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Nutritional and Environmental Assessment of Increasing the Content of Fruit and Vegetables in the UK Diet

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Abstract: Despite the interest in increasing the consumption of fruit and vegetables in the UK, the total average consumption is still below the recommended intakes. Evidence indicates that the UK government's "five-a-day" policy has not been effective in reaching its goal. The results of fiscal policies (e.g., subsidies) to increase fruit and vegetable consumption are uncertain due to complex substitutions done by consumers amongst overall food choice. The goal of the present study was to estimate the prices (i.e., shadow prices) at which consumers can increase their intake of fruits and vegetables by 10% (higher than that achieved by the "five-a-day" policy) without changing the overall taste of the diet (utility). We estimated the ex-ante effect of increasing the UK's fruit and vegetable consumption by 10% on household nutrient purchases and greenhouse gas emissions. The required changes in prices were estimated by extending the model of consumer behaviour under rationing. The model combines consumption data, demand elasticities estimated from home scan data, and nutrient coefficients for 20 foods consumed in the UK. Our results suggest that to increase vegetable and fruit consumption by 10% (under the current preferences), their prices should decline by 21% and 13%, respectively. However, there is a trade-off between nutrition and environmental goals; total average household caloric purchase declined by 11 kcal, but greenhouse gas emissions increased by 0.7 CO_2-eq kg/kg of food.

Keywords: five-a-day; emissions; sustainable diets; fruit and vegetable consumption

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1. Introduction

Dietary choices have been named as one of the leading global cause of poor population and environmental health [1,2]. Environmental problems associated with unsustainable diets and their implications on production include climate change, water pollution, and loss of habitats and biodiversity [1]. In addition, health-related problems include non-communicable diseases such as cardiovascular diseases and diabetes [3].

From above, it is clear that individual consumption decisions have major implication for both climate and human health [4]. Therefore, there is a need for behavioural change and nutritional policies towards more sustainable lifestyles [5]. However, efforts are largely minimal toward integrated sustainable policies that tackle both environmental and health-related problems [1].

Healthy diets are widely considered those high in fruit and vegetables. These foods are considered essential in dietary guidance because of their concentrations of vitamins, especially vitamins C and A; minerals; and more recently phytochemicals, especially antioxidants [6]. They are also rich in antioxidant compounds, which have been suggested to reduce the risk of chronic diseases such as diabetes and cancers [7]. For instance, an increase in consumption of fruit and vegetables to 400 g or five portions a day has been advocated by national and international bodies [8–10] on the assumption that such a change would reduce the incidence of both cancer and cardiovascular diseases. Lin &

Morrison also found that people who eat more servings of fruit each day have a lower body mass index (BMI); a higher BMI is associated with certain cardiovascular diseases and diabetes [11].

Despite the substantial evidence that diets rich in fruit and vegetables could reduce the incidence of cardiovascular disease (CVD) and cancers of the upper gastrointestinal tract [12–15], fruit and vegetable intakes in the UK remain below recommended levels [16]. On average, 314 g of fruit and vegetables are consumed per person daily in the UK (Great Britain National Food Survey Committee, 2000). This makes Britain's average intakes no more than three servings a day [17]. National and international agencies such as the Health Education Board for Scotland and the World Health Organization have therefore promoted the "five-a-day" message as a means of helping to reduce those diseases [18,19]. Empirical studies by Capacci and Mazzochi showed that the "five-a-day" message was able to increase fruit and vegetable consumption by 0.3 portions between 2002 and 2006 [20]. However, this is unsustainable due to the continuous rise in the prices of fruit and vegetables in the UK.

Apart from the relevance of dietary choices for healthy nutrition, evaluating and reducing the environmental impacts of food systems are critical to ensuring sustainable supply chains [21]. Food consumption is one of the most resource intensive activities performed by households [22]. Since food consumption cannot be replaced, most studies recommend changes in dietary choices to lessen the environmental burden [23].

However, food consumption does not only reflect nutritional needs but also preferences in taste, odour, and texture, as well as culture and ethics. According to Carlsson-Kanyama, sustainable dietary goals should not only be considered from the context of environmental degradation, but also for all their immaterial qualities as well as their cultural acceptance [24], a term Irz et al. described as "taste of change" [25].

A major impediment to dietary change is related to "taste of change," which Irz et al. described as the utility forgone as a result of dietary change to induce long-term health goals and short-term pleasure and hedonistic rewards [25]. This clearly suggests that consumers are unable to comply with national and regional dietary goals because these recommendations impose changes in the palatability of diets.

A substantial body of research shows that diets high in fruit and vegetables are protective of health and have relatively low environmental impact [2]. According to Capacci and Mazzocchi, the 8.2% increase in fruit and vegetable consumption between 2002 and 2006 was a result of the UK government's "five-a-day" policy [20]. However, "Family Food" data by UK Department for Environment, Food and Rural Affairs (DEFRA) in 2020 showed that fruit and vegetable consumption has declined since 2006. To circumvent this downward trend, we simulated the prices at which consumers could increase their fruit and vegetable consumption by 10% (higher than the 8.2% achieved by the "five-a-day" policy from 2003 and 2006). We go further to model the implications for nutrition and environmental health. Specifically, we take into account the concept of "taste cost" in our demand modelling, we estimate the implication of a 10% increment in fruit and vegetable consumption on (1) the cost of fruit and vegetable purchase, (2) the nutritional composition of diets, and (3) the overall carbon footprint of diets.

Most studies addressing dietary recommendations use restrictive methods such as linear programming to estimate the least-cost diets when complying with a list of nutritional or environmental constraints [26]. Other strands of studies have relied on empirically estimated complete and incomplete demand systems to simulate the influence of government policies such as taxes on food consumption and nutrient intakes [27,28]. The former has been proven to have the following limitations: (1) The model produces unrealistic diets that are extremely cheap and made up of few food items or ingredients, and (2) the diets produced from linear programming (LP) models are not compatible with consumer taste and preferences. Following these limitations, Henson used a linear programming model that considers consumers taste and preferences, i.e., palatability, however, the number of constraints imposed was unrealistic [29].

A major limitation of using demand models is that the estimation of nutrient-based recommendations can only be assessed ex-post rather than through the price modifications required to comply with nutritional or food constraints.

Considering the above limitations, in this paper we use the approach proposed by Irz et al., which considers consumers' preferences and required substitutions to achieve a given norm [25]. According to Votruba this is important because the desirability of a nutritional policy often centres on the magnitude of taste cost [30]. Second, it permits the assessment of the effectiveness of the policy in improving diet quality and health goals as well as environmental health. Finally, the model applied here can identify the optimal set of subsidies that should be implemented, and the optimal income transfers required to achieve given nutritional objectives.

Hence, this paper contributes to the literature on sustainable diets in the UK by (1) estimating the shadow prices at which fruit and vegetable consumption can be increased (2) using a model that takes into account taste cost or constant utility, and (3) assessing the effect that increasing the quantities of fruit and vegetables in the UK diet has on nutrition and the environment (represented by the carbon footprint).

2. Literature Review

Worldwide obesity nearly tripled between 1975 and 2016; in 2016, 39% of men and 40% of women were obese [31]. Within the UK, according to the Organisation for Economic Co-operation and Development (OECD), more women than men were obese in 2020 [32]. Statistically, the percentage of individuals who are severely obese or obese has risen from 2.84% and 9.71% in 1975 to 10.44% and 28.79%, respectively. On the contrary, the percentage of individuals who have a normal body mass index has fallen from 55% to 33% [33]. Such a growing trend is worrisome and requires policy interventions that can reduce the prevalence of obesity. In addition, the number of persons in the UK with diabetes mellitus rose from 5823 persons in 2011 to 6768 persons in 2016 [33]. The continuous rise in the number of persons with diabetes follows the same trend as the number of persons who are obese in the UK. As such, cardiovascular and chronic diseases are partly attributed to overweight and obesity [34].

Treatment of obesity and related diseases has resulted in a higher cost of achieving better quality of life, as well as increased government expenditure on health care [35]. For instance, Allender and Rayner estimated the direct cost of overweight and obesity to the National Health Service (NHS) at GBP 3.2 billion [36]. As a result, various policymakers have advocated for the use of fiscal policies to internalise the social cost of obesity and related diseases [37]. From the nutrition perspective, the World Health Organization (WHO) recommended the consumption of 400 g of fruit and vegetables per day to reduce the incidence of non-communicable diseases [38,39].

2.1. Fresh Fruit and Vegetable Consumption in the UK

Despite the interest in increasing the consumption of fruits and vegetables in the UK, the total average consumption (excluding potatoes) has been below the recommended weekly intakes since 1974 (see Figure 1). The recommended intake of fruit and vegetable per person per week is 2800 g (400 g/person/day). However, the highest consumption of fruit and vegetables recorded in the UK was 2454 g per person per week (350 g/person/day) in 2006. Capacci and Mazzochi [21] attributed this figure to the UK government's "five-a-day" campaign message. However, this level could not be sustained, falling to 2230 g per person per week (318 g per person per day) in 2018. The falling rate in the consumption of fruit and vegetables requires stringent policy interventions that favour both fruit and vegetable consumption and diet palatability.

