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Abstract

Introduction

When considering proposals to improve diets, it is important to understand how factors like price and income can affect saturated fat intake and demand. This is even more important when considering economic interventions on a global scale. In this study, we examine and estimate the influence of price and income on intake across 160 countries, by age and sex, and derive sensitivity measures (elasticities) that vary by age, sex, and geographic region.

Methods

Secondary data were used for this analysis. Intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank). We estimated intake responsiveness to income and prices, accounting for differences by world region, age, and sex.

Results

Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. Results indicated that the highest price sensitivity was due to meat consumption. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were e 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Intake differences due to income were insignificant.

Conclusion

The results of this study show heterogeneous associations among prices and intake within and across countries. Policymakers should consider these heterogenous effects as they address global nutrition and health challenges.

What is already known on this topic

- It is generally understood that affordability is an important driver of food demand, underscoring the importance of income and prices in dietary choices. Research has confirmed significant associations among income, prices, and food demand. What is missing, however, is a better understanding of how price and income influence actual nutrient intake, particularly on a global scale, and how price and income relationships could vary by demographics within and across countries.

What this study adds

- For the first time to our knowledge, we derive and compare global saturated fat intake elasticities by age and sex, characteristics which have been identified as likely to influence dietary responses to income or prices. Our study also provides a deeper understanding of how prices impact saturated fat intake across the full spectrum of countries from least developed to high-income economies.

How this study might affect research, practice or policy

- This study shows that the economics of food demand and nutrient intake can be assessed on a global scale. Our results can inform the effectiveness of price intervention strategies and provide evidence of where intervention policies would have the largest impact.

INTRODUCTION

While nutritional guidelines call for reductions in saturated fat (SF), the literature is not clear and remains controversial on the causal link between SF intake and cardiovascular disease risk and other health-related outcomes.(1-3) Studies note that different food sources of SF may have different relationships with risk, for example with higher risk for red meats and their fats, generally neutral relationships for dairy foods and their fats, and protective associations for plant oils.(4) In addition, low SF intake has been associated with higher mortality risk in studies comprising mostly low- and middle-income countries, and very low SF intake is associated with higher risk of hemorrhagic stroke, potentially due to increased cerebral vascular fragility.(3, 4)

Governments and international organizations have proposed economic interventions to improve diets and health outcomes (5-8). In considering these proposals to improve diets, it is important to understand how factors like price and income can affect SF intake and demand.(6, 9-11) Sensitivity to prices of SF-source foods could vary by per capita income, age, sex, educational attainment, etc. This relationship may also vary by world region, given differing cultural preferences and priorities around animal source foods. These factors could have important implications for policy interventions around animal source foods across countries and regions and in different population subgroups.(12) However, to-date, no evidence exists on the global income and price sensitivity of SF intake, nor potential variation by important demographic characteristics. Other than a few noted exceptions, global assessments of SF intake have been limited, particularly when considering price and income effects.(13, 14)

To help address these knowledge gaps, this investigation assessed how price and country income relate to SF intake. We used nationally representative intake estimates from the 2018

81 Global Dietary Database to estimate how per capita income and prices jointly relate to SF intake by age and sex globally. Since nutrients are found in food, examinations of nutrient demand must consider food source demand, with price and income as explanatory variables.(15-17) Using price and expenditure data from the World Bank International Comparison Program, we constructed a global price series based on three food categories: meat, dairy, and oils and fats. This series sufficiently explained SF intake differences across countries and allowed for assessing the relationships of per capita income and price in each food category.

METHODS

Data and sources

We used secondary data sources for the analysis. SF intake data measured in percent of total energy per day (% energy/d) for a representative individual was obtained from the 2018 Global Dietary Database (GDD). The GDD, maintained by the Global Nutrition and Policy Consortium at Tufts Friedman School of Nutrition Science and Policy provides comprehensive and comparable dietary intakes for major foods and nutrients in 185 countries and territories. The GDD was developed using systematic searches of available survey data of individual-based dietary intakes for key food and nutrient categories at the national and subnational level. GDD intake estimates are based on the results of existing surveys (1,248 in total), representing 188 countries and approximately 99% of the global population. It is the first database to provide estimates of daily consumption levels by food or nutrient category and contains representative individual intake data by age (0-1 year, 1-2 years, 2-5 years, and then by increments of 5 years to age 97.5) and sex. The GDD also disaggregates individual intakes by three education levels and residence (urban and rural). The GDD data estimation process included extensive communication with researchers and government authorities and large subnational surveys, when other options were are unavailable (18, 19). For details on the GDD coverage, data methodology, and data collection, see: https://www.globaldietarydatabase.org/methods/summary-methods-and-data-collection.

