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Nutritional implications of substituting plant-based proteins for meat: evidence from home scan data

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Abstract

There is growing concern among policymakers and researchers about the negative health and climate impacts of meat consumption. Consumers are encouraged to re-evaluate their dietary choices to preserve our ecosystem and reduce the burden of diet-related diseases. However, limited information is available about how price changes in animal protein sources affect plant-based protein demand and the consequences for nutrient intake and/or diet quality. The goal of the present paper is to fill this gap by explaining how consumers react to price changes in animal protein types and to present the implications for nutrition or diet quality. This paper applied the exact affine stone index implicit (EASI) Marshallian demand system to 2021 home scan panel data collated by the Kantar Worldpanel to estimate both price and expenditure elasticities. Twelve food groups of seven animal-based protein products and five plant-based protein products were considered. The results revealed that dairy and eggs are daily necessities for the people of Scotland. The demand for fish and non-dairy milk are the most sensitive to price. Estimates based on expenditure elasticities show that beef is considered a luxury and a highly substitutable product in the Scottish diet. Peas are relatively basic, essential foodstuffs. In general, increasing the price of animal protein sources will shift demand towards plant protein. On the positive side, there will be a significant reduction in cholesterol and fat purchases. However, there would also be a significant reduction in the total amount of protein, carbohydrates, and healthy fats, such as unsaturated fatty acids, purchased by the average household. This shows that increases in plant-based protein are not enough to compensate for the reductions in essential macro- and micronutrient purchases from animal protein. From the climate perspective, reductions in meat purchases could reduce emissions from production and consumption.

Keywords: Plant-based protein, EASI demand system, Animal protein, Diet quality, Scotland

Background

Carbohydrates, fats, and proteins are the three main important macronutrients derived from food (de Graaf et al. 1992). They supply 90% of the nutrients and all the energy required for the smooth functioning of the body (Bhupathiraju and Hu 2023). Although both plant and animal proteins form essential parts of today's diet, animal protein is usually considered to be superior to plant protein for building muscle mass (Berrazaga et al. 2019; Gorissen and Witard 2018; van Vliet et al. 2015). The nutritional quality of protein is based on the content of essential amino acids compared to defined standards, requirements for body functions, digestibility and bioavailability (Boye et al. 2012; Marinangeli et al. 2017; Who et al. 2007).

Animal proteins are proteins derived from animal body tissues and include meat (e.g. beef, pork, and lamb), fish, dairy products (e.g. milk, cheese, and yoghurt) and eggs. Animal proteins are usually rich in all the amino acids (histidine (His), isoleucine (Ile), leucine (Leu), lysine (Lys), methionine (Met), phenylalanine (Phe), threonine (Thr), tryptophan (Trp), and valine (Val)) required by the body and are particularly high-quality proteins (Sá et al. 2020), the nutrients of which are more readily absorbed and utilised by the body (Day et al. 2022). In addition, animal proteins also provide rich sources of micronutrients such as vitamins (e.g. vitamin B12) and minerals (e.g. iron and zinc). On the other hand, plant proteins are derived from plant tissues, and the main sources of plant proteins include legumes (e.g. soybeans, black beans, red beans, cowpea, and lupin), cereals (e.g. wheat, rice, and maize) and nuts (e.g. walnuts, almond, and cashew nuts) (Lqari et al. 2002; Stahmann 1963). Although plant proteins supply essential amino acids for human needs, they are often considered nutritionally inferior to animal proteins (Hughes et al. 2011; Millward 1999). They are usually deficient in essential amino acids. For instance, the abundance of cereals is usually low in Lys, while legumes are deficient in sulphur-containing amino acids (Met and Cys) (Sá et al. 2020). Grimble (2006) explained that Lys is essential for the body's balance of nitrogen, the building of calcium in bones, and liver activities, while Met and Cys are essential for the functioning of the immune system.

However, other strands of literature suggest that high levels of meat consumption pose significant risks to public health (Funke et al. 2022). For instance, epidemiological studies suggest that the long-term consumption of high levels of red meat, especially processed meat, is associated with an increased risk of cardiovascular disease, certain types of cancer, and type 2 diabetes (Richi et al. 2015). In addition, there is growing concern about climate change and sustainability, and consumers are recognising the impact of animal protein production/consumption on climate change, soil and water resources (Moran and Wall 2011) and are beginning to re-evaluate their dietary choices. In this context, plant-based proteins are of increasing interest to UK consumers as alternatives to animal proteins. For instance, six in ten UK consumers are willing to try plant-based products, many of which are already on the market (Ibrahimi Jarchlo and King 2022). Plant proteins are often rich in other nutrients, such as dietary fibre (Dhingra et al. 2011), vitamins, minerals and antioxidants, and are low in saturated fat and cholesterol, which can help maintain heart health and reduce the risk of chronic diseases (Hertzler et al. 2020; Qin et al. 2022). Moreover, the production of plant-based proteins has a lower environmental impact and has a positive effect on reducing greenhouse gas emissions and conserving natural resources (Detzel et al. 2022). For instance, Springmann et al. (2018) reported that replacing animal protein with plant protein in diets could help reduce total greenhouse gas emissions from the diet. In addition, Ferrari et al. (2022) concluded that the consumption of vegetable protein sources is associated with better health outcomes (for cardiovascular diseases) overall than animal-based product use. The intake of animal proteins, especially red meat and poultry, was associated with weight gain for both men and women, while there was no overall association between the intake of plant proteins and weight change (Halkjær et al. 2011).

Many countries have been reluctant to consider taxes on meat and dairy products because of the strong social and political controversy that such taxes can cause (Cornelsen et al. 2019). Funke et al. (2022) noted that the only taxes on meat are value-added taxes, often at reduced rates. However, with the increasing severity of global climate change, researchers have emphasised that changing dietary patterns are one of the key areas for limiting the impact of GHG emissions from livestock (British Nutrition Foundation 2019; Nelson et al. 2016).

Therefore, to rapidly reduce carbon emissions from the agricultural sector to counter the threat of global warming and to limit global temperature increases to 1.5 °C (Funke 2022), one of the measures that government and the international community may want to consider is to impose taxes on meat and dairy products. By raising taxes on these foods, people may be financially incentivised to reduce their consumption of high GHG-emitting foods and move towards more environmentally friendly and low-carbon dietary choices. From a health perspective, reducing the consumption of red and processed meat would result in 220,000 fewer deaths per year from chronic diseases such as coronary heart disease, stroke, cancer, and type 2 diabetes (Springmann 2018).

The EAT-Lancet Commission recommended that red meat consumption be limited to 28 g/day (Willett et al. 2019). However, in 2021, 32% of adults in Scotland exceeded the 70 g/day recommended intake of red and red processed meat (Stewart et al. 2023). A strategy to reduce meat intake is in line with public health goals and to achieve environmental health. Sadly, there is little research on how a tax on animal-based proteins could nudge Scottish households from animal protein sources towards plant protein.

However, consumers also face several challenges when switching from animal to plant-based proteins, one of which is price and supply and demand. Plant protein products are usually available on the market at relatively high prices, which may limit the choices available to some consumers. In addition, consumer preferences, cultural habits, product availability, price and taste may all influence consumers' willingness and ability to switch from animal-based to plant-based proteins (Jeske et al. 2018). Similarly, Pohlmann (2021) found that the choice between plant-based and animal-based protein is influenced by both consumer characteristics and dietary preferences. Both Pohlmann (2021) and Jeske et al. (2018) agreed that protein choice is influenced by a variety of interacting biological, situational, psychological, and economic factors. A survey conducted by the Plant-Based Foods Association in 2018 showed that the market for plant-based meat substitutes had grown by more than 20% (Plant Based Foods Association 2018) compared to the previous year. Demand studies suggest that consumers are very responsive to price changes, which affect both their demand for and preference for healthier food options. It is, therefore, believed that the rising cost of living is likely to push consumers away from healthier, less carbon footprint plant-based protein to a high carbon footprint and less healthy animal-based proteins. This would significantly increase the number of consumers who do not meet the EAT-Lancet Commission's recommendation for animal protein consumption. It is therefore necessary to assess the extent to which consumers are sensitive to the prices of plant protein and how a shift from animal-based protein to plant-based protein affects diet quality and vice versa.

Specifically, the main objectives of this study are (1) to explain consumer sensitivity to changes in the own price of plant and animal proteins; (2) to understand how consumers perceive the relationship between plant and animal proteins, i.e. as substitutes or complements; and (3) to estimate the extent to which a switch from animal to vegetable protein affects overall diet quality.