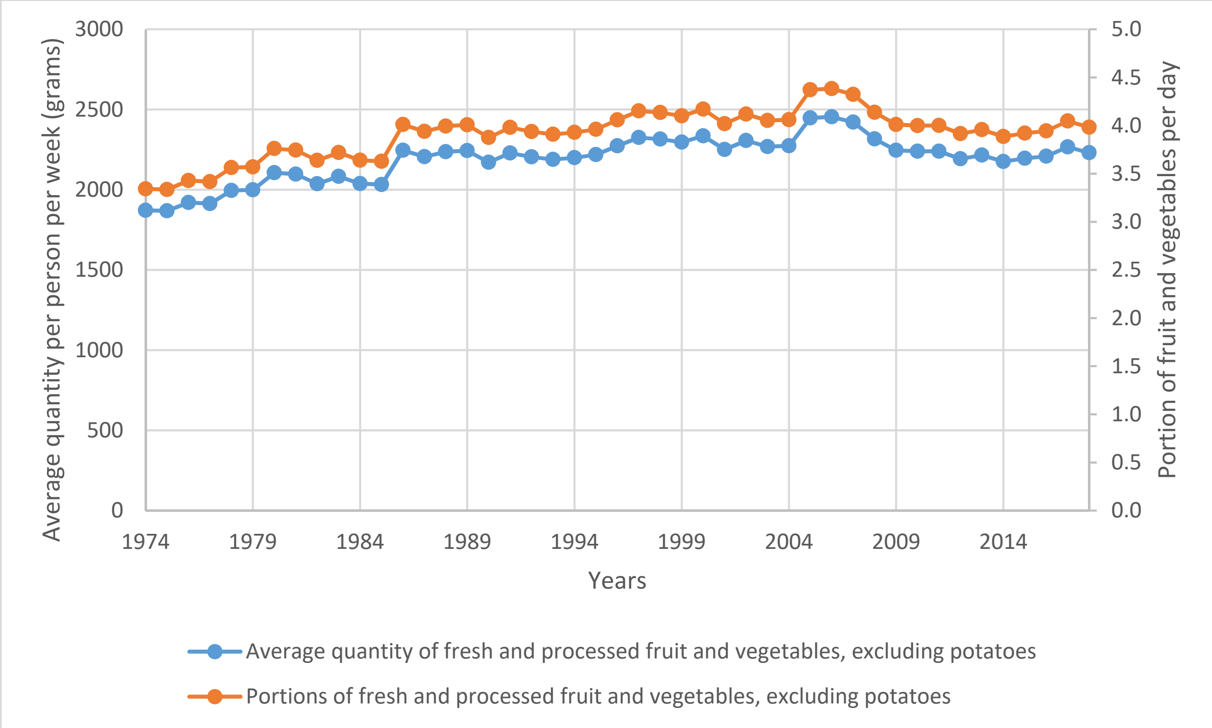

Figure 1. Average weekly consumption of fruits and vegetables in the UK. Source: Authors' computation based on National Dietary and Nutritional Survey data.

Figure 2 shows both the weekly spending and average prices of fruit and vegetables purchases from 1974 to 2018. Prices are presented on the secondary axis and the trend indicates that the cost of a gram of fresh fruits and vegetables has been on the increase since 1974. This has resulted in increased weekly expenditure per person on fruit and vegetable consumption, a phenomenon that may be an important cause of the low consumption. For instance, in 1974 the average consumer bought 1872 g of fruits and vegetables for GBP 0.48 (equivalent to 39 g/GBP 0.01) but bought 2230 g of fruits and vegetables for GBP 0.511 (equivalent to 4.4 g per GBP 0.01) in 2018. Similarly, average prices of fruit and vegetables have increased from GBP 0.0003 per gram in 1974 to GBP 0.0023 per gram in 2018. Even though we do not show the income effect on consumption, any pricing policy that could reduce the prices consumers pay for fruits and vegetables could also increase their consumption.

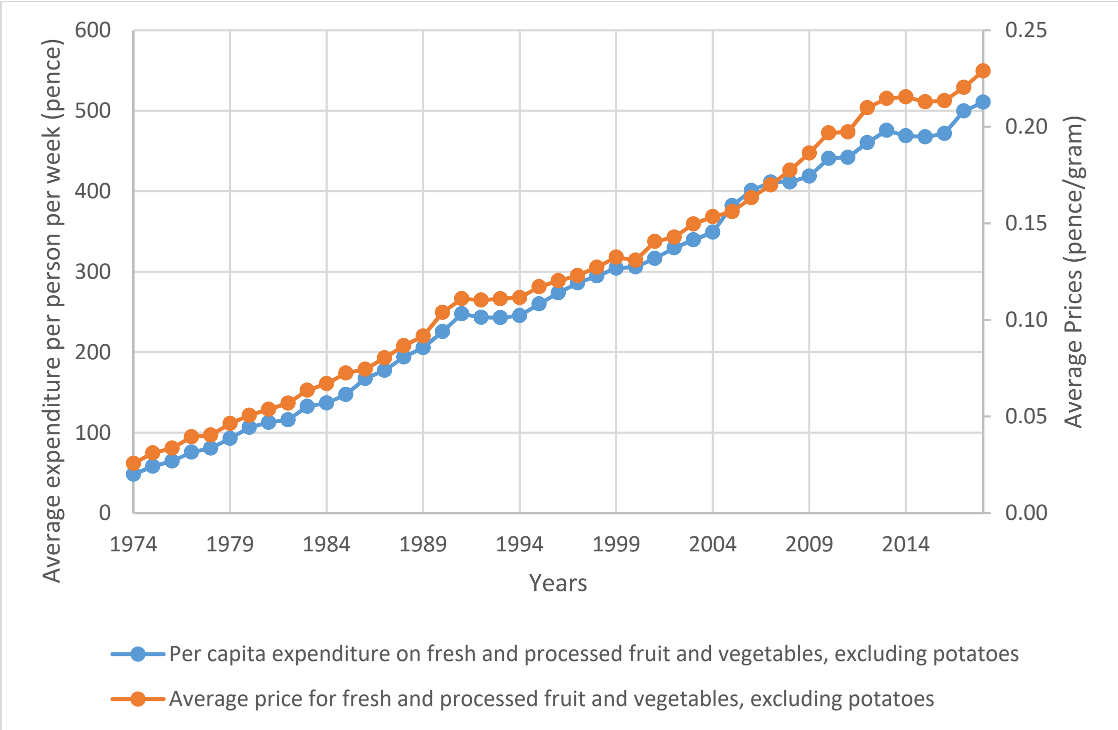

Figure 2. Average expenditure per person per week and average prices of fruits and vegetables in the UK. Source: Authors' computation based on National Dietary and Nutritional Survey data.

2.2. Evolution of Nutrient Intakes

The average daily energy intake in the UK has reduced since 1974. In addition, the average intake of carbohydrates has reduced drastically following a similar trend as the average caloric intake. However, the consumption of proteins and total fats remained constant between 2000 and 2018. Figure 3 shows that in 2018, the total average daily intakes of carbohydrates, proteins, total fat, sugars, and saturated fats consumed were 238 g, 66 g, 82 g, 104 g, and 31 g, respectively. These figures were outside the NHS' recommend average daily intake of at least 260 g of carbohydrates, less than 70 g of total fat, less than 50 g of total protein, less than 90 g of total sugar, and less than 20 g of saturated fats [40]. Compared to macronutrient intakes in 1974, total carbohydrates, fat, and protein have declined by 27%, 27%, and 11%, respectively. Current intake of fibre (13 g) is below the recommended level of 18 g per day, whereas sugar and saturated fat intakes are above their recommended levels of 90 g and 20 g, respectively.

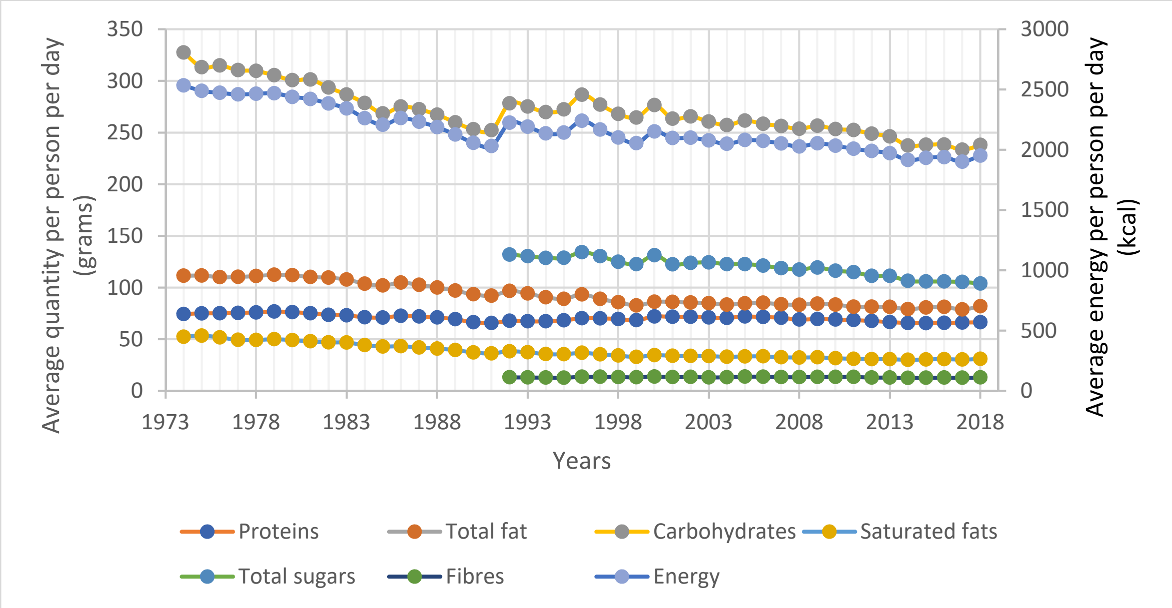

Figure 3. Caloric and macronutrient intakes between 1974 and 2018. Source: Authors' computation based on National Dietary and Nutritional Survey data.

