecolecon.2018.11.016.

Chalfant, J.A., Alston, J.M., 1988. Accounting for changes in tastes. The journal of political economy 96, 390–410. URL: https://www.journals.uchicago.edu/doi/abs/10.1086/261543, doi:10.1086/261543.

Crippa, M., Oreggioni, G., Guizzardi, D., Muntean, M., Schaaf, E., Lo Vullo, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J., Vignati, E., 2019. Fossil co2 and ghg emissions of all world countries. Luxemburg: Publication Office of the European Union .

Deaton, A., 1986. Demand analysis. Handbook of Econometrics 3, 1767–1839. doi:10.1016/S1573-4412(86)03010-6.

Deaton, A., 1988. Quality, Quantity, and Spatial Variation of Price. American Economic Review 78, 418–430. URL: http://www.jstor.org/stable/1809142%5Cnhttp://www.jstor.org/stable/pdfplus/1809142.pdf?acceptTC=true.

Deaton, A., Muellbauer, J., 1980. An Almost Ideal Demand System. The American Economic Review 70, 312–326.

Department for Environment, Food, and Rural Affair, 2019. Living costs and food survey, 2015-2016. 3rd Edition. UK Data Service. SN: 8210, http://doi.org/10.5255/UKDA-SN-8210-5.

Department for Environment, Food, and Rural Affair, 2020. Uk's carbon footprint 1997-2017. URL: https://www.gov.uk/government/statistics/uks-carbon-footprint.

Department for Environment, Food, and Rural Affairs, 2017. Family Food 2015. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/597667/Family_Food_2015-09mar17.pdf.

Griffith, R., Lluberas, R., Lührmann, M., 2016. Gluttony and sloth? Calories, labor market activity and the rise of obesity. Journal of the European Economic Association 14, 1253–1286. URL: https://academic.oup.com/jeea/article-lookup/doi/10.1111/jeea.12183, doi:10.1111/jeea.12183.

Hawkins, J., Ma, C., Schilizzi, S., Zhang, F., 2018. China's changing diet and its impacts on greenhouse gas emissions: an index decomposition analysis. Australian Journal of Agricultural and Resource Economics 62, 45–64. URL: http://doi.wiley.com/10.1111/1467-8489.12240, doi:10.1111/1467-8489.12240.

Heien, D.M., Wessells, C.R., 1988. The Demand for Dairy Products: Structure, Prediction, and Decomposition. American Journal of Agricultural Economics 70, 219–228. doi:10.2307/1242060.

Herrero, M., Henderson, B., Havlík, P., Thornton, P.K., Conant, R.T., Smith, P., Wirsenius, S., Hristov, A.N., Gerber, P., Gill, M., et al., 2016. Greenhouse gas mitigation potentials in the livestock sector. Nature Climate Change 6, 452–461.

Hoolohan, C., Berners-Lee, M., McKinstry-West, J., Hewitt, C.N., 2013. Mitigating the greenhouse gas emissions embodied in food through realistic consumer choices. Energy Policy 63, 1065–1074. URL: http://dx.doi.org/10.1016/j.enpol.2013.09.046, doi:10.1016/j.enpol.2013.09.046.

Karagiannis, G., Velentzas, K., 2004. Decomposition analysis of consumers' demand changes: an application to Greek consumption data. Applied Economics 36, 497–504. URL: http://www.tandfonline.com/doi/abs/10.1080/00036840410001682205, doi:10.1080/00036840410001682205.

Lang, T., Mason, P., 2018. Sustainable diet policy development: Implications of multi-criteria and other approaches, 2008-2017. Proceedings of the Nutrition Society 77, 331–346. doi:10.1017/S0029665117004074.

National Statistics, 2021. Final uk greenhouse gas emissions national statistics: 1990 to 2019. URL: https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2019.

Nelson, J.A., 1991. Quality variation and quantity aggregation in consumer demand for food. American Journal of Agricultural Economics 73, 1204–1212.

Nelson, J.P., 1997. Economic and Demographic Factors in U.S. Alcohol Demand: A Growth-Accounting Analysis 1. Technical Report.

OECD, 2009. What are equivalence scales? URL: http://www.oecd.org/economy/growth/OECD-Note-EquivalenceScales.pdf.

Okrent, A.M., Macewan, J.P., 2014. The Effects of Prices, Advertising, Expenditures, and Demographics on Demand for Nonalcoholic Beverages. Technical Report 1. URL: http://ageconsearch.umn.edu/record/165903, doi:10.22004/AG.ECON.165903.

Selvanathan, E.A., Selvanathan, S., 2004. Economic and demographic factors in Australian alcohol demand. Applied Economics 36, 2405–2417. URL: http://www.tandfonline.com/doi/abs/10.1080/0003684042000280346, doi:10.1080/0003684042000280346.

Tauchmann, H., 2005. Efficiency of two-step estimators for censored systems of equations: Shonkwiler and Yen reconsidered. Applied Economics 37, 367–374. URL: http://www.tandfonline.com/doi/abs/10.1080/0003684042000306987, doi:10.1080/0003684042000306987.