The rest of the paper is organised as follows: "Literature review" section presents descriptive statistics relevant to the study and a summary of relevant research performed by previous scholars. Section three presents the research methodology on how the above objectives were conducted. Section four presents and discusses the results of this study, and "Conclusion" section presents the conclusions and recommendations.

Literature review

Trends in plant and animal protein consumption

Figure 1 shows the average daily animal and plant protein supplies per person in different countries and continents from 2018 to 2020. With the exception of Africa and China, the per capita supply of animal protein is greater than that of plant protein. The USA has the largest per capita share of animal protein intake, followed by Europe and the UK, with Africa having the least. For plant protein, China has the largest per capita share, followed by Africa, and the USA has the least.

Figure 2 also shows that chicken and fish are the most popular choices in the UK. Poultry is the best choice for British people, probably because it has a short production cycle (Yakovleva and Flynn 2004). Fish are also popular because the majority of UK cities are close to coastlines and have access to relatively inexpensive fresh fish. In addition, fish

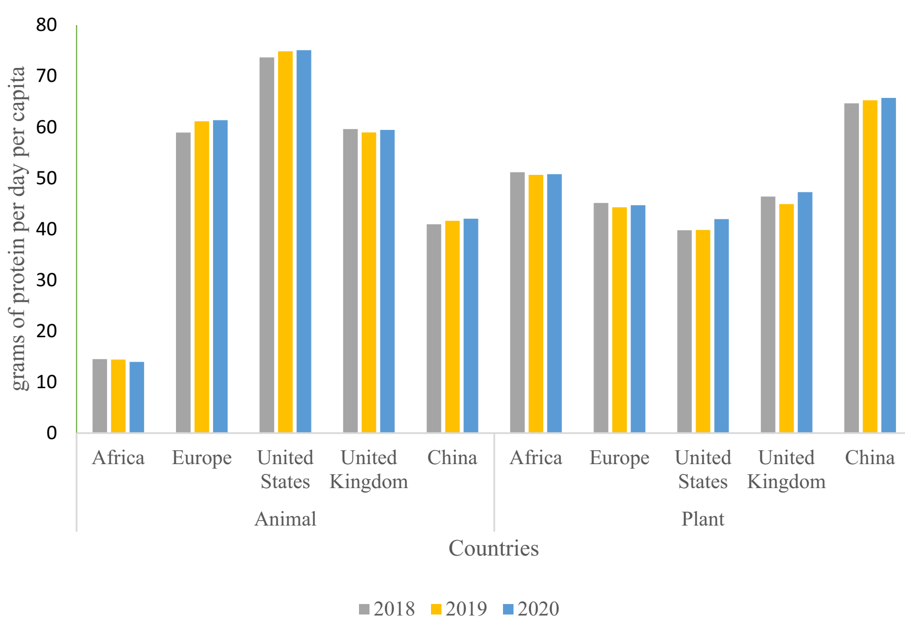

Fig. 1 Animal protein vs. vegetable protein by region. *Source*: Author's own computation based on Our World in Data (2023)

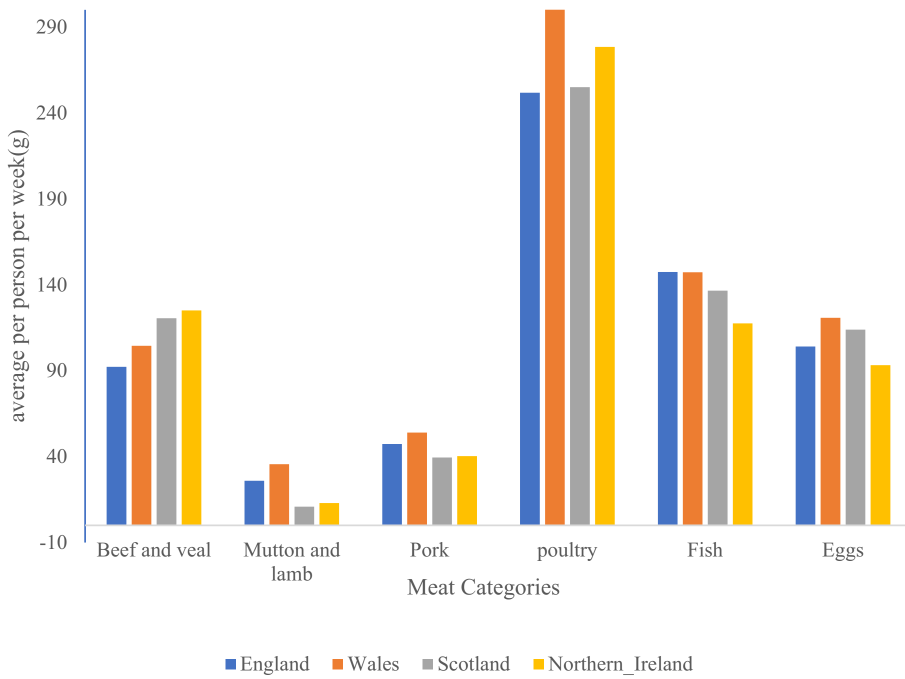

Fig. 2 Meat consumption by region—average per person per week (UK). *Source*: Author's own computation based on family foods datasets, 2023

and chips are considered one of Britain's national dishes and are traditional foods that are very popular with the British. Among the regions in the UK, Scotland is the second largest consumer of beef and vegetables and the third largest consumer of poultry and fish. She is also the least consumer of mutton and lamb.

Figure 3 shows the importance of plant protein as one of the main sources of protein in the UK diet. Beans are the dominant plant protein consumed in the UK, while dry

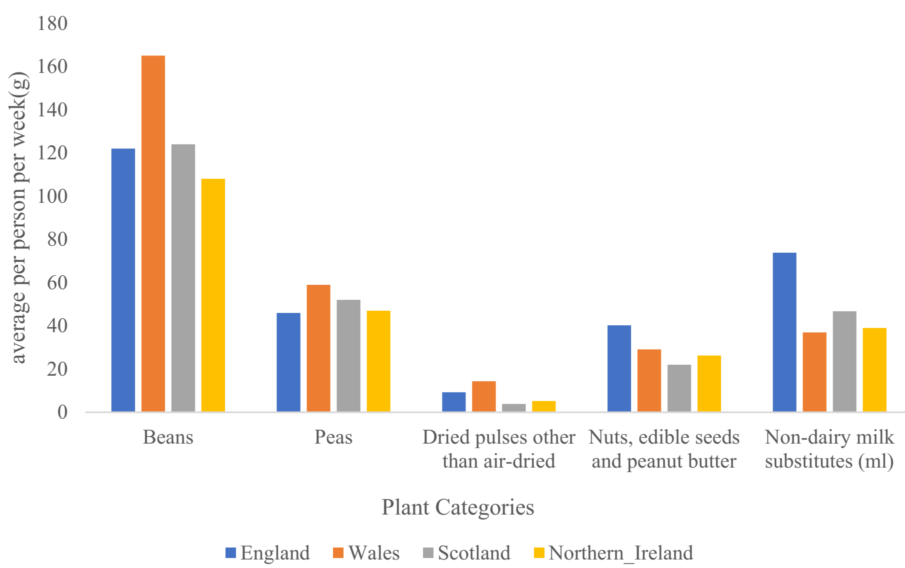

Fig. 3 Plant consumption by region—average per person per week (UK). *Source*: Author's own computation based of Family foods dataset, 2023

pulses are the least important plant protein. The importance of beans in the British diet could be due to having a higher protein content than peas and providing a wide range of essential amino acids and dietary fibre (Geil and Anderson 1994). Among these regions, Scotland is the second largest consumer of peas and a non-dairy milk substitute. However, it consumes the least number of dry pulses.

Drivers of animal and plant protein consumption

First, the potential health benefits associated with plant-based proteins are the main driver. Red meat (e.g. beef, pork and lamb) is associated with an increased risk of diseases such as cardiovascular disease, type 2 diabetes and certain cancers (Abete et al. 2014; Barnard et al. 2014) and an increased risk of colorectal cancer (Larsson and Wolk 2006). Tilman and Clark (2014) found that replacing meat intake with plant-based protein substitutes reduced the risk of coronary heart disease by 20–26% and type II diabetes by 16–41%.