2.3. Recommended Nutrient Intake Ratios

The World Health Organization (WHO) dietary reference intakes suggest that adults consume 55% to 75% (average 55%) of their total calories from carbohydrates, 15% to 30% (average 27.5%) from fat, and 10% to 15% from protein [41]. Following the NHS guidelines, the average adult should consume no less than 58% of total calories from carbohydrates, no more than 30% of total calories from fat, and no more than 11% of total calories from protein [40].

Figure 4 shows the evolution of macronutrient intake ratios from 1974 to 2018. In 2018, the percentage contribution of carbohydrates, fats, and proteins to total caloric intake were 49%, 38%, and 14%, respectively. These estimates show that the intake of carbohydrates was below the recommended level, whereas protein and total fat were above the recommended levels. Similarly, the intake ratios of sugar (21%) and saturated fats (18%) were above their recommended levels of 11%.

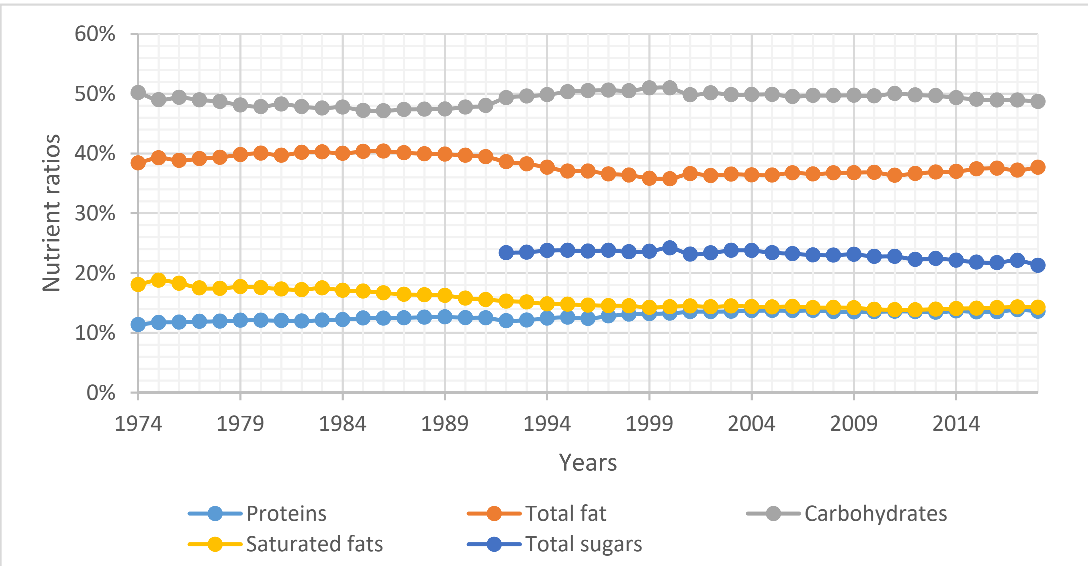

Figure 4. Evolution of macronutrient intake ratios from 1974 to 2018. Source: Authors' computation based on National Dietary and Nutritional Survey data.

2.4. Food Consumption and CO_2 Equivalent Emission

Studies by Berners-Lee et al. [42] and Garnett [43] suggested that food consumption in the UK is responsible for approximately 20% of all greenhouse gas (GHG) emissions produced in a year. However, foods containing animal products are known to generally have much greater emissions than plant-based products per unit weight [44–46]. Animal production relies on cereal crops produced from mostly inefficient systems and produces high amount of methane responsible for global warming [46]. Figure 5 shows the trend in CO_2-eq emission from food and from alcoholic and non-alcoholic beverages in the UK. The average CO2-eq emission from beverages has been on the decline since 1990, suggesting marginal gains in emissions reduction. However, emissions from food consumption compared to the national average have been cyclical. The lowest emissions of 10.43% were recorded in 2007, after which emissions began to increase. The latest data, in 2017, shows that average emissions from food consumption was 12.71% of total UK emissions. According to Vieux et al., change in national dietary levels towards healthy, low greenhouse gas emission (GHGe) is feasible in Europe [47]. This suggests that any policy that changes food consumption towards low GHGe levels without affecting taste or culture of food is plausible.

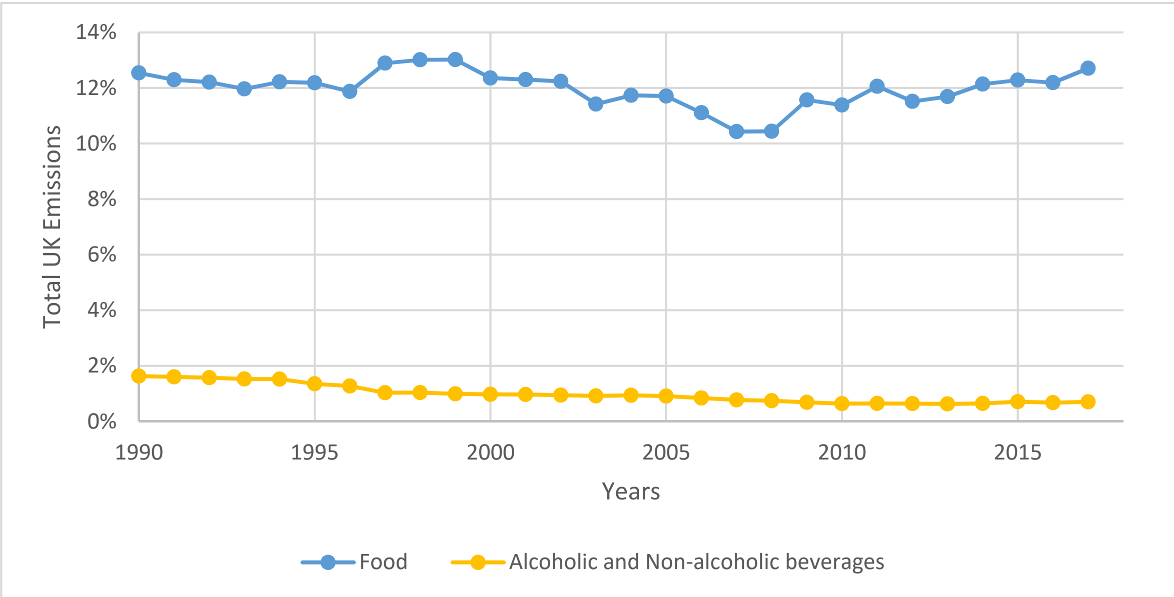

Figure 5. Evolution of emissions from food and alcoholic and non-alcoholic beverages in the UK. Source: Authors' computation based on Department for Environment, Food and Rural Affairs (DEFRA) data on consumption emissions.

3. Methods

3.1. Ex-Ante Evaluation of Increasing Fruits and Vegetables

The approach for the ex-ante evaluation of increasing fruits and vegetables used in this paper is from Irz et al. [25]. It is based on the conventional neoclassical consumer theory by assuming that consumers choose the consumption of a bundle of H goods in quantities $q = (q_1, \dots, q_H)$ to maximise a strictly increasing utility, quasi-concave, twice differentiable utility function $U(q_1, \dots, q_H)$, subject to a linear budget constraint $p.q \leq M$, where p and M are price and income vectors, respectively. We also assumed here that the consumer operates under a set of linear nutritional constraints and food-based constraints, i.e., N maximum nutrients or food intakes based on the government's "five-a-day" policy. In this study the constraints were the fruits and vegetables. Mathematically, the nutritional constraints are expressed by $\sum_{i=1}^{H} a_i^n q_i \leq r_n, \forall n = 1, \dots, N$. We relied on the notion of shadow prices to solve our modified version of the utility maximisation problem. We used the duality theory to relate the unconstrained Hicksian demand function $h_i(p, U)$ to the constrained food-based model $\tilde{h}_i(p, U, A, r)$, where A is the N X H matrix of nutritional coefficients and r is the N vector of maximum nutritional amounts.

Shadow prices were calculated by maximizing $\tilde{C}_i(p, U, A, r)$ subject to $\sum_{i=1}^{H} a_i^n q_i \leq r_n, \forall n = 1, \dots, N$.

The Lagrangian model of the virtual price problem is expressed by

$$L = C(\tilde{p}, U) + \sum_{j=1}^{H}(p_j - \tilde{p}_j)h_j + \sum_{n=1}^{N} \mu_n \left(r_n - \sum_{j=1}^{H} a_j^n h_j\right) \quad (1)$$

where μ_n is the Lagrangian multiplier associated with the nth nutritional or food-based constraint.

We derived the Kuhn–Tucker conditions for Equation (1) based on the assumption of non-satiation and strictly positive virtual prices as

$$\frac{\partial C}{\partial \tilde{p}_i} - h_i + \sum_{j=1}^{H}(p_j - \tilde{p}_j)\frac{\partial h_j}{\partial \tilde{p}_i} - \sum_{n=1}^{N} \mu_n \sum_{j=1}^{H} a_j^n \frac{\partial h_j}{\partial \tilde{p}_i} = 0, i = 1, \dots, H \quad (2)$$

$$\mu_n\left(r_n - \sum_{j=1}^{H} a_j^n h_j\right) = 0 \quad (3)$$

$$\mu_n \geq 0, n = 1, \dots, N \quad (4)$$

By applying Shephard's Lemma and replacing $\frac{\partial h_j}{\partial \tilde{p}_i}$ by s_{ij}, Equation (2) reduces to

$$\sum_{j=1}^{H}\left[(p_j - \tilde{p}_j) - \sum_{n=1}^{N} \mu_n a_j^n\right] s_{ij} = 0, \text{ i=1,…,H} \quad (5)$$

Assuming that all N equations are binding, our virtual price problem reduces to

$$\tilde{p}_i = p_i - \sum_{n=1}^{N} \mu_n a_j^n, i, \dots, H \quad (6)$$

$$\sum_{i=1}^{H} a_i^n h_i(\tilde{p}_i, U) = r_1 \quad (7)$$

According to Irz et al., the first set of Equation (6) implies that deviations between shadow prices and market prices are proportional to the nutritional coefficients of the goods entering the single nutritional constraint [25], whereas the second set of Equation (7) suggests that the nutritional constraints are binding.