Wang, H., Ang, B.W., Su, B., 2017. Assessing drivers of economy-wide energy use and emissions: IDA versus SDA. Energy Policy 107, 585–599. URL: http://dx.doi.org/10.1016/j.enpol.2017.05.034, doi:10.1016/j.enpol.2017.05.034.

Zhang, X., Wang, Y., 2017. How to reduce household carbon emissions: A review of experience and policy design considerations. Energy Policy 102, 116–124. URL: http://dx.doi.org/10.1016/j.enpol.2016.12.010, doi:10.1016/j.enpol.2016.12.010.

A Appendix

A.1 Decomposition of changes in budget share from the 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:

$$\begin{aligned}
\Delta w &= E_{price,i} + E^{nominal}_{expen,i} + E_{demo,i} + E_{pref,i} \\
&= \sum_j \gamma_{ij1}(\ln p_{j1} - \ln p_{j0}) + \beta_{i1}(\ln P_{0,\Theta_1} - \ln P_{1,\Theta_1}) \\
&+ \beta_{i1}(\ln x_1 - \ln x_0) + \lambda_{i1}(\mathbf{d_1} - \mathbf{d_0}) + \alpha_{i1} - \alpha_{i0} \\
&+ \ln p_{j0} \sum_j (\gamma_{ij1} - \gamma_{ij0}) + \ln x_0(\beta_{i1} - \beta_{i0}) \\
&- \beta_{i1} \ln P_{0,\Theta_1} + \beta_{i0} \ln P_{0,\Theta_0} + \mathbf{d_0}(\lambda_{i1} - \lambda_{i0})
\end{aligned} \tag{A.1}$$

After some algebra, (A.1) becomes:

$$\begin{aligned}
\Delta w_i &= \alpha_{i1} - \alpha_{i0} + \sum_j \gamma_{ij1} \ln p_{j1} - \sum_j \gamma_{ij0} \ln p_{j0} \\
&+ \beta_{i1} \ln \frac{x_1}{P_1} - \beta_{i0} \ln \frac{x_0}{P_0} + \lambda_{i1}\mathbf{d_1} - \lambda_{i0}\mathbf{d_0}
\end{aligned} \tag{A.2}$$

which corresponds to writing $\Delta w = w_i(\mathbf{p_1}, x_1, P_1, \mathbf{d_1}|\Theta_1) - w_i(\mathbf{p_0}, x_0, P_0, \mathbf{d_0}|\Theta_0)$, or in short $w_{i1} - w_{i0}$ as in (13).

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:

$$\Delta q_i = w_{i1} \frac{x_1}{p_{i1}} - w_{i0} \frac{x_0}{p_{i0}} \tag{A.3}$$

where x_t is the total food and drink expenditure and p_{it} is the price for good i at time t. In order to decompose Δq_i, we want to isolate the effects of changes in prices, demographics, expenditure and preferences on purchased quantities, 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:

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

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:

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

where the last term is defined as:

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

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:

$$\begin{aligned}
&E^{Q,subs}_{price,i} = E^{subs}_{price,i}\ r_{i1} = \sum_j \gamma_{ij1}(\ln p_{j1} - \ln p_{j0})\ r_{i1} \\
&E^{Q,inc}_{price,i} = E^{inc}_{price,i}\ r_{i1} = \beta_{i1}(\ln P_{0,\Theta_1} - \ln P_{1,\Theta_1})\ r_{i1} \\
&E^{Q,nominal}_{expen,i} = E^{nominal}_{expen,i}\ r_{i1} = \beta_{i1}(\ln x_1 - \ln x_0)\ r_{i1} \\
&E^Q_{demo,i} = E_{demo,i}\ r_{i1} = \lambda_{i1}(\mathbf{d_1} - \mathbf{d_0})\ r_{i1} \\
&E^Q_{pref,i} = E_{pref,i}\ r_{i1} = [\alpha_{i1} - \alpha_{i0} + \ln p_{j0}\sum_j(\gamma_{ij1} - \gamma_{ij0}) + \\
&+ \ln x_0(\beta_{i1} - \beta_{i0}) - \beta_{i1}\ln P_{0,\Theta_1} + \beta_{i0}\ln P_{0,\Theta_0} + \mathbf{d_0}(\lambda_{i1} - \lambda_{i0})]\ r_{i1}
\end{aligned} \quad \text{(A.7)}$$

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 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:

$$E^{Q,real}_{expen,i} = E^{Q,nominal}_{expen,i} + E^{Q,inc}_{price,i} + E^{Q}_{PP} \tag{A.8}$$

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
Fruit	*53.85*	*-0.95*	*1.72*	*2.13*	*3.85*	*6.76*
Vegetables	*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
Beef & Lamb	*11.48*	*-16.87*	*1.16*	*1.11*	*-5.47*	*-20.06*
Chicken	*15.77*	*-5.59*	*-2.58*	*-1.19*	*6.10*	*-3.27*
Pork	*8.78*	*1.58*	*1.51*	*1.20*	*-13.69*	*-9.40*
Other meats	*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
Milk & yoghurt	*130.64*	*12.75*	*0.19*	*2.48*	*-18.09*	*-2.67*
Butter, cheese & dairy	*10.33*	*-3.31*	*-2.34*	*0.97*	*9.16*	*4.48*
Eggs	*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}.