Second, there are ethical issues concerning the treatment of animals. For instance, between 2006 and 2016, concerns for animal welfare increased by 20% for European citizens and 68% for UK residents (Alonso et al. 2020). In addition, the public is becoming increasingly aware of the possible risk, quality or safety issues associated with meat consumption. Yamoah and Yawson (2014) found that all meat markets experienced weekly declines in retail sales and volume following the announcement of the UK horsemeat scandal. This has shifted sales towards vegetarian meat alternatives (Butler 2013).

Third, consumers may choose to stay away from animal proteins because of the high carbon footprints associated with their production and consumption. Greenhouse gases such as methane (25%), carbon dioxide (CO_2) (32%), and nitrous oxide (N_2O) (31%) are the main consequences of animal production (Moran and Wall 2011). In addition, population growth and limited land resources can drive farmers or herders to overgraze their limited land, causing damage to the land and ecosystems. Abril and Bucher (1999) and Zou et al. (2006) reported that overgrazing caused a reduction in soil fertility and water retention. In addition, Sy et al. (2015) found through different satellite images that 71% of the rainforest in South America was converted into pasture for farmed animals and 14% was used for commercial cultivation. The destruction of natural habitats for many plants and animals affects biological interdependence and may lead to a decrease in the stability of the entire ecosystem. A study by Goldstein et al. (2017) revealed that the widespread adoption of plant-based beef alternatives could significantly reduce greenhouse gas emissions, water consumption, and agricultural land use in the USA. Similarly, Stehfest et al. (2009) found that by switching to a meat-free diet, in which all protein is derived from plants, CO_2, CH_4 and N_2O emissions were reduced to varying degrees globally.

The mutual substitutability of animal and plant proteins

Different scholars have different views on the substitutability and complementarity of animal and plant proteins. Some scholars believe that plant proteins are unlikely to completely replace animal proteins in meat and poultry products in general. Sha and Xiong (2020) argue that meat will continue to be the main source of protein in North America in the future, that meat substitutes cannot completely replace animal meat, and that the term "meat substitutes" should be used instead of "meat analogues" to avoid misleading consumers into thinking that these products can completely replace traditional animal meat. Similarly, in terms of nutrition, Clegg et al. (2021) found that plant-based dairy alternative (PBDA) products were at risk of nutritional deficiencies through ANOVA using a linear model and pairwise comparisons and that many PBDAS were not fortified with micronutrients and therefore could not replace milk.

Some scholars believe that there is complementarity between animal and plant proteins and that both can be consumed to obtain more complete nutrition. Vainio et al. (2016), after conducting structural equation modelling (SEM), found that most beef eaters were not opposed to eating plant proteins. Almost half of the respondents had established a pattern of combining beef consumption with the consumption of beans and/or soy products. However, a limitation of the article is that the sample studied was only Finnish consumers who consume fewer beans in their diet. This may lead to differences in the applicability of the study results across regions.

Some academics consider animal and vegetable proteins to be complete substitutes. This may be due to concerns about issues such as animal welfare, environmental protection, and sustainable development. In addition, plant protein intake is associated with a lower risk of disease. However, some consumers avoid dairy products for a variety of reasons, including medical reasons such as lactose intolerance, milk allergy, lactase deficiency, cholesterol problems and phenylketonuria. The main treatment is to avoid lactose-containing foods and to replace milk and dairy products with lactose-free dairy products or dairy-free alternatives (Mäkinen et al. 2015), which include plant-based milk alternatives. Salomé et al. (2021), using ANOVA, multiple comparisons, and Kruskal–Wallis nonparametric and post hoc Dwass–Steel–Critchlow–Fligner tests, found that plant-based protein alternatives had minimal alterations and that legumes were largely perfect substitutes for animal protein in terms of nutrition.

Factors limiting plant protein consumption

Meat substitutes are often more expensive than traditional meat products because they use different ingredients and production techniques, some of which are fortified with micronutrients (Clegg et al. 2021). The authors also found that plant-based dairy alternatives (PBDAs) cost much more than their dairy equivalents and predicted that if a household switched to a plant-based protein diet, the cost of dairy consumption would be three times greater than before. Axworthy (2022) reported that the current price of plant-based meat far exceeds that of animal meat and that higher prices reduce the likelihood of consumption. However, surprisingly, the average retail sales of plant-based meat increased by 45% in 2020. Similarly, Tosun et al. (2020) found the negative impact of price changes to be minimal, accounting for only 4% of participants in the survey. Although the current market environment is still favourable, as the market develops and competition increases, the price of some meat alternatives may gradually decline and be priced at parity with conventional meat. Finally, Axworthy (2022) predicts price parity in 2023 for meat substitutes made from soy, peas, and other leguminous plant-based proteins.

Table 1 Household food consumption statistics. *Source*: Author's own computation, 2023

Categories	Weekly expenditure per capita (£)		Weekly quantity per capita (kg)		Budget shares		Prices	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Dairy	5.14	3.06	3.83	2.67	0.08	0.04	4.35	4.02
Beef and veal	1.49	1.63	0.20	0.20	0.02	0.02	8.48	4.91
Mutton and lamb	0.19	0.47	0.02	0.04	0.00	0.01	3.88	5.52
pork	1.71	1.47	0.29	0.25	0.02	0.02	7.23	3.17
poultry	1.53	1.53	0.32	0.34	0.02	0.02	6.04	3.00
Fish	1.67	1.60	0.33	0.35	0.02	0.02	9.76	5.44
Eggs	0.48	0.48	3.19	3.18	0.01	0.01	0.20	0.72
Peas	0.20	0.43	0.10	0.16	0.00	0.01	2.94	5.36
Beans and pulses	0.39	0.35	0.26	0.25	0.01	0.01	2.58	2.86
Nuts, seeds and peanut butter	0.41	0.55	0.09	0.16	0.01	0.01	7.53	4.73
Non-dairy substitutes	0.07	0.27	0.05	0.27	0.00	0.00	1.11	4.02
All other expenditure	54.50	27.02	33.98	17.88	0.80	0.06	7.41	6.54

Methodology

Data

This study relies on 2021 home scanner data collated by the Kantar Worldpanel. Kantar Worldpanel is a market research company that collects data on daily household purchases made by consumers using barcodes from purchase receipts. The data collected included restaurant and retail food purchases and demographic data. Every household participating in the data collection procedure received a scanner to record the Universal Product Code (UPC) details for all items bought. This study was conducted on a sample of 1,589 Scottish households that had been observed for at least 40 weeks. The product-specific data considered are type of animal protein, type of plant protein, price (£) and weight (kg), as well as total weekly expenditure. The demographic variables collected were location, age, gender, employment status of the lead shopper, household size, marital status, access to the internet, presence of smokers, and vegetarians in the household. For this study, seven animal protein products, dairy, beef and veal, mutton and lamb, pork, poultry, fish, and egg, four plant protein products, peas, beans and pulses, nuts, seeds and peanut butter, and non-dairy alternatives were considered for analysis.[1] All other products bought by the household were summed under "all other products" or miscellaneous products.

Summary of data

Table 1 presents the weekly consumption of the different types of animal and plant protein products bought by Scottish households. Dairy products had the largest average weekly purchase of approximately 3.83 kg, followed by eggs at approximately 3.19 kg, while mutton and lamb were the least purchased meats, with weekly per capita purchases of approximately 0.02 kg. In terms of expenditure, dairy products

[1] The aggregation of the plant and animal proteins is based on their nutritional value and use.

had the highest weekly expenditure (£5.14), followed by pork (£1.71) and fish (£1.67). Among the meat group, mutton and lamb had the lowest weekly average expenditures (£0.19). In terms of the share of expenditures, dairy products had the largest share, and lambs had the smallest share.

Overall, plant protein consumption is much lower than animal protein consumption. Beans and pulses had the largest average weekly quantity of purchases, at approximately 0.26 kg per capita, while non-dairy substitutes had the lowest, at just 0.05 kg per capita. This is reflected in the average weekly expenditure. In terms of expenditure shares, plant protein products have a very small share compared to animal protein products, indicating relatively less importance of these groups among Scottish consumers.

Tables 2 and 3 display the demographic characteristics included in the probit and EASI demand models: gender, number of children, Scottish Index of Multiple Deprivation Quintiles, rural–urban classification, income decile, life stage, employment status, and marital status.