Finally, a change in the shadow price because of a change in the nutritional constraints can be expressed as

$$\frac{\partial \tilde{p}_i}{\partial r_1} = \frac{a_i^1}{\sum_{i=1}^{H}\sum_{i=1}^{H} s_{ij} a_i^1 a_j^1}, i, \dots, H \quad (8)$$

In addition, a change in product k due to a change in the nutritional constraints is expressed by

$$\frac{\partial \tilde{h}_k}{\partial r_1} = \frac{\sum_{i=1}^{H} s_{ki} a_i^1}{\sum_{i=1}^{H}\sum_{i=1}^{H} s_{ij} a_i^1 a_j^1}, k = 1, \dots, H \quad (9)$$

Equations (8) and (9) suggest that a change in the nutritional constraint has an impact on the entire diet of the consumer through substitution and complementary relationships across food products. Equation (9) was therefore used to evaluate how consumers react to a change in nutritional norm such as reducing saturated fat intake towards the recommended level. Equation (9) is estimated by combining a matrix of Hicksian demand parameters to a set of nutritional coefficients. We derived the Hicksian demand parameters from an approximate Exact Affine Stone Index Demand System (EASI).

3.2. Estimation of Demand Elasticities

In the full EASI model (see [48]), the budget share w_j of each food *j* is represented by

$$w_j = \sum_{r=0}^{5} E_{rk} y^r + \sum_{l=0}^{L} A_{kj} z_l lnP_k + \sum_{k=1}^{J} B_{kj} lnP_k y + \sum_{l=0}^{L} (C_{lj} z_l + D_{lj} z_l y) + u_j \quad (10)$$

where y is real food expenditure, specified as

$$y = ln(x) - \sum_{j=1}^{J} \ln(P_j)\, w_j + \frac{1}{2} \sum_{j=1}^{J} \sum_{k}^{K} A_{ij} \log(p_j) \log(p_k) \quad (11)$$

The regressors in Equation (10) are a fifth-order polynomial in y, log prices lnP_k of each good *k*, and *L* different demographic characteristics z_l, as well as interaction terms of the forms $lnP_k y$, $z_l lnP_k$, and $z_l y$. Parameters to be estimated are A_{kj}, B_{kj}, C_{lj}, D_{lj}, and E_{rj}.

In order to ensure that Equation (10) was homogenous of degree one in prices, satisfied Slutsky symmetry, and added up, we imposed the following restrictions:

$$A_{kj} = A_{jk} \text{ and } \sum_{k=1}^{J} A_{kj} = \sum_{k=1}^{J} A_{kj} = 0 \text{ for all k, j=1,...,J} \quad (12)$$

$$\sum_{i=1}^{L} C_{lj} \boldsymbol{z_l} = \sum_{i=1}^{L} D_{ij} = 0, \text{ for all } i = 1\ldots\ldots L \quad (13)$$

$$\sum_{k=1}^{J} E_{kr} = 0 \text{ for r = 1,.....R and } \sum_{k=1}^{J} E_{kr} = 1 \text{ for r = 0} \quad (14)$$

Given that y is a function of the budget shares, we had endogeneity. Additionally, Equation (11) appears on the right-hand side of the budget share equations, making the system non-linear. Lewbel and Pendakur proposed the use of non-linear GMM or an iterated linear approximation for the estimation of the parameters [48]. Similar to Reaños and Wölfing, we adopted an iterated linear approximation [49].

To deal with expenditure endogeneity in the estimation of the iterated linear approximate model, first, y in Equation (10) was replaced by the Stone deflated real expenditure $y = ln(x) - \sum_{k=1}^{J} \ln(P_{kj})\, w_j$, where A_{ij} is set to zero and x_i is annual nominal household expenditure. Second, we estimated another Stone deflated real expenditure by setting A_{ij} in Equation (11) to zero and replacing the budget shares w_j with their sample average $\overline{w}_j$, leading to $\tilde{y}_i = \ln(x) - \sum_{j=1}^{J} \ln(P_{kj})\, \overline{w}_j$ as an instrument for food group expenditure (x).

The approximate EASI model was estimated using iterative linear three-stage least squares (3SLS). The expenditure elasticities and Hicksian and Marshallian price elasticities were derived from Equation (7) following Castellón et al. [50] and Zhen et al. [51].

The Hicksian elasticity of demand for goods *k* with respect to the price of the good *j* was derived as

$$\epsilon_{kj} = \frac{(z_l A_{kj} + B_{kj} y)}{w_k} + w_j - \delta_{kj} \quad (15)$$

where $\delta_{kj} = 1$ if k = j, and 0 otherwise.

The vector of food expenditure elasticities $\boldsymbol{\vartheta}$ were subsequently derived as

$$\vartheta = (diag(\gamma))^{-1} [(I_j + \sigma\omega')^{-1} \sigma] + 1_j \quad (2)$$

where $\boldsymbol{\gamma}$ is the $J \times 1$ vector of observed budget shares, σ is a $J \times 1$ vector whose *n*th element equals $\sum_{r=0}^{5} r E_{rj} y^{r-1} + \sum_{l=0}^{L} D_{lj} z_l + \sum_{k=1}^{J} B_{kj} P_k$, ω is the $J \times 1$ vector of log prices, and 1_j is a $J \times 1$ vector of ones.

The Marshallian elasticities of demand, $\boldsymbol{\varepsilon_{kj}}$, were derived from the Slutsky equation using

$$\varepsilon_{kj} = \epsilon_{kj} - w_j * \vartheta_n \quad (3)$$

where ϑ_n is the *n*th element of ϑ.

3.3. Consumer Purchase Data

Due to data availability, this study relied on the 2012 Kantar Worldpanel database for Scotland, which consists of household food purchases as well as demographic information to compute food elasticities. Comparing our data with that from the 2018/2019 Family Food dataset (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/928475/UKHHcons-29oct20.ods) suggests that Scottish data are a good approximation of average UK purchases [52]. For instance, in 2012, sugar and preservatives consumed in the UK and Scotland were 124 g per person per week. In addition, the average consumption of fresh fruits in both Scotland and UK was 693 g per person per week and 744 g per person per week, respectively. These examples indicate why the Scottish data were a good approximation for the UK data for the analysis.

A total of 1518 households that had remained in the sample for at least 40 weeks were considered for our analysis. The categories of food products were aggregated into 20 food groups consumed in the home, including (1) grains and grain-based products; (2) vegetables and vegetable products; (3) starchy roots, tubers, legumes, nuts, and oilseeds; (4) fruit, fruit products, and fruit and vegetable juices; (5) beef, veal, and lamb; (6) pork; (7) poultry, eggs, and other fresh meat; (8) processed and other cooked meats; (9) fish and other seafood; (10) milk, dairy products, and milk product imitates; (11) cheese; (12) sugar and confectionary and prepared desserts; (13) soft drinks; (14) animal fats; (15) plant-based fats; (16) tea, coffee, cocoa, and drinking water; (17) alcoholic beverages; (18) composite dishes (animal and vegetable composite dishes); (19) snacks and other foods; and (20) residual category (residual category refers to all food products that were not allocated into any of the 19 food categories in our data.). The foods consumed were totalled to obtain weekly expenditures on the aggregated food groups.

Table 1 shows the summary of the data used to estimate the model. The shares show that the highest amount of expenditure (27%) was spent on tea, coffee, cocoa, and drinking water. Animal fats made up the lowest share of total expenditure on food. Vegetables and vegetable products, and fruit, fruit products, and fruit and vegetable juices made up 3.3 and 5.7% of the total expenditure on food purchases, respectively. Fish and red and white meat made up 3.3, 3.1, and 3.3% of the total food expenditure. Among animal protein, beef, veal, and lamb were considered expensive products whereas pork was the least expensive source of protein. Among the sources of vitamins, fruit, fruit products, and fruit and vegetable juices were more expensive than vegetables and vegetable products. Among the drinks, alcoholic beverages were more expensive than soft drinks.

Table 1. Summary of data used for the analysis.

Goods	**Quantities**	**Initial**	**Total**	**Food**
	100 g/ mL	**Prices**	**Expenditure**	**Shares**
	Cap/Day	**GBP/100 g or mL**	**(GBP)**	**(%)**
Vegetables and vegetable products	1.17	0.20	0.24	3.3
Fruit, fruit products, and fruit and vegetable juices	1.61	0.25	0.41	5.7
Grains and grain-based products	2.00	0.24	0.48	6.7
Starchy roots, tubers, legumes, nuts, and oilseeds	1.16	0.35	0.40	5.6
Beef, veal, and lamb	0.23	0.79	0.18	2.5
Pork	0.08	0.60	0.05	0.6
Poultry, eggs, and other fresh meat	0.36	0.65	0.23	3.3
Processed and other cooked meats	0.30	0.62	0.19	2.6
Fish and other seafood	0.26	0.90	0.23	3.3

Milk, dairy products, and milk product imitates	1.70	0.10	0.17	2.4
Cheese	0.17	0.76	0.13	1.8
Sugar and confectionary and prepared desserts	0.32	0.33	0.11	1.5
Soft drinks	2.34	0.09	0.22	3.0
Animal fats	0.03	0.44	0.01	0.2
Plant-based fats	0.10	0.26	0.03	0.4
Tea, coffee, cocoa, and drinking water	10.51	0.18	1.92	26.9
Alcoholic beverages	2.65	0.49	1.29	18.1
Composite dishes (animal and vegetable)	1.26	0.49	0.62	8.7
Snacks and other foods	0.12	0.72	0.09	1.2
Residual category	0.32	0.46	0.15	2.1

Source: Authors' computation based on Kantar Worldpanel data.