National food expenditure and price data from the World Bank International Comparison Program (ICP) were used to derive a SF price series based on contributing food categories: meats, dairy, and oils and fats. The *meats* category in the ICP database is an aggregation of the following: beef and veal; pork; lamb, mutton, and goat; poultry; and other meats and meat preparations. *Dairy* – fresh milk; preserved milk and other milk products; cheese and curd; and eggs and egg-based products. *Oils and fats* – butter and margarine; and other edible oils and fats (20). Although saturated fat is readily found in a wide array of foods, these categories have been identified as major contributors to saturated fatty acids in diets. In the U.S., for instance, meats, dairy, and oils and fats accounts for over two-thirds of SF intake (21). While other foods, such as sweet and savory snacks, may also contribute, global price series for these categories are not widely available.

The ICP is a global initiative that estimates purchasing power parities (PPPs) and price level indices (PLIs) across countries, which allows for global comparisons of spending and economic wellbeing. PPPs are spatial price deflators that make it possible to compare expenditures across economies.(22) PLIs are PPPs standardized to a common currency (generally the U.S Dollar) or indexed to a global average or base country.(23) The most recent ICP data round (2017) included comparative prices and expenditure data from 176 participating economies.(23)

126 For income, we used 2018 PPP-adjusted, gross domestic product (GDP) per capita from
127 the World Development Indicators (WDI) database. Because differences in currency values and
128 exchange rates do not always consistently reflect price-level differences across countries, PPP-
129 adjusted GDP allowed for cross-country comparisons because overall price disparities across
130 countries are taken into account.(24)

The analysis was limited to the 160 countries represented in all three databases (GDD, ICP, and WDI), which are listed in Supplementary Table 1 by geographic region (see the Supplemental Appendix): East Asia, Southeast Asia, and the Asian Pacific (Asia) (14 countries); Central and Eastern Europe and Central Asia (CEE) (27 countries); Latin America and Caribbean (LAC) (29 countries); Middle East and North Africa (MENA) (17 countries); South Asia (S-Asia) (7 countries); Sub-Saharan Africa (SSA) (43 countries), and High-Income/Western Countries (HIC) (24 countries). HIC is an aggregation of high-income countries in the Western hemisphere, Australia, and New Zealand, with the addition of a few surrounding islands.

See the Supplemental Appendix for a more detailed discussion of the price, expenditure, and income data by geographic region.

Patient and public involvement

We used secondary data for this study. All data are publicly available and did not require direct patient involvement in the study design or implementation.

Model and estimation

To estimate SF intake demand, we used a semi-log functional form that has been proven to be consistent with economic theory and rational consumer behavior.(25, 26) Many studies have used a double-log form.(27) However, a problem with the double-log form is that significant intake differences across subgroups can be lost in log conversions. A semi-log relationship allowed for a better assessment of subgroup effects on intake responsiveness. Also, it has been shown that semi-log models contain the necessary information for obtaining, for instance, reliable measures of consumer welfare and the underlying preference structure of consumers.(25) Prior studies have also used a demand-system approach, primarily due to the adding-up property when using expenditure data (i.e., expenditures on all food categories "add up" to total food expenditures), which results in the error terms being correlated across equations specific to each food category. Since this relationship does not exist with individual intakes, particularly when the correspondence between purchases and intakes is not one to one, we can estimate intake demand for a single food or nutrient category separately.(28, 29)

Let q_{gC} represent the % energy/d from saturated fat for demographic subgroup *g* (*g*: sex and age) in country *C* and let p_C represent the price level index for the contributing food categories in country *C*. Let Y_C and P_C represent real per capita income and the food price level index, respectively, in country *C*. Given these terms, the following model was used to estimate the relationship between intake, income, and prices:

$$q_{gC} = \beta_0^* + \beta_1^* \ln(Y_C) + \beta_2^* \ln\left(\frac{p_C}{P_C}\right) + u_{gC}. \qquad (1)$$

The β_k^* terms [$k = \{0,1,2\}$] are parameters to be estimated and u_{gC} is a random error term. Note that the price term is defined by the price of contributing food categories (p_C) relative to overall food prices (P_C). Thus, the model discounts any price differences across countries due to differences in overall food prices and implicitly accounts for the cross-price effects of other foods. For instance, if dairy prices were the same in two countries, but overall food prices differed, intake would be greater in the country with the higher food-price level since dairy is *relatively* cheaper when compared to food overall. Note that equation (1) does not include higher order income and price effects (e.g., quadratic income and price-income interactions). In preliminary analysis, these higher-order terms were highly insignificant, which implied that price or income responsiveness did not depend on the level of per-capita income level.