Approximately 27% of the participants in the dataset were men. Married respondents made up a greater proportion of the sample, at approximately 21%. More than half of the households had no children. The percentage of households living in the most deprived areas is 17.94%. The largest proportion of respondents, approximately 45 per cent, had an annual income of £29,999 or less. More than half of the households aged 45 and over had no children. Approximately 0.06 per cent of the respondents chose not to disclose their employment status. The largest percentage of heads of household, 43.30 per cent, worked more than 30 h per week.

The percentage of zero purchases for household food consumption is shown in Table 4. A lower percentage of zero purchasers indicates that more consumers bought the product. Milk is a daily necessity for Scottish residents, while fish

Table 2 Descriptive statistics of household composition and characteristics

Variable	Percentage
Gender	
Female	72.56
Male	27.44
Number kids	
0	69.98
1	15.67
2	11.52
3	2.52
4	0.31
Scottish index of multiple deprivation quintiles (*SIMD*)	
SIMD 1 (Most deprived areas)	17.94
SIMD 2	20.52
SIMD 3	20.20
SIMD 4	22.84
SIMD 5 (least deprived areas)	17.81
NA	0.69

Table 3 Descriptive statistics of household composition and characteristics cont'd. *Source*: Authors' computation based on Kantar Worldpanel data, 2023

Variable	Percentage
Rural–urban classification	
Large Urban Areas	30.84
Other Urban Areas	39.65
Accessible Small Towns	7.11
Remote Small Towns	3.21
Accessible Rural	11.20
Remote Rural	5.54
NA	2.45
Income decile	
£0–£29,999	44.87
£30,000–£39,999	13.09
£40,000–£49,999	10.70
£50,000–£59,999	5.98
£60,000–over	5.79
NA	19.57
Life stage	
Prefamily	15.73
Young family	11.26
Middle family	9.00
Older family	8.68
45 + no children	55.32
Employment status	
Over 30 h	43.30
8–29 h	19.89
Under 8 h	2.01
Unemployed	2.89
Retired	18.44
Full time education	1.13
Not working	12.27
NA	0.06
Marital status	
Married	21.71
Single	5.54
Widowed/divorced/separated	4.34
Unknown	68.41

products are second only to dairy. These two categories have become the main food items consumed by the population. Fish consumption varies geographically, and for Scotland, the region has a vast coastline and abundant marine resources. As a result, Scots have easy access to fresh seafood, and fish are an essential part of their diet. Over 60% of the population did not consume mutton or lamb for at least 40 weeks, and similarly, more than 75% did not consume non-dairy milk substitutes for at least 40 weeks. This suggests that the consumption of mutton and lamb and non-dairy milk substitutes is infrequent and not an essential part of the daily diet of Scottish residents.

Table 4 Households reporting zero consumption. *Source*: Author's own computation of Kantar Worldpanel data, 2023

Categories	**Total sample**	**Percentage of zero purchases (%)**
Dairy	1589	0.06
Beef and veal	1589	6.92
Mutton and lamb	1589	64.07
pork	1589	3.84
poultry	1589	5.60
Fish	1589	0.69
Eggs	1589	5.60
Peas	1589	17.31
Beans and pulses	1589	3.46
Nuts, seeds and peanut butter	1589	10.51
Non-dairy milk substitutes	1589	77.85

Conceptual framework

In this research, the exact alkaline stone index (EASI) demand model of Lewbel and Pendakur (2009) was employed to estimate the demand for animal protein products and plant protein products. The EASI demand system establishes a connection between the budget share w_i and the polynomials of real expenditure on food (y_i), the vector of demographic characteristics (z_i), and the vector of prices (p_i).

The budget share equation of each food in the LA/EASI demand system is indicated by:

$$w_i = \sum_{r=0}^{5} b_r y_i^r + Cz_i + Dz_i y_i + Ap_i + Bp_i y_i + \varepsilon_i \tag{1}$$

where y, the real food expenditure, is specified as:

$$y_i = \ln(x_i) - p_i{}' w_i \tag{2}$$

In Eq. (2), the variable x_i represents overall weekly household spending, and the parameter matrices that need to be estimated are $A, B, C, D,$ and b_i.

The satisfaction of the following constraints is necessary to ensure the cumulative homogeneity of the cost function:

$$1_n{}'A = 1_n{}'B = 0_n{}'; 1_n{}'C = 1_n{}'D = 0n \tag{3}$$

$$1_n{}'b_0 = 1, 1_n{}'b_r = 0 \quad \forall r \neq 0 \tag{4}$$

A and B symmetry ensures Slutsky symmetry. The EASI demand system produces an implicit Marshallian demand equation rather than a traditional Marshallian demand function. Therefore, the Marshallian demand elasticity is derived indirectly from the Hicksian price elasticity and expenditure elasticity via the Slutsky equation (Lewbel and Pendakur 2009).

Given the prevalence of households with high reported zero expenditures on food categories, we utilise a censored equation system and apply a consistent two-step estimation procedure (Shonkwiler and Yen 1999). This technique involves two steps: (1) estimating the probit or sample selection equation and (2) estimating the EASI demand system.

In the initial step, a general sample selection model is specified, comprising 12 equations, each corresponding to a specific food group, namely, dairy, beef and veal, mutton and lamb, pork, poultry, fish and eggs, peas, beans and pulses, nuts, seeds and peanut butter, non-dairy milk substitutes, or all other foods considered in the analysis. The probit equation for the $i-th$ food group is expressed as follows:

$$w_i^* = X_i{}'\beta_i + \varepsilon_i; \quad d_i^* = Z_i{}'v_i + u_i \tag{5}$$

$$di = \left\{ \begin{matrix} 1 \text{ if } d_i > 0 \\ 0 \text{ if } d_i < 0 \end{matrix} \right\} \; w_i = d_i w_i^* \tag{6}$$

w_i and d_i are the observed dependent variables, w_i is the latent variable for the budget share, d_i is the latent variable for the probit equation, X_i and Z_i are vectors of exogenous variables determining level and participation, respectively, β_i and v_i are parameter vectors, and ε_i and u_i are error terms. Using the vectors of the estimated parameters, a set of cumulative density functions (CDFs) and probability density functions (PDFs) $(Z_i{}'v_i)$ were calculated and included in the final demand model.

The demand model

The standard linear approximate exact affine stone index (LA/EASI) with censorship is specified as follows:

$$w_i^* = \hat{\Phi}_i \left(\sum_{r=0}^{5} b_r y_i^r + Cz_i + DZ_i y_i + Ap_i + Bp_i y_i \right) + \delta\hat{\phi}_i + \varepsilon_i \tag{7}$$

where $\widehat{\Phi}_i$ and $\widehat{\phi}_i$ represent nxn identity matrices with ones replaced by *cdf* and *pdf* values, respectively. Additionally, δ is an n-vector of parameters that need to be estimated. It is important to note that economic theory does not provide specific guidance on the selection of sociodemographic variables to be included in the probit model (x_i vector) and demand equation (z_i vector) for the sample section (Castellón et al. 2015). However, to mitigate potential multicollinearity concerns in the censored model outcomes, additional demographic factors were included in the x_i vector.

The final LA/EASI demand system, accounting for zero purchases, price, and spending endogeneity and excluding interactions, is represented as follows:

$$w_i = \hat{\Phi}_i \left(\sum_{r=0}^{5} b_r y_i^r + Cz_i + Ap_i \right) + \delta\hat{\phi}_i + \varepsilon_i \tag{8}$$

Lewbel and Pendakur (2009) suggest that the presence of y on the right-hand side of Eq. (8) and the left-hand side of Eq. (2) introduces endogeneity in the demand model.

The authors suggested using the log of real expenditure estimated from the mean budget shares ($\overline{w}$) (i.e. $\overline{y_i} = \ln(x_i) - {p_i}'\overline{w}_i$) as an instrument to correct for this form of endogeneity. The final $n - 1$ equations were estimated using iterative three-stage least squares (3SLS) with $\overline{y_i}$ as an instrument to correct for endogeneity.

Price and expenditure elasticities were derived from Eq. 8. The matrix of own and cross-price elasticities was recovered from the censored LA/EASI demand system:

$$\xi = \varpi^{-1}\Phi(A) + \Omega\varpi - I \tag{9}$$

where ξ represents an *nxn* matrix of compensated demand elasticities, while ϖ is an identity matrix with the budget share of each food group replacing the original elements. Additionally, Ω is an *nxn* matrix of ones, and I denotes an identity matrix.