3.4. Nutritional Information

To measure the impact of the 10% reduction in fruit and vegetable prices on micro- and macronutrient intake, we needed nutritional data for our food groups. We relied on nutrient information from the European Food Safety Authority (EFSA), which were in turn supplied by the National Diet and Nutrition Survey (NDNS) years 1 to 3 (2008–2011) [53]. These NDNS data contain 3073 individuals and their mean intake of nutrients associated with the food groups [54].

The average nutritional coefficients are shown in Table 2. Cheese was the highest source of calories (732.6 kcal/100 g) whereas tea, coffee, cocoa, and water were the lowest source of calories (1.2 kcal/100 g) in the average diet. Vegetable and vegetable products contained 30.9 kcal/100 g of energy, which was lower than the energy from fruits, fruit products, and fruit and vegetable juices (52.5 kcal/100 mls). Among the food groups, vegetable and vegetable products and fruits, fruit products, and fruit and vegetable juices had the highest sources of vitamin C.

Table 2. Nutritional coefficients and greenhouse gas emissions.

Nutritional Coefficients	Vegetables and Vegetable Products	Fruit, Fruit Products, and Fruit and Vegetable Juices	Grains and Grain-Based Products	Starchy Roots, Tubers, Legumes, Nuts, and Oilseeds	Beef, Veal, and Lamb	Pork	Poultry, Eggs, and Other Fresh Meat	Processed and Other Cooked Meats	Fish and Other Seafood	Cheese
Energy (kcal/100 g)	30.85	52.48	248.71	130.14	199.71	216.78	163.56	225.64	177.51	361.65
Protein (g/100 g)	1.30	0.58	7.07	3.58	26.83	28.92	24.97	19.13	19.63	22.72
Fibre (g/100 g)	1.49	0.83	2.59	2.36	0.01	0.05	0.02	0.79	0.24	0.01
Carbohydrates (g/100 g)	4.44	12.73	46.37	20.74	0.42	0.53	0.38	4.75	5.37	0.97
Sugar (g/100 g)	3.55	12.21	7.09	1.92	0.07	0.28	0.31	0.95	0.28	0.88
Fats—Monounsaturated (g/100 g)	0.32	0.10	1.68	1.76	3.65	4.44	2.99	6.06	3.40	7.04
Fats—Saturated (g/100 g)	0.23	0.06	1.85	0.87	4.43	3.86	1.89	5.46	1.87	18.66
Fats—Polyunsaturated (g/100 g)	0.34	0.07	1.03	1.26	0.56	1.89	1.17	1.95	2.36	0.66
Lipids (g/100 g)	1.00	0.27	5.19	4.23	10.08	11.08	6.91	14.55	8.76	29.69
Cholesterol (g/100 g)	0.29	0.01	6.46	0.50	90.64	81.56	144.92	60.80	71.38	84.72
Free sugar (g/100 g)	0.18	5.47	4.55	0.69	0.03	0.24	0.28	0.16	0.05	0.11
Minerals—Sodium (mg/100 g)	38.49	16.85	298.21	83.28	106.96	108.20	117.19	1005.65	357.42	678.59
Minerals—Magnesium (mg/100 g)	9.78	10.88	32.81	26.61	21.66	24.92	25.71	18.85	28.23	25.97
Minerals—Phosphorus (mg/100 g)	33.58	14.73	128.35	70.39	202.95	225.72	237.70	223.65	220.23	459.49
Minerals—Potassium (mg/100 g)	195.58	169.58	162.60	407.43	310.26	357.02	311.59	255.54	308.01	91.63
Minerals—Calcium (mg/100 g)	22.33	11.36	102.57	18.41	12.89	14.77	18.87	52.31	60.30	628.59
Minerals—Iron (mg/100 g)	0.55	0.22	1.93	0.96	2.45	1.00	0.83	1.17	0.90	0.26
Minerals—Zinc (mg/100 g)	0.21	0.08	0.92	0.49	5.32	2.54	1.18	2.11	0.80	3.35
Vitamins—Retinol (mg/100 g)	0.42	0.01	11.35	1.84	350.42	0.89	34.99	143.69	14.45	308.49
Vitamins—Carotene (mg/100 g)	1603.49	58.27	10.51	59.14	10.98	2.62	2.04	2.67	6.44	141.62
Vitamins—A (mg/100 g)	310.06	11.10	13.31	11.91	352.19	1.32	35.35	144.14	15.56	332.41
Vitamins—D (mg/100 g)	0.00	0.00	0.13	0.01	0.58	0.88	0.56	0.75	2.55	0.31
Vitamins—E (mg/100 g)	0.73	0.29	0.65	0.75	0.18	0.08	0.42	0.36	1.67	0.48
Vitamins—C (mg/100 g)	16.05	23.10	0.66	8.00	0.48	0.10	0.02	2.57	0.06	0.04
Vitamins—B1 (mg/100 g)	0.07	0.04	0.22	0.19	0.08	0.73	0.09	0.43	0.09	0.04
Vitamins—B2 (mg/100 g)	0.03	0.03	0.13	0.03	0.30	0.21	0.19	0.17	0.13	0.37
Vitamins—B6 (mg/100 g)	0.11	0.11	0.15	0.28	0.34	0.46	0.38	0.33	0.25	0.09

Vitamins—B9 (mg/100 g)	26.75	10.79	30.68	28.68	20.91	5.45	12.51	4.87	12.89	29.47
Vitamins—B12 (mg/100 g)	0.00	0.01	0.07	0.00	3.56	0.96	0.43	1.00	3.57	2.02
Greenhouse gas equivalent (kg CO2/100 g)	0.12	0.08	0.12	0.08	3.88	1.05	0.60	0.56	0.46	0.83
	Milk, Dairy Products and Milk Product Imitates	**Sugar and Confectionary and Prepared Desserts**	**Soft Drinks**	**Animal Fats**	**Plant Based Fats**	**Tea, Coffee, Cocoa, and Drinking Water**	**Alcoholic Beverages**	**Composite Dishes (Animal and Vegetable Dishes)**	**Snacks and Other Foods**	**Residual Category**
Energy (kcal/100 g)	58.02	342.29	16.05	732.57	586.58	1.24	47.62	159.99	386.29	146.60
Protein (g/100 g)	3.54	3.12	0.01	0.58	0.25	0.06	0.24	7.96	5.36	2.51
Fibre (g/100 g)	0.04	0.60	0.01	0.00	0.00	0.00	0.00	1.07	3.53	1.09
Carbohydrates (g/100 g)	5.77	63.33	4.17	0.70	0.49	0.17	2.39	14.46	49.89	12.59
Sugar (g/100 g)	5.57	60.40	4.16	0.63	0.27	0.17	2.39	2.15	3.00	6.82
Fats—Monounsaturated (g/100 g)	0.56	3.09	0.00	21.11	29.00	0.01	0.00	3.25	11.69	4.06
Fats—Saturated (g/100 g)	1.54	5.76	0.00	47.46	15.72	0.03	0.01	2.61	2.72	1.95
Fats—Polyunsaturated (g/100 g)	0.11	0.66	0.00	4.59	16.85	0.00	0.00	1.54	4.47	3.15
Lipids (g/100 g)	2.47	10.25	0.00	80.85	64.85	0.04	0.02	8.21	19.76	9.94
Cholesterol (g/100 g)	8.04	10.62	0.00	221.26	20.73	0.09	0.04	48.54	1.46	10.36
Free sugar (g/100 g)	1.08	56.87	4.08	0.00	0.00	0.11	2.38	0.71	1.31	4.09
Minerals—Sodium (mg/100 g)	48.24	65.02	3.92	472.82	488.21	1.33	7.48	295.67	471.05	777.96
Minerals—Magnesium (mg/100 g)	11.13	19.63	1.09	2.04	2.35	1.10	7.30	16.79	40.53	16.36
Minerals—Phosphorus (mg/100 g)	100.10	77.31	11.83	24.39	40.76	2.07	15.50	102.91	120.85	53.46
Minerals—Potassium (mg/100 g)	164.04	160.87	5.60	28.83	62.47	14.84	52.13	168.86	696.12	224.64
Minerals—Calcium (mg/100 g)	122.47	76.02	3.70	22.37	19.23	1.44	6.55	50.04	37.38	39.77
Minerals—Iron (mg/100 g)	0.05	0.67	0.01	0.03	0.11	0.01	0.20	1.04	1.28	1.14
Minerals—Zinc (mg/100 g)	0.43	0.45	0.00	0.09	0.14	0.01	0.02	0.92	0.67	0.33
Vitamins—Retinol (mg/100 g)	26.57	31.65	1.43	1479.29	545.25	0.23	0.27	28.04	3.07	15.77
Vitamins—Carotene (mg/100 g)	13.61	34.87	23.71	564.49	608.26	0.24	0.13	209.43	86.72	296.90
Vitamins—A (mg/100 g)	28.92	37.57	5.47	1573.79	649.02	0.28	0.29	66.40	18.63	67.28
Vitamins—D (mg/100 g)	0.03	0.11	0.00	5.55	5.25	0.00	0.00	0.34	0.01	0.07
Vitamins—E (mg/100 g)	0.13	0.63	0.01	7.42	12.95	0.00	0.00	1.08	3.62	3.02
Vitamins—C (mg/100 g)	1.79	1.72	1.30	0.61	0.01	0.04	0.00	2.60	6.92	2.66
Vitamins—B1 (mg/100 g)	0.04	0.05	0.00	0.04	0.00	0.00	0.00	0.10	0.16	0.14
Vitamins—B2 (mg/100 g)	0.22	0.16	0.00	0.07	0.03	0.01	0.03	0.11	0.09	0.14

Vitamins—B6 (mg/100 g)	0.09	0.04	0.03	0.02	1.28	0.00	0.06	0.12	0.46	0.11
Vitamins—B9 (mg/100 g)	7.51	6.76	0.40	1.88	128.24	0.45	7.49	16.26	30.85	33.40
Vitamins—B12 (mg/100 g)	0.68	0.24	0.03	0.24	0.86	0.01	0.01	0.48	0.02	0.15
Greenhouse gas equivalent (kg CO2/100 g)	0.15	0.30	0.03	0.90	0.20	0.03	0.14	0.50	0.09	0.13

Source: Authors' computation based on Kantar Worldpanel data.