Using equation (1), we estimated intake demand using a procedure that allowed for error correlations among observations from the same country (i.e., country-clustered errors).(30) To account for differences in preferences across countries due to cultural differences or other related factors, we included regional binary variables in the analysis (ASIA, CEE, LAC, MENA, S-ASIA, and SSA). We accounted for age and sex by allowing these factors to have a direct effect on intake, as well as an additional effect through income and prices. Thus, the beta terms (β_k^*) were expanded to account for age and sex interactions: $\beta_k^* = f(sex, age)\forall k$. Further disaggregations (education level and residence) were not considered due to estimation concerns resulting from negligible differences in SF intake across these factors. Although we used a single price index (p_C) to represent the three food categories (meats, dairy, and oils and fats), intake responsiveness with respect to the price of each food category were easily derived. Defining the conditional expenditure share and price for the *i*th food category in country *C* as s_{iC} and p_{iC}, respectively, p_C is as follows: $p_C = \sum_i s_{iC} p_{iC}$. Thus, relationships between q_{gC} and p_{iC} were derived using the estimate on the price term in equation (1) (β_2^*) and the conditional expenditure share s_{iC} as follows: $\frac{\partial q_{gC}}{\partial p_{iC}} = \frac{\partial q_{gC}}{\partial p_C}\frac{\partial p_C}{\partial p_{iC}} = \frac{\beta_2^*}{p_C} s_{iC}$.

RESULTS

Descriptive statistics and SF intake overview

Table 1 shows the descriptive statistics for the variables used in the model. Mean SF intake across all observations was 10.3% energy/d and ranged from 2.39 to 27.28. PPP-adjust real

GDP per capita ranged from \$780 to \$117,245 (mean = \$22,226). The deflated price index $\left(\frac{p_C}{P_C}\right)$ ranged from 0.71 to 1.40 (mean = 1.00). Mean values for the region and sex variables reflect the country and subgroup representation in the data.

Figure 1 contains violin plots for SF intake by sex, age, and region based on all observations (n = 7,040). Violin plots use kernel densities to visualize the distribution of intake. The width of the violin plot corresponded to the probability of an observation taking a specific value of SF intake and the vertical black line in each violin plot corresponds to the median value. In general, the violin plots showed that the distribution of SF is similar across age and sex subgroups, although there was greater variation across regions. Additionally, the presence of long right tails across most subgroups suggested the presence of outliers with very high values of SF intake.

While the median value for SF intake was around 10.60 % energy/d, there were notable differences (Figure 1). Median SF intake was slightly higher in females (females = 10.88, males=10.40). Across regions, median SF intake was lowest in S-Asia (6.42) and highest in HIC (13.78). Overall, the maximum value for saturated fat intake occurred in the Philippines (27.48) amongst female infants (< 1 year old), while the overall minimum occurred in Nepal (2.39) amongst females between the ages of 20 and 25. Even within regions, notable differences occurred. In HIC, for instance, intake ranged from a high of 23.02 % energy/d in France amongst female infants to 9.45 % energy/d in Portugal amongst males, age 95 years and older.

Estimation results

We first estimated the model using intake values at the country level (i.e., intake averaged over all demographic subgroups) (n = 160) (Table 2). Since our explanatory variables (price and income) were country specific and did not vary with demographic subgroups, it was useful to examine the significance of price or income without age and sex differences. The country-level analysis also revealed the importance of each variable in explaining global differences in SF intake. For instance, Model 1 showed that regional differences accounted for a large share of intake differences across countries (Adjusted R^2 = 0.39). When regional differences were not accounted for, both income (1.03, $p < 0.01$) (Model 2) and price (-3.90, $p < 0.05$) (Model 3) were significant. When regional differences were accounted for (Model 4), price was still significant (-4.33, $p < 0.05$), but income was insignificant. The negative price estimate was consistent with economic theory (higher prices being associated with lower intake) and indicated that a unit increase in the log of price was associated with lower SF intake by 4.33 percentage points.