Similarly, the elasticity of expenditure (η_i) derived from the implicit Marshallian equation of demand is:

$$\eta = \varpi^{-1}(I + \Phi\mathfrak{b}p')^{-1}\Phi\mathfrak{b} + 1_n \tag{10}$$

where η denotes the J X 1 vector of estimated expenditure elasticities, $\mathfrak{b}$ represents the expenditure semi-elasticity coefficients, p is the vector of mean prices, and 1_j stands for a $J \times 1$ vector of ones.

The matrix of uncompensated Marshallian elasticity (ε) was derived from the Slutzky equation:

$$\varepsilon = \xi - \varpi\eta \tag{11}$$

Changes in average weekly consumption (ΔQ_i) are estimated as follows:

$$\Delta Q_i = \varepsilon_{i,j} * Q_{\text{av}} * \Delta P_i \tag{12}$$

If a 10 per cent increase in the original price is applied, the change in weekly nutrient intake (Δq_n) is estimated from the changes in quantity following the price change as follows:

$$\Delta q_n = \Delta Q_i * q_{\text{av}} \tag{13}$$

where $\varepsilon_{i,j}$ refers to estimated own price and cross-price elasticities, Q_{av} refers to the average weekly consumption, and q_{av} refers to the average weekly nutrient intake. The estimated Δq_n is converted into percentages by dividing by the initial average weekly nutrient intake and multiplying by 100.

Simulation scenarios

Table 5 illustrates the price increase scenarios adjusted by the current level of inflation. In scenario 1, the prices of all meat and meat products (i.e. dairy, beef and veal, mutton and lamb, pork, poultry, fish and eggs) increased by 10 per cent from the current level. In scenario 2, the prices of red meat (beef and veal, mutton and lamb, pork) increased by 10 per cent. Under scenario 3, prices of white meat (poultry, fish) were increased by the current inflation rate (10 per cent) from the initial level; finally, scenario 4 considers an increase in egg and dairy prices of 10 per cent from its initial level.

Table 5 Description of tax scenarios. *Source*: Author's own computation of Kantar Worldpanel data, 2023

Food groups	All Meat and Product	Red Meat	White Meat	Eggs and Dairy
Dairy	T			T
Beef and veal	T	T		
Mutton and lamb	T	T		
Pork	T	T		
Poultry	T		T	
Fish	T		T	
Eggs	T			T
Peas				
Beans and pulses				
Nuts, seeds and peanut butter				
Non-dairy milk substitutes				

T is a 10 per cent price increase

Results and discussion

Results

Table 6 shows that all the estimated own price elasticities are significant and negative. Own-price elasticity can be used to measure the sensitivity of quantity demand to changes in the price of a good (Davidson and Hellegers 2011). The price elasticity of a good can be elastic (when the coefficient is greater than 1), inelastic (when the coefficient is less than 1) or elastic (when the coefficient is equal to 1). Table 6 shows that dairy products and eggs are price inelastic. A 1% price increase in dairy products will cause the quantity demanded to decrease by 0.89%. Similarly, when the price of eggs increases by 1%, the quantity demanded decreases by 0.75%. This indicates that these two products have low price sensitivity and are necessary for consumers.

The own price elasticities of beef and veal, mutton and lamb, pork, poultry, and fish are greater than 1. The demand for fish is most sensitive to price; if the price increases by 1%, demand will decrease by 1.583%. The price elasticity of plant protein products is greater than 1, especially for non-dairy milk substitutes, for which demand is most sensitive to price; a 1% increase in price would result in a 1.633% decrease in demand. The above data indicate that these products are highly price-sensitive. Therefore, consumers can easily choose other substitutes.

Table 6 shows that among the animal-based proteins, dairy is a substitute for all meat products; beef and veal are substitutes for dairy, fish, and eggs and are complementary to other meats. Similarly, mutton and lamb are substitutes for dairy and are complementary to other meats. The results for pork and poultry are similar, with demand for dairy and eggs increasing when prices rise by 1 per cent each. Fishes can be substituted with dairy, beef and veal, and eggs can be substituted with mutton, lamb and fish.

To address the relationship between animal and plant proteins, the results suggest that peas are substitutes for dairy, beef, veal, and pork. For instance, when the price of peas increases by 1%, the demand for dairy, beef and vegetables and pork increases by 0.01%, 0.03% and 0.02%, respectively. On the other hand, peas complement mutton

Table 6 Uncompensated elasticity of demand for animal protein plant protein in Scottish households. *Source*: Author's own computation of Kantar Worldpanel data, 2023

Demands	Products												
	Dairy	**Beef and veal**	**Mutton and lamb**	**Pork**	**Poultry**	**Fish**	**Eggs**	**Peas**	**Beans and pulses**	**Nuts, seeds and peanut butter**	**Non-dairy milk substitutes**	**Miscellaneous**	**Expenditure**
Dairy	**−0.890**	0.046	0.026	0.040	0.019	0.039	0.008	0.012	0.008	0.001	0.007	0.363	0.925
	(0.031)	(0.013)	(0.008)	(0.013)	(0.014)	(0.018)	(0.006)	(0.014)	(0.004)	(0.007)	(0.011)	(0.036)	(0.027)
Beef and veal	0.158	**−1.526**	−0.072	−0.087	−0.038	0.122	0.015	0.030	0.018	0.068	−0.034	−0.432	1.145
	(0.046)	**(0.025)**	(0.018)	(0.026)	(0.023)	(0.031)	(0.014)	(0.025)	(0.011)	(0.016)	(0.026)	(0.064)	(0.041)
Mutton and lamb	0.292	−0.186	**−1.318**	−0.177	−0.161	−0.102	−0.059	−0.080	0.018	−0.005	−0.030	−0.586	0.634
	(0.078)	(0.047)	**(0.103)**	(0.050)	(0.042)	(0.052)	(0.020)	(0.064)	(0.012)	(0.020)	(0.041)	(0.164)	(0.176)
Pork	0.113	−0.072	−0.058	**−1.308**	−0.031	−0.015	0.027	0.022	−0.003	0.046	0.029	−0.309	1.096
	(0.041)	(0.023)	(0.016)	**(0.028)**	(0.026)	(0.026)	(0.019)	(0.023)	(0.011)	(0.016)	(0.026)	(0.061)	(0.038)
Poultry	0.055	−0.036	−0.060	−0.036	**−1.286**	−0.015	0.017	−0.038	0.004	0.006	−0.000	−0.456	1.112
	(0.049)	(0.022)	(0.016)	(0.029)	**(0.034)**	(0.030)	(0.016)	(0.026)	(0.015)	(0.016)	(0.027)	(0.079)	(0.048)
Fish	0.122	0.108	−0.035	−0.013	−0.010	**−1.583**	−0.028	−0.012	0.027	0.007	0.025	−0.387	0.993
	(0.056)	(0.026)	(0.017)	(0.026)	(0.026)	**(0.047)**	(0.014)	(0.024)	(0.014)	(0.018)	(0.021)	(0.065)	(0.040)
Eggs	0.097	0.050	−0.063	0.096	0.056	−0.088	**−0.750**	−0.040	0.012	0.007	0.032	0.523	0.811
	(0.059)	(0.040)	(0.021)	(0.063)	(0.047)	(0.047)	**(0.044)**	(0.036)	(0.030)	(0.026)	(0.026)	(0.104)	(0.055)
Peas	0.288	0.184	−0.174	0.161	−0.223	−0.074	−0.083	**−1.102**	0.040	−0.047	0.664	0.773	0.768
	(0.310)	(0.153)	(0.139)	(0.158)	(0.155)	(0.169)	(0.077)	**(0.463)**	(0.044)	(0.075)	(0.280)	(0.760)	(0.537)
Beans and pulses	0.108	0.066	0.021	−0.010	0.016	0.114	0.014	0.023	**−1.316**	−0.008	0.029	0.066	0.982
	(0.055)	(0.038)	(0.016)	(0.047)	(0.054)	(0.057)	(0.037)	(0.026)	**(0.032)**	(0.029)	(0.021)	(0.097)	(0.042)
Nuts, seeds and peanut butter	0.023	0.237	−0.009	0.191	0.028	0.031	0.009	−0.027	−0.007	**−1.511**	0.057	0.148	0.790
	(0.086)	(0.053)	(0.025)	(0.063)	(0.057)	(0.072)	(0.031)	(0.043)	(0.027)	**(0.030)**	(0.039)	(0.133)	(0.071)
Non-dairy milk substitutes	0.096	−0.137	−0.044	0.130	−0.003	0.111	0.043	0.442	0.032	0.066	**−1.633**	0.023	1.134
	(0.161)	(0.101)	(0.059)	(0.120)	(0.111)	(0.093)	(0.036)	(0.183)	(0.025)	(0.046)	**(0.169)**	(0.260)	(0.145)
Miscellaneous	0.030	−0.008	−0.009	−0.007	−0.010	−0.012	0.003	0.003	0.000	−0.000	0.001	**−1.013**	1.005
	(0.004)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.003)	(0.001)	(0.001)	(0.002)	**(0.008)**	(0.005)