3.5. Information on CO2-eq Emission

The CO2-eq emission estimates used were obtained from the Sustainable Diets (SUSDIET) project. The estimates were based on a holistic literature review by Hartikainen and Pulkkinen [55]. They made the following assumptions: (1) The estimates are restricted to the food chain excluding emissions from transport activities, and (2) the emissions from land-use changes and food waste are not accounted for. Even though the above assumptions restrict the usage of these estimates, the estimates were the most comprehensive for our analysis.

The average CO_2 equivalent emissions from the food groups are presented in last column of Table 2. Beef, veal, and lamb had the highest carbon footprint (3.9 kg CO2-eq/100 g) whereas soft drinks and tea, coffee, cocoa, and water had the least carbon footprint (0.03 kg CO2-eq/100 g). Vegetable and vegetable products had a higher carbon footprint (0.12 kg CO2-eq/100 g) than fruit, fruit products, and fruit and vegetable juices.

3.6. Simulation

The simulation was based on the effect of a 10% increase in the consumption of fruits and vegetables on dietary compositions. First, we simulated how increasing the current consumption of fruit and vegetables by 10% affected overall food purchases and the prices of fruits and vegetables. Second, based on the overall changes in food purchases, we analysed the expected changes in CO_2-equivalent emissions for the average consumer. Third, also based on the expected changes in purchases, we analysed the implications of the policy on weekly macro- and micronutrient intake.

4. Results and Discussion

4.1. Price and Expenditure Elasticities

Table 3 shows that all own-price elasticities were negative and significant at the 1% level. Two food groups—namely, soft drinks and snacks and other foods—were price elastic, suggesting buyers are very responsive to price changes. Vegetable and vegetable products and fruit, fruit products, and vegetable juices had own-price elasticities of 0.48 and 0.77, respectively. The implication is that these food groups are less responsive to price changes [56–58] and that any policy aimed at increasing consumption must be huge to have a significant impact [59]. The cross-price elasticities show the degree of substitution and complementarity between the food groups. This has implications for the policy to increase fruit and vegetable consumption. For instance, vegetables and vegetable products are complementary to red meat, white meat, and processed meat, suggesting that lower prices for vegetable and vegetable products increases the consumption of these food groups. This confirms the findings of Dong and Lin that subsidies for vegetables, i.e., lettuce and tomatoes, might encourage households to purchase more ground beef and breads [59].

Table 3. Unconditional food price and expenditure elasticity.

	Vegetables and Vegetable Products	Fruit, Fruits Products, and Fruit and Vegetable Juices	Grains and Grain-Based Products	Starchy Roots, Tubers, Legumes, Nuts, and Oilseeds	Beef, Veal, and Lamb	Pork	Poultry, Eggs, and Other Fresh Meat	Processed and Other Cooked Meats	Fish and Other Seafood	Milk, Dairy Products, and Milk Product Imitates
Vegetables and vegetable products	−0.4756 *	−0.0018	−0.0021	−0.0017 *	−0.0007 *	−0.0002 *	−0.0010 *	−0.0008	−0.001	−0.0008
Fruit, fruit products, and fruit and vegetable juices	−0.001	−0.7706 *	−0.0021 *	−0.0016	−0.0007 *	−0.0002	−0.0009 *	−0.0007	−0.001	−0.0007 *
Grains and grain-based products	−0.001	−0.0018 *	−0.9272 *	−0.0017	−0.0007 *	−0.0002	−0.0009	−0.0007	−0.001	−0.0007
Starchy roots, tubers, legumes, nuts, and oilseeds	−0.0012 *	−0.002	−0.0024	−0.7996 *	−0.0008	−0.0002 *	−0.0011 *	−0.0009	−0.0011 *	−0.0009 *
Beef, veal, and lamb	−0.0015 *	−0.0026 *	−0.0030 *	−0.0024	−0.5092 *	−0.0002	−0.0013 *	−0.0011	−0.0014 *	−0.0011
Pork	−0.0014 *	−0.0024	−0.0029	−0.0023 *	−0.0009	−0.9193 *	−0.0013	−0.001	−0.0014	−0.001
Poultry, eggs, and other fresh meat	−0.0013 *	−0.0023 *	−0.0027	−0.0021 *	−0.0008	−0.0002	−0.8261 *	−0.0010 *	−0.0013 *	−0.001
Processed and other cooked meats	−0.0013	−0.0022	−0.0026	−0.0021	−0.0008	−0.0002	−0.0012 *	−0.6388 *	−0.0012 *	−0.0009
Fish and other seafood	−0.0011	−0.0019	−0.0022	−0.0018 *	−0.0007	−0.0002	−0.0010 *	−0.0008 *	−0.4408 *	−0.0008
Milk, dairy products, and milk product imitates	−0.0009	−0.0016 *	−0.0019	−0.0015 *	−0.0006	−0.0002	−0.0009 *	−0.0007	−0.0009	−0.8892 *
Cheese	−0.0011 *	−0.0019	−0.0023	−0.0018 *	−0.0007	−0.0002	−0.0010 *	−0.0008	−0.0011	−0.0008 *
Sugar and confectionary and prepared desserts	−0.0011	−0.0019 *	−0.0022 *	−0.0018	−0.0007 *	−0.0002 *	−0.001	−0.0008 *	−0.0011	−0.0008
Soft drinks	−0.0014	−0.0025	−0.0029 *	−0.0023 *	−0.0009	−0.0002	−0.0013	−0.0011	−0.0014	−0.0011
Animal fats	−0.0011	−0.0018	−0.0021 *	−0.0017	−0.0007	−0.0002	−0.0010 *	−0.0008 *	−0.001	−0.0008
Plant-based fats	−0.001	−0.0018	−0.0021 *	−0.0017	−0.0007	−0.0002	−0.0009 *	−0.0008	−0.001	−0.0008
Tea, coffee, cocoa, and drinking water	−0.001	−0.0017	−0.0020 *	−0.0016 *	−0.0006	−0.0002	−0.0009	−0.0007	−0.001	−0.0007
Alcoholic beverages	−0.0018 *	−0.0031 *	−0.0036	−0.0029	−0.0012	−0.0003	−0.0016	−0.0013	−0.0017	−0.0013

Composite dishes (animal and vegetable)	−0.0011 *	−0.0019 *	−0.0022	−0.0017	−0.0007	−0.0002	−0.0010 *	−0.0008 *	−0.001	−0.0008 *
Snacks and other foods	−0.0014	−0.0024	−0.0029 *	−0.0023 *	−0.0009	−0.0002	−0.0013	−0.001	−0.0014	−0.0010 *
Residual category	−0.0012	−0.002	−0.0023	−0.0019	−0.0007	−0.0002	−0.001	−0.0008	−0.0011	−0.0008

	Cheese	**Sugar and Confectionary and Prepared Desserts**	**Soft Drinks**	**Animal Fats**	**Plant-Based Fats**	**Tea, Coffee, Cocoa, and Drinking Water**	**Alcoholic Beverages**	**Composite Dishes (Animal and Vegetable Dishes)**	**Snacks and Other Foods**	**Residual Category**	**Expenditure Elasticity**
Vegetables and vegetable products	−0.001 *	0	−0.001 *	0	0	−0.009	−0.004 *	−0.003 *	0	−0.001	0.309 *
Fruit, fruit products, and fruit and vegetable juices	−0.001	0.000 *	−0.001	0	0	−0.008	−0.004 *	−0.003 *	0	−0.001	0.296 *
Grains and grain-based products	−0.001	0	−0.001 *	0.000 *	0.000 *	−0.008 *	−0.004 *	−0.003 *	0.000 *	−0.001	0.298 *
Starchy roots, tubers, legumes, nuts, and oilseeds	−0.001 *	−0.001	−0.001 *	0	0	−0.010 *	−0.005 *	−0.003	0.000 *	−0.001	0.345 *
Beef, veal, and lamb	−0.001	−0.001	−0.001	0	0	−0.012	−0.006	−0.004	0	−0.001	0.432 *
Pork	−0.001	−0.001 *	−0.001	0	0	−0.012	−0.006 *	−0.004	0	−0.001	0.414 *
Poultry, eggs, and other fresh meat	−0.001 *	−0.001	−0.001	0.000 *	0.000 *	−0.011	−0.005 *	−0.003 *	0	−0.001	0.382 *
Processed and other cooked meats	−0.001	−0.001 *	−0.001	0.000 *	0	−0.011	−0.005 *	−0.003 *	0	−0.001	0.375 *
Fish and other seafood	−0.001	0	−0.001	0	0	−0.009	−0.005 *	−0.003	0	−0.001	0.321 *
Milk, dairy products, and milk product imitates	−0.001 *	0	−0.001	0	0	−0.008	−0.004 *	−0.002 *	0.000 *	−0.001	0.278 *
Cheese	−0.977 *	0	−0.001	0	0	−0.009	−0.005 *	−0.003	0	−0.001	0.327 *
Sugar and confectionary and prepared desserts	−0.001	−0.921 *	−0.001	0.000 *	0	−0.009	−0.005	−0.003	0	−0.001	0.322 *
Soft drinks	−0.001	−0.001	−1.115 *	0	0.000 *	−0.012 *	−0.006 *	−0.004	0	−0.001	0.423 *
Animal fats	−0.001	0.000 *	−0.001	−0.671 *	0	−0.009	−0.004	−0.003	0.000 *	−0.001	0.308 *
Plant-based fats	−0.001	0	−0.001	0	−0.773 *	−0.008	−0.004	−0.003	0	−0.001	0.302 *