Since the intake variable was measured as a percent, it is important to clarify the difference between a percentage point change and percent change. For instance, intake falling from 10.83 to 6.50 % energy/d, is a 4.33 percentage point decline, but a 40% decline: -4.33 ÷ 10.83). This distinction is important when considering elasticity relationships where both intake and prices are measured in percentage. Assuming mean intake (10.83 % energy/day) as the base, intake falling by 4.33 percentage points or 40% given a unit change in the log of price (a two-fold increase) suggested a price elasticity of about -0.40. That is, SF intake declines by 0.40% for every 1.0% increase in price, which indicates minimal price sensitivity and inelastic demand. Note that this result is based on a price increase across all three food categories. As discussed later in this section, intake responsiveness to the price of a particular food category (e.g., dairy) was smaller.

Estimation results for the full model (Model 4) are reported in Table 3. Other than ASIA, SF intake was significantly lower in all regions relative to HIC intake. Intake also decreased with higher age (-0.10, $p < 0.01$), but this effect was less significant with older adults. Results (Model 4) indicated a price effect of -7.16 ($p < 0.01$), where the magnitude became smaller with age (0.20, $p < 0.01$), but then increased for older populations. There was no significant difference in the price effect by sex – and like the country-level analysis – the income effect on intake was insignificant when regional differences were considered. Consequently, we did not examine income effects in detail and the price-specific measures that follow are not specific to sex.

Intake responsiveness and food prices

Using the country-level estimates from Table 2, we derived measures of aggregate intake change with respect to category-specific prices (meat, dairy, and oils and fats) (Figure 2). A price increase in the meat category resulted in the largest intake decrease: -2.47 percentage points from a two-fold increase in price (IQR: -2.29 to -2.78). Assuming mean intake as the base, this implied a price elasticity of about -0.23 (i.e., a 0.23% decline for every 1.0% increase in meat prices). Dairy had the next highest intake decrease (-1.30 percentage points and IQR: -1.01 to -1.56), implying a price elasticity of -0.12. The results for oils and fats implied the lowest intake decrease (-0.55 percentage points and IQR: -0.29 to -0.65) and a price elasticity of about -0.06.

Using the estimates from Table 3, we assessed intake responsive by food category, age, and region (See Figure 3). Across regions, meat prices resulted in the largest variation in SF intake, with S-Asia being the only exception. In HIC, for instance, median SF intake reductions at age 40 were 1.37, 0.78, and 0.15 percentage points, for 1% higher prices of meat, dairy, and oils and fats, respectively. In contrast, intake reductions in S-Asia at age 40 were highest for dairy (1.14 percentage points) followed by meat (0.62 percentage points) and oils and fats (0.48 percentage points). However, the IQR overlap for meat and dairy in S-Asia suggested that the two categories were not significantly different.

Across regions, there were key differences in intake responsiveness with respect to price changes. In HIC, there was no IQR overlap, suggesting significantly higher intake responsiveness to meat prices when compared to dairy, and diary compared to oils and fats. Similar patterns were observed for CEE, LAC, and MENA. In SSA, however, intake changes from meat prices were significantly larger when compared dairy or oils and fats, but the estimates for dairy and oils and fats prices show considerable IQR overlap.

Results also indicated that middle-aged groups (age 40-60 years) were the least sensitive to price changes. This was consistent with expectations as the middle-aged often have higher incomes and may be less sensitive to price changes. Based on the "All Countries" estimates (upper left panel), the median intake response from a two-fold increase in meat prices was -2.10 percentage points (age 20), responsiveness then decreased to -1.32 percentage points by age 50, and then increased to -2.71 percentage points by age 80. There was a similar pattern for dairy and oils and fats, but the differences between age groups were not as large.

DISCUSSION

This investigation provides evidence on how differences in income and food prices might jointly influence SF consumption by sex and age across the spectrum of rich and poor countries. Both the country-level and disaggregated (age and sex) analysis indicated that intake differences due to income were insignificant. These results suggest that intake differences across countries are better explained by regional dissimilarities and not economic wellbeing as measured by per-capita income. In contrast, differences due to food prices were highly significant. Globally, a one-percent increase in prices of meat, dairy, and oils and fats was estimated to decrease SF intake by about 0.40%, and by 0.23%, 0.12%, and 0.06%, respectively. Across regions, meat-price sensitivity of SF intake was relatively high, except for S-Asia where dairy price sensitivity of SF intake was higher. Within regions and by age, price sensitivity was lowest among middle-aged adults.