Standard errors are in parentheses; own-prices elasticities are in the diagonals and in bold and lamb, poultry, fish and eggs. Beans and pulses are weakly complementary to pork; when the price of beans and pulses increases by 1%, the demand for pork decreases by 0.003%. Otherwise, beans and pulses are substitutable with other animal protein products to varying degrees. For example, when the price of beans and pulses increases by 1%, the demand for dairy, beef and vegetables, mutton and lamb, and poultry, fish and eggs increase by 0.008%, 0.01% and 0.01%, 0.004%, 0.02% and 0.01%, respectively. Additionally, nuts, seeds and peanut butter complement mutton and lamb, indicating that when the price of nuts, seeds and peanut butter increases by 1%, the demand for mutton and lamb decreases by 0.005%. Similarly, non-dairy milk substitutes can complement beef and veal and mutton and lamb, and they are substitutes for other animal protein products.

Figure 4 shows the household expenditure elasticities for 11 different types of animal and plant protein products for Scottish households, with expenditure elasticities ranging between 0.634 and 1.145. Among animal protein products, mutton and lamb are the least responsive to changes in expenditure. Dairy and egg expenditure elasticities are less than 1, which shows that they are necessities, while beef and veal are the most responsive to changes in spending and may be considered luxury foods by Scottish households. Among the plant protein types, peas are less responsive to changes in total expenditure, indicating that peas or pea products are relatively basic, essential food items for consumers. non-dairy milk is the most responsive to changes in spending.

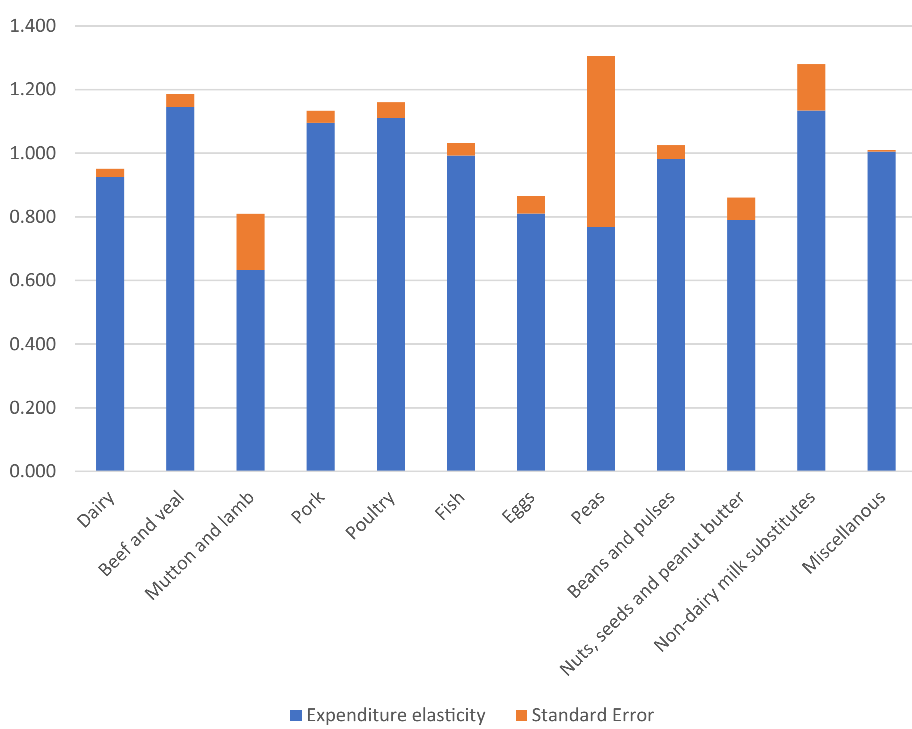

Fig. 4 Expenditure elasticity for animal and plant protein products consumed in the Scottish household. *Source*: Author's own computation of Kantar Worldpanel data, 2023

Effect of price increases in animal protein on demand for plant protein

Figure 5 shows the potential effect of a 10% price increase for all meat and meat products on the demand for animal and plant protein products. The demand for mutton and lamb decreased the most, by 17.10%, while the demand for eggs decreased the least, by 5.99%. Consumers are very sensitive to changes in the price of mutton and lamb, and an increase in price has a greater impact on their purchasing decisions. While eggs are a more essential everyday item in Scottish households, the demand for this product has a more stable impact even if the price increases. Among the plant protein products, nuts, seeds, and peanut butter have the highest increase in demand (5.13%), which indicates that consumers may be more willing to buy nuts, seeds and peanut butter when the price of animal protein increases, whereas among the plant protein products, peas have the lowest increase in demand (0.82%). It can be inferred that the impact of consumer demand for peas is more stable.

Figure 5 shows that when red meal alone is taxed, consumer demand for the remaining untaxed animal protein products will still decrease, except for dairy, fish and eggs.

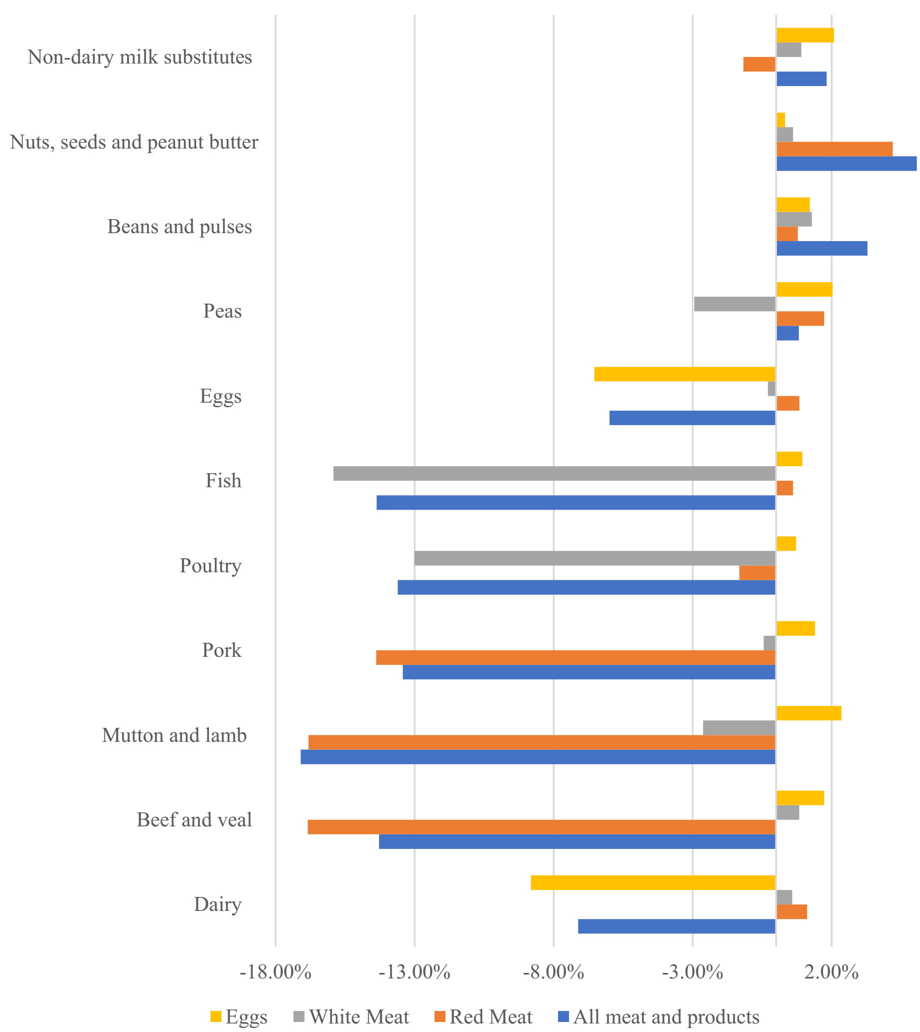

Fig. 5 Per cent change in quantities. *Source*: Author's own computation of Kantar Worldpanel data, 2023

This could translate into reduced impacts on the environment, animal welfare and health. Positively, the demand for plant protein products would increase, except for non-dairy milk substitutes. This result could be potentially helpful for government policymaking.