Tea, coffee, cocoa, and drinking water	−0.001	0	−0.001 *	0	0	−0.805 *	−0.004 *	−0.003 *	0.000 *	−0.001	0.292 *
Alcoholic beverages	−0.001	−0.001 *	−0.001 *	0	0	−0.015	−0.899 *	−0.005 *	−0.001	−0.001	0.521 *
Composite dishes (animal and vegetable)	−0.001 *	0	−0.001	0	0	−0.009	−0.004 *	−0.744 *	0.000 *	−0.001	0.314 *
Snacks and other foods	−0.001 *	−0.001	−0.001	0.000 *	0.000 *	−0.012 *	−0.006	−0.004 *	−1.124 *	−0.001	0.414 *
Residual category	−0.001	−0.001	−0.001	0	0	−0.009	−0.005	−0.003	0	−0.923	0.337

* Denotes significance at the 5% level. Note: Unconditional elasticities were calculated using an average food expenditure share of 0.138.

The estimated expenditure elasticities were all positive and significant at the 1% level (see Table 3). All the estimates were less than 1, suggesting that buyers consider these products to be normal goods [60]. An increase in consumer income while holding prices fixed also resulted in a less than proportionate increase in expenditure on all the food groups.

4.2. Price Adjustments

We first considered the effect of increasing fruit and vegetable consumption by 10% (equivalent to an increase of 32 g per day (this figure is based on average daily consumption per person in 2018 in the UK)) on prices. The model considers the substitution and complementary relationship across all food groups. The estimated results suggest that there is a need to reduce the prices of vegetables by 21% and fruits by 13% (these were the changes between the current prices and the shadow prices once the fruit and vegetable constraint was imposed). Our results confirmed that consumer level subsidies have positive implications for consumption [61–63]. Even though the subsidies (the difference between actual and shadow prices) required to achieve the recommended intakes were relatively high, previous literature has shown that the consumption of fruit and vegetables is beneficial for both personal and environmental health. A diet rich in a variety of fruits and vegetables has shown to prevent cancers of the upper gastrointestinal tract [15,64] and coronary heart disease [65], improve mental health [66–68], and prevent diabetes mellitus [69]. In addition, the consumption of diets high in fruits and vegetables has been associated with a lower prevalence of obesity [70,71].

4.3. Consumption of Other Foods

By assuming 100% for the baseline consumption, we compared consumption before and after the implementation of the policy. Figure 6 indicates the baseline consumption levels with dotted lines. Significant changes in dietary composition were observed at the same utility level.

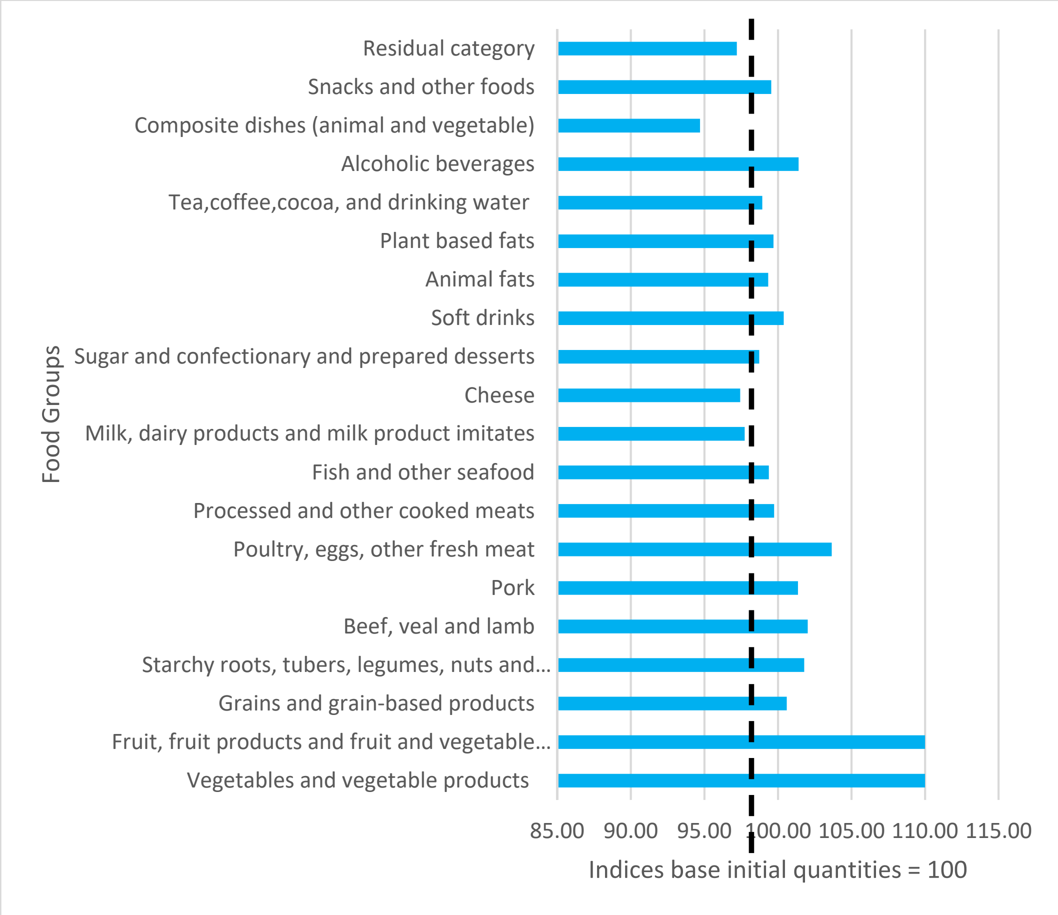

Figure 6. Changes in quantities of food purchased per household per week after policy to increase fruit and vegetable consumption.

On the positive side, the consumption of poultry, eggs, and other fresh meat increased by 3.7%. The consumption of plant-based fats and animal fats also declined by 0.7% and 0.3%, respectively. The consumption of grains and grain-based products (0.6%) as well as starchy roots, tubers, legumes, and nuts (1.8%) increased. On the negative side, the consumption of red meat such as pork (1.4%), beef, veal, and lamb (2.0%) increased above the baseline intakes. Food groups that increased their quantities were considered complementary to fruits and vegetables, whereas those whose quantities reduced were considered substitutes for fruits and vegetables [72,73].

We compared our results to those obtained in France by Irz et al. [25]. The changes in consumption were found to be very different. First, our results showed an increase in the consumption of meat, whereas those of Irz et al. [25] showed a decrease in meat consumption. In addition, whereas our results showed that fish and seafood consumption increases by 0.6%, Irz et al. estimated a 10% increase in the consumption of fish. The differences are, of course, due to the specific preferences in both countries.

Finally, for the UK, dietary changes due to increased consumption of fruits and vegetables had a negative implication for alcoholic beverages and soft drinks.

4.4. Impact on Greenhouse Gas Emissions

Unlike Irz et al. [25], we went further to estimate the changes in greenhouse gas emissions following the changes in food purchases. As expected, emissions from food groups for which purchases reduced showed a decline in their CO_2-eq emission levels. Subsidizing vegetable and fruit purchases had a negative impact on emissions reduction. For instance, estimates from Figure 7 show that emissions from vegetables and vegetable products and fruit, fruit products, and fruit and vegetable juices increased by 14.13 CO_2-eq g/100 g per day and 12.68 CO_2-eq g/100 g per day, respectively. This confirms studies that suggest that shifting to sustainable diets has higher environmental impacts [47,74]. For instance, Vieux et al. found that meat reduction supplemented isocalorically by fruits and vegetables showed an increase in GHG emissions [47]. In addition, the complementary relationship between vegetables and vegetable products; fruit, fruit products, and fruit and vegetable juices; and red and white meat aggravated GHG emissions [75]. For instance, the increased purchase of beef, veal, and lamb; pork; and poultry, eggs, and other fresh meat increased emissions by 17.88 CO_2-eq g/100 g per day, 1.09 CO_2-eq g/100 g per day, and 7.89 CO_2-eq g/100 g per day, respectively. On the positive side, emissions from processed and other cooked meats and fish and seafood was reduced by 0.45 CO_2-eq g/100 g per day and 0.73 CO_2-eq g/100 g per day, respectively. Emissions from milk, dairy products, and milk product imitates and cheese were also reduced 5.76 CO_2-eq g/100 g per day and 3.62 CO_2-eq g/100 g per day, respectively. Finally, the highest decline in emissions was estimated for composite dishes, i.e., 33.22 CO_2-eq g/100 g per day. In summary, the overall impact of subsidizing fruit and vegetables on household greenhouse gas emissions is negative: a 0.7 CO_2-eq kg/kg increase in emissions per household per day. This conclusion supports the results by Tainio et al. [76].

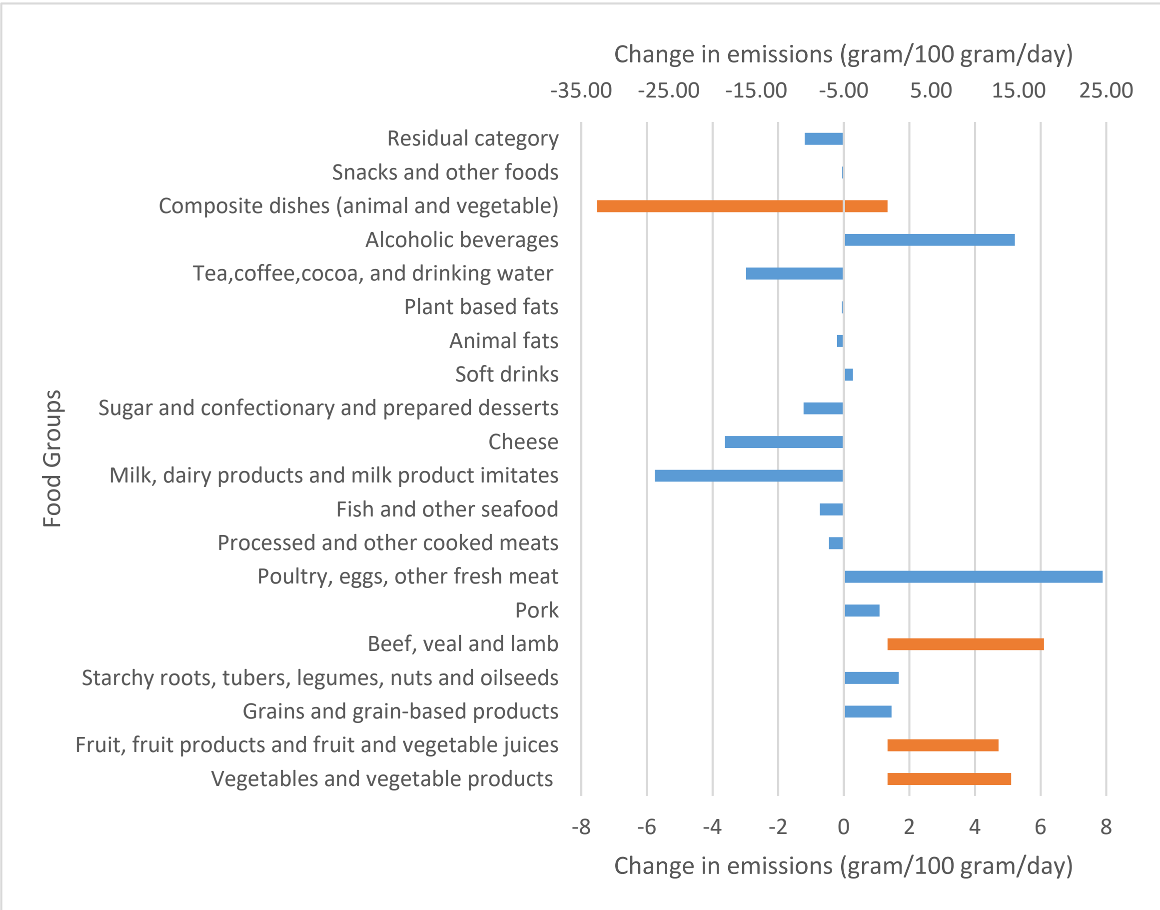

Figure 7. Changes in emissions per household per day.

4.5. Impact on Net Nutrient Composition

First, subsidizing fruit and vegetable consumption (i.e., reducing the price by the level indicated by the shadow price) reduces the average daily caloric purchase (11.81 kcal) [77] (see Figure 8). Among the three macronutrients, carbohydrates and protein increased by 0.09 g/100 g and 0.75 g/100 g, respectively. However, similar to Blakely et al. and Fulton et al., total lipid purchase was reduced (by 1.74 g/100 g) whereas dietary sugar and fibre increased [61,78]. Among the vitamins, increasing fruit and vegetable purchases had the highest impact on Vitamin A (12.77 mg/100 g), Vitamin C (3.76 mg/100 g), and Vitamin B9 (2.07 mg/100 g). The results from this subsection confirms the conclusion by Fulton et al. that increasing fruit and vegetable consumption increases micronutrient, carbohydrate, and fibre intakes but reduces fat intake [78].

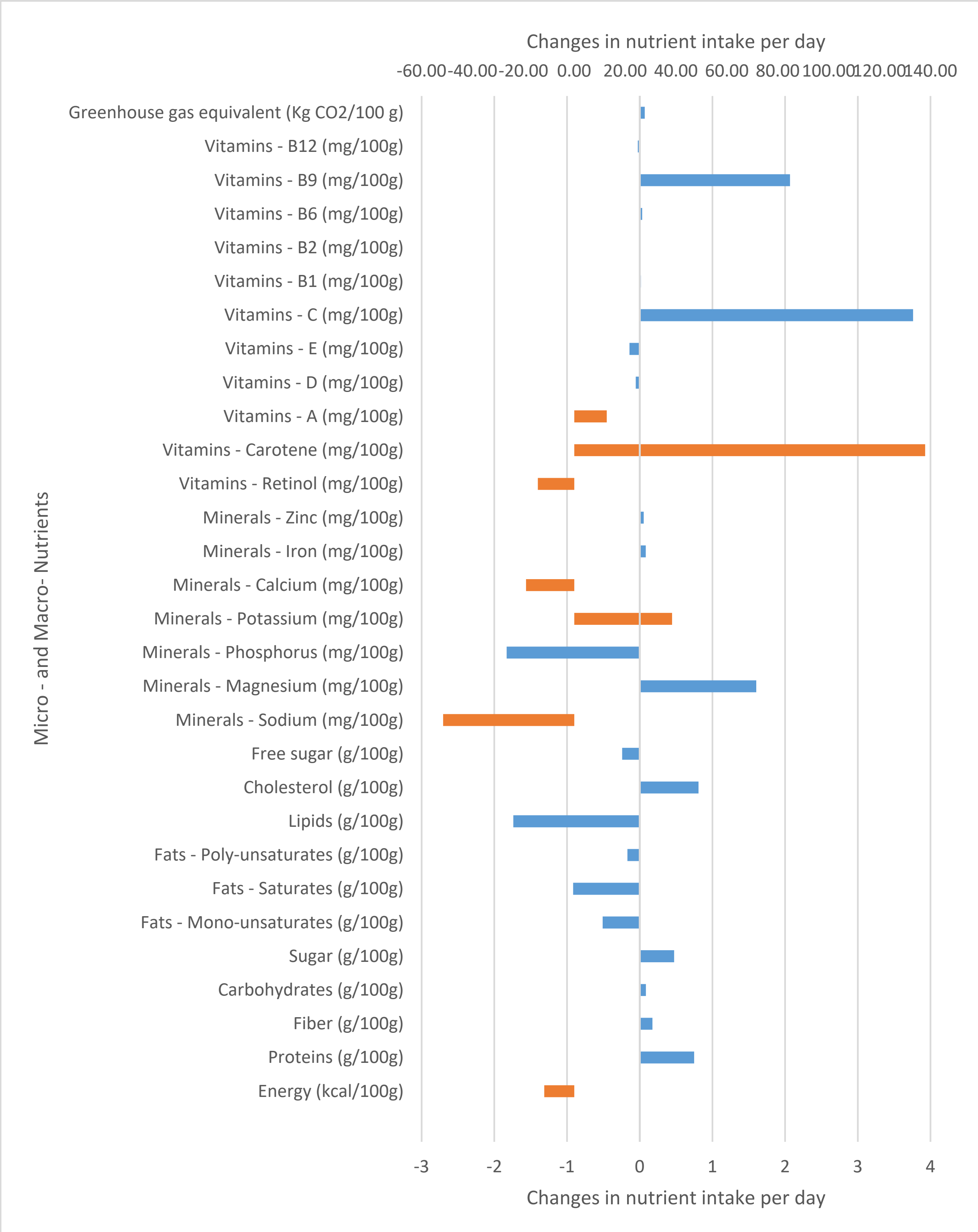

Figure 8. Changes in nutrient and CO_2-eq purchases per household per day.

The estimation encountered certain limitations. First, we used purchase data to estimate changes in consumption. We understand not all foods purchased are consumed, so as a result our estimates should be interpreted with caution. Second, our emissions data were not generated from foods consumed in the UK but rather from averages in Europe. The variation in the level of technologies used in food production across Europe can affect the figures we derived from our simulations. Finally, our nutritional data are based on UK averages and not actual foods bought by consumers.

5. Conclusions

Despite the 8.2% increase in fruit and vegetable consumption between 2003 and 2006 due to the UK government's "five-a-day" policy, fruit and vegetable consumption was on the decline soon after 2006. As such, the goal of the present study was to estimate the prices (shadow prices) at which consumers could increase their intake of fruits and vegetables by 10% (higher than that achieved by the "five-a-day" policy) without changing the overall taste of their diet (utility).

The results suggest that to increase fruit and vegetable consumption by 10%, prices need to decline by 21% and 13%, respectively. The change in the consumption of fruits and vegetables has implications for overall food choices, as shown by the changes in daily nutrient intake and CO_2-eq emissions.

First, total daily caloric intake is reduced; however, the policy incites consumers to increase their intake of carbohydrates and protein. The increase in vitamins and minerals is important for the prevention of certain cancers, whereas the decline in the consumption of lipids and saturated fats is important for the fight against the growing rates of overweight and obesity in the UK.

Second, adjustments in diet due to changes in fruit and vegetable consumption have unintended environmental consequences. Overall emissions per household per day increase by 0.7 CO_2-eq kg/100 g of food consumed. This net change in emissions is a result of increases in the emissions from red meat and white meat groups.

From the policy perspective, the large difference between the estimated shadow prices and actual prices of fruits and vegetables has implications for fiscal policies. In effect, larger taxes or subsidies are required for fiscal policies to be effective. In addition, fiscal policies create unintended effects depending on the overall objective of the policymaker; in this case they increase the overall carbon footprint from consumption.

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