When the price of white meat increases by 10%, demand for dairy, beef and wine increases by 0.58% and 0.84%, respectively, indicating a substitution effect. However, the demand for the remaining animal protein products decreased to varying degrees; for instance, the demand for fish and poultry decreased by 15.92% and 13%, respectively. A price increase for white meat only resulted in a demand increase for all vegetable proteins, except for peas, for which the demand decreased (− 2.95%).

When the prices of eggs and dairy increase by 10%, the demand for the remaining animal and plant proteins increases. The largest increase was estimated for mutton and lamb, while the smallest increase was recorded for poultry. The results show that consumers consider the remaining plant animal and plant proteins to be substitutes for eggs and dairy. The implication is that any policy that increases the prices of eggs and dairy would cause an increase in all other animal proteins.

Implication for nutrient demand

Figure 6 shows the potential impact of the different policy scenarios on macro- and micronutrient purchases. The discussion focuses on the following: protein, fat, energy (kcal), total sugar, carbohydrate, and cholesterol.

When the price of all meat and products increases by 10%, the overall nutrient demand will decrease, especially for cholesterol (7%), followed by calories (7%) and fat (7%). Even though Fig. 5 shows an increase in plant protein demand, the net effect is negative for calorie and total fat intake. This impact is positive, as the average calorie intake in the UK is currently higher than the recommended level, and the UK tops the European obesity league table (Sky News 2018). Such nutritional findings can be explained by the fact that, first, meat is usually high in cholesterol and fat, so a decrease in cholesterol levels is to be expected when people reduce their meat consumption. Second, meat is a high-fat, high-calorie food source, so reducing meat intake also means that people cut down on energy-dense foods. This helps to control weight and reduces the risk of obesity and associated health problems. Finally, rising meat prices may prompt people to pay more attention to their eating habits and health. Having realised that meat intake may have a negative impact on health, people may be more inclined to choose healthier food alternatives to meat, thus improving their overall nutritional intake.

When the price of only red meat increases by 10%, the figure shows that the intake of all nutrients decreases, except for carbohydrates and total sugars, which increase (1%). An increase in the price of red meat may encourage people to choose lower-priced alternatives to red meat, such as foods that are higher in carbohydrates and sugar. This resulted in a slight increase in carbohydrate and total sugar intake. In addition, higher red meat prices may encourage people to try a variety of other protein sources, such as poultry, pulses, and soya products, to maintain dietary diversity. This leads to a decrease in total protein and energy intake, as these alternative protein sources may contain less protein and energy.

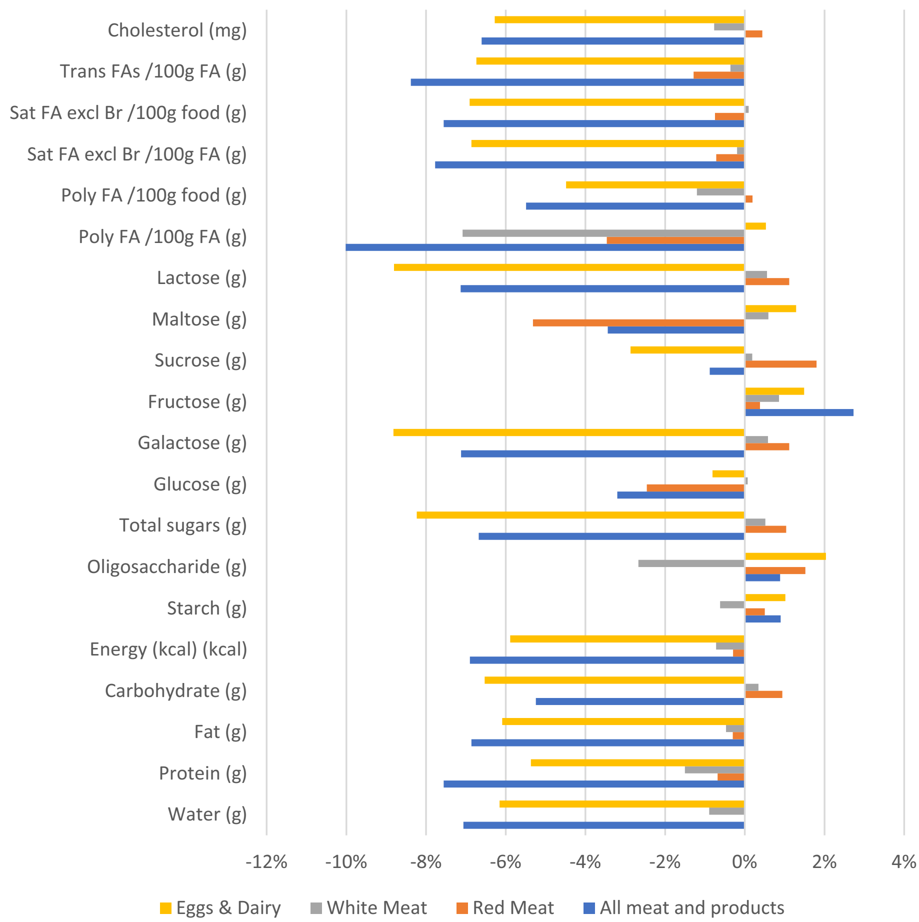

Fig. 6 Percentage Changes in Weekly Nutrient Intake. *Source*: Author's own computation of Kantar Worldpanel data, 2023

When only white meat prices increased by 10%, all nutrient intake decreased except for total sugars, which did not change. Typically, white meat is considered a relatively healthier source of protein because it usually contains less saturated fat and cholesterol. However, when prices rise, people may look for a more economical source of protein, something low in energy density or low in fat, to balance their diet.

Finally, when only the price of eggs and dairy increased by 10%, nutrient intake decreased, with total sugars decreasing the most, at 8%. This may be because eggs and dairy products are often used in the preparation of many processed foods, such as desserts and pastries, which may be high in sugars. When prices rise, people may consume less of these processed foods, leading to lower intake of nutrients such as sugar.

Discussion

According to the above results, as the price of animal protein increases, many consumers turn to plant protein products. This will in turn have a positive effect on the environment and animal welfare. However, this shift may lead to a reduction in overall nutrient intake, which is consistent with Mariotti and Gardner (2019). The findings of that nutrient intake from plant proteins is low and that there is a need to recognise the nutritional challenges involved and to take appropriate measures to ensure access to complete and balanced nutrition.

Research shows that it is possible to reduce the demand for meat by increasing the price of meat protein without fully eliminating meat or dairy products from the diet. This is consistent with the findings of Bonnet et al. (2018). By reducing the pressure of livestock farming on the environment and thus contributing to the reduction of greenhouse gas emissions, Westhoek et al. (2014) reported that halving meat, dairy and egg consumption in Europe would reduce nitrogen emissions by 40% and greenhouse gas emissions by 25–40%. In addition, reducing the demand for meat reduces the demand for water resources and land, with positive impacts on combating climate change and environmental sustainability (Almeida et al. 2023; Bimbo 2023; Moberg et al. 2021). In addition, by reducing the consumption of meat in response to pricing policies, farmers and livestock farmers may be encouraged to improve animal welfare by improving the conditions and treatment of animals. For example, the provision of larger grazing areas improved animal husbandry (Michalk et al. 2019).

The nutritional implications show that the shift to plant protein products could lead to a decrease in overall nutrient intake. In terms of protein, to ensure adequate protein intake, consumers can contribute to balancing and diversifying their diets by increasing the supply of plant protein types such as pulses, grains, nuts and seeds, which promotes good health and nutrition. As stated by Mariotti and Gardner (2019), the transition to 100% plant protein can be considered to involve little risk of inadequate protein intake when animal proteins are replaced with mixtures of protein-rich plant foods (i.e. legumes, nuts, and seeds). In addition, the shift in consumption will help in the adjustment of overall fat, cholesterol and calorie intake, a shift that is good for the obese population and encourages healthier eating habits. At the same time, plant protein products tend to be combined with healthier foods such as vegetables, fruits and whole grains (Hu 2003), which helps to provide more nutrients, fibre and antioxidants while lowering the intake of high-fat and high-calorie foods.

In terms of health, replacing animal sources with plant proteins can modestly improve glycemic control in diabetic patients. Viguiliouk et al. (2015) reported significant improvements in fasting blood glucose and fasting insulin levels in diabetic patients after the replacement of some animal protein with plant protein. Similarly, plant protein intake, rather than animal protein intake, reduces cancer risk. Although the risk of developing cancer is influenced by a number of factors, such as genetic predisposition, environment, diet and lifestyle habits, Andersen et al. (2019) found that high meat intake was associated with a greater risk of colorectal cancer in carriers of certain genes than in those with the same genetic predisposition but who consumed a lower-meat-intake diet. Finally, there are also studies linking protein intake to mortality. For instance, Huang et al. (2020) reported that replacing animal proteins with plant proteins reduced overall mortality by 10% in both men and women.

Conclusion

This paper applies the exact affine stone index implicit Marshallian demand system (EASI model) proposed by Lewbel and Pendakur (2009) to 2021 home scan data collated by the Kantar Worldpanel to investigate the nutritional impact of trade-offs between animal and plant proteins because of recent price inflation. Twelve food groups of seven animal-based protein products and five plant-based protein products were considered. The results are important for understanding cross-category relationships and relevant policy makers.

The results of the study show that dairy and eggs in animal proteins are necessary for the people of Scotland. The demand for fish and non-dairy milk substitutes are the most price-sensitive among animal and plant proteins, respectively. This implies that the demand for these two types of goods is more responsive to price changes, and price fluctuations may directly affect consumers' purchasing decisions in these markets. For cross-price elasticities, the results show that substitution is highest between eggs and dairy and other food categories. Estimates based on expenditure elasticities show that beef is considered a luxury or highly substitutable product in the Scottish diet. Peas are relatively basic, essential foodstuffs.

In general, increasing the price of animal protein products increases the demand for these products. This translates into changes in nutrient demand that cannot be ignored. By taxing all meat products, red meat, white meat, eggs, and dairy separately, consumers can increase their intake of plant proteins. This results in significant reductions in cholesterol, calorie, and fat purchases.

The results of the present work have significant implications for policy. First, reductions in red meat will significantly reduce the environmental damage associated with meat consumption. This will push Scotland towards achieving its net zero emission targets. Second, many studies have associated noncommunicable diseases such as cardiovascular diseases with the overconsumption of meat. Indeed, the average consumption of meat in Scotland is above the recommended targets, making a policy that makes meat relatively expensive necessary to nudge consumers towards plant-based proteins. However, the study does not underscore the relevance of meat in diets but supports moderate consumption. Third, the study showed that consumers are very sensitive to prices, especially for all plant-based protein types. This suggests that a small reduction in price will significantly increase demand. Retailers could shift promotions away from high fat, sugar and salt foods to these categories to encourage consumption. Finally, this study proposes a policy such as the 'five-a-day' campaign for plant-based proteins to encourage their consumption. In addition, consumers need education about the different types of plant-based proteins and their value in their diets.

This study has certain limitations that could affect the interpretability of the results. First, it focuses on common meat and plant protein products and does not address how artificial products such as cultured meat and plant-based meat, for example, may affect consumers' choices. Second, the impact of the taxes on the supply of animal proteins was not considered in the simulation. Price increases may lead consumers and producers to make different choices, such as finding alternatives or changing production methods. Understanding these behavioural changes is essential for assessing the impact of tax policies on environmental health. It is therefore important to conduct careful supply chain analyses to predict possible responses and to take these predictions into account in the policymaking process.

Future research could model both the environmental impact and the health impact of nutritional changes. This will provide a complete picture of the impact of switching from animal to plant proteins. In addition, research on the impact of laboratory-cultured meat is required to understand the market for meat alternatives.

Appendix A1: Percentage change in quantities

Food products	All meat and products	Red meat	White meat	Eggs
Dairy	− 7.12	1.12	0.58	− 8.82
Beef and veal	− 14	− 16.85	0.84	1.73
Mutton and lamb	− 17	− 16.82	− 2.63	2.35
Pork	− 13	− 14.38	− 0.45	1.40
Poultry	− 14	− 1.32	− 13.00	0.72
Fish	− 14	0.61	− 15.92	0.94
Eggs	− 6	0.84	− 0.29	− 6.53
Peas	1	1.73	− 2.95	2.03
Beans and pulses	3	0.78	1.29	1.21
Nuts, seeds and peanut butter	5	4.20	0.61	0.33
Non-dairy milk substitutes	2	− 1.18	0.91	2.08

Appendix A2: Percentage change in weekly nutrient intake

Nutrients	All meat and products	Red meat	White meat	Eggs and dairy
Water (g)	− 7.06	− 0.02	− 0.89	− 6.15
Total nitrogen (g)	− 7.52	− 0.68	− 1.51	− 5.32
Protein (g)	− 7.56	− 0.68	− 1.50	− 5.37
Fat (g)	− 6.86	− 0.30	− 0.47	− 6.09
Carbohydrate (g)	− 5.24	0.94	0.34	− 6.53
Energy (kcal) (kcal)	− 6.90	− 0.29	− 0.72	− 5.89
Energy (kJ) (kJ)	− 6.90	− 0.29	− 0.72	− 5.89
Starch (g)	0.90	0.50	− 0.62	1.02
Oligosaccharide (g)	0.89	1.52	− 2.67	2.04
Total sugars (g)	− 6.68	1.04	0.51	− 8.23
Glucose (g)	− 3.20	− 2.46	0.07	− 0.81
alactose (g)	− 7.12	1.12	0.58	− 8.82
Fructose (g)	2.73	0.38	0.86	1.49
Sucrose (g)	− 0.88	1.80	0.19	− 2.87
Maltose (g)	− 3.44	− 5.32	0.59	1.29
Lactose (g)	− 7.13	1.12	0.56	− 8.80
NSP (g)	2.60	1.24	0.17	1.20
AOAC fibre (g)	1.66	0.89	− 0.34	1.11
Satd FA/100 g FA (g)	− 7.51	− 1.01	− 1.45	− 5.05
Satd FA/100 g fd (g)	− 7.24	− 0.10	− 0.14	− 7.00
$n-6$ poly/100 g FA (g)	− 4.98	− 2.92	− 1.02	− 1.03

Nutrients	All meat and products	Red meat	White meat	Eggs and dairy
$n-6$ poly/100 g food (g)	−5.06	0.29	−0.33	−5.02
$n-3$ poly/100 g FA (g)	−8.93	−0.92	−6.51	−1.50
$n-3$ poly/100 g food (g)	−8.31	−0.08	−4.07	−4.17
cis-Mono FA/100 g FA (g)	−6.71	−0.05	−0.82	−5.84
cis-Mono FA/100 g Food (g)	−6.78	−0.36	−0.53	−5.89
Mono FA/100 g FA (g)	−11.70	−6.15	−5.15	−0.39
Mono FA/100 g food (g)	−6.81	−0.47	−0.71	−5.63
cis-Polyu FA/100 g FA (g)	−5.55	0.20	−1.12	−4.63
cis-Poly FA/100 g Food (g)	−5.42	0.25	−0.77	−4.90
Poly FA/100 g FA (g)	−10.02	−3.46	−7.08	0.53
Poly FA/100 g food (g)	−5.49	0.19	−1.20	−4.48
Sat FA excl Br/100 g FA (g)	−7.77	−0.72	−0.19	−6.86
Sat FA excl Br/100 g food (g)	−7.56	−0.75	0.10	−6.91
Branched chain FA/100 g FA (g)	−8.22	−1.10	0.03	−7.14
Branched chain FA/100 g food (g)	−11.00	−7.86	−0.01	−3.14
Trans FAs/100 g FA (g)	−8.38	−1.28	−0.36	−6.74
Cholesterol (mg)	−6.60	0.44	−0.77	−6.28

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Availability of data materials
The data that support the findings of this study are available from the Kantar Worldpanel. Restrictions apply to the availability of these data, which were used under licence for this study.

Declarations

Ethics approval and consent to participate
Ethics approval was not required for this study. This study used secondary data collected by the Kantar Worldpanel (KWP). During the procurement process, ethical requirements were considered as part of the legal requirements for the federal procurement procedure. KWP's data collection requires voluntary reporting by the participants.

Competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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