The higher sensitivity of SF intake to price changes in meat consumption suggests that fiscal policies focused on a reducing SF intake would be more effective through meat-price interventions. That said, the magnitudes of price sensitivity were small, indicating relatively inelastic demand. Thus, high taxes would be needed to reduce intake: for example, global findings suggest that a two-fold increase in meat prices (i.e., a 100% tax) is associated with decreased intake of only 2.47 percentage points. Our results are consistent with previous findings. Research has shown that fat taxes in Denmark, Hungary, and France had small and ambiguous effects on demand.(31, 32) A similar outcome was observed from the Danish fat tax experience that targeted dairy and vegetable fat sources.(33)

The findings in this study can help to inform strategies that counter worsening diets. However, our modeling cannot prove causality of price changes on intake, and thus our findings should be interpreted cautiously when informing interventions and evaluations. Furthermore, the invariability of price and income across demographic subgroups ignores differences within countries and may have affected results, although we address this issue, in part, with age and sex variable interactions. That said, the benefit of our analysis is the country coverage. While relationships between income, prices, and food choice have been studied, combining GDD, World Bank, and ICP data allowed for a global coverage rarely seen in food and nutrition research, allowing for comparisons across individuals in rich and poor countries and an examination of intake responsiveness by age and sex.(28, 29)

CONCLUSION

Our results provide novel global evidence on how income and prices influence SF intake by region, age, and sex. Our results confirm that the effectives of price interventions would be limited in most countries but provide evidence where interventions would be most effective if implemented (meat versus dairy or oils and fats; youth, young adults, and the elderly). These observed relationships can assist policymakers as they consider how pricing policies can be leveraged to tackle nutrition challenges.

Table 1. Descriptive statistics for study variables

Variable	Measure	Mean	Std. Dev.	Min	Max
SF intake	% energy/d	10.83	3.09	2.39	27.48
Female	binary	0.50	0.50	0	1
Age	5-year intervals*	45.6	30.83	1	98
ASIA	binary	0.09	0.29	0	1
CEE	binary	0.17	0.37	0	1
HIC	binary	0.15	0.36	0	1
LAC	binary	0.18	0.39	0	1
MENA	binary	0.10	0.30	0	1
S-ASIA	binary	0.04	0.20	0	1
SSA	binary	0.27	0.44	0	1
Real GDP per capita (PPP)	$/person	$22,226	$21,646	$780	$117,245
Deflated price	index (US=1)	1.00	0.12	0.71	1.40

SF is saturated fat. Note that n = 7,040 (160 countries × 44 demographic subgroups); n = 160 for the GDP and price index. East and Southeast Asia (ASIA), Central and Eastern Europe and Central Asia (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), Sub-Saharan Africa (SSA), and High-Income Countries/Rest of World (HIC). PPP is purchasing power parity.

Table 2. Saturated fat intake estimates using country level data (*n* = 160)

	Model 1	Model 2	Model 3	Model 4
Constant	13.66 (0.46)***	1.03 (1.75)	10.81 (0.23)***	12.05 (2.87)***
ASIA	-1.19 (0.76)			-0.66 (0.81)
CEE	-1.36 (0.63)**			-1.16 (0.67)*
LAC	-4.07 (0.62)***			-4.26 (0.74)***
MENA	-3.43 (0.73)***			-2.85 (0.77)***
S-ASIA	-7.41 (0.97)***			-6.34 (1.10)***
SSA	-4.07 (0.58)***			-3.65 (0.90)***
ln(Y)		1.03 (0.18)***		0.14 (0.26)
ln(P)			-3.90 (1.94)**	-4.33 (1.89)**
Adjusted R^2	0.39	0.16	0.02	0.41

Dependent variable is saturated fat intake measured in % energy/d. Robust standard errors are in (parenthesis). *$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$. East and Southeast Asia (ASIA), Central and Eastern Europe and Central Asia (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), and Sub-Saharan Africa (SSA). Y is real GDP per capita, purchasing-power-parity adjusted. P is an inflation adjusted price index for meats, dairy products and eggs, and oils and fats.

Table 3 Saturated fat intake estimates using country and demographic (sex and age) level data (*n* = 7,040)

	Model 1	Model 2	Model 3	Model 4
Constant	14.64 (0.39)***	2.81 (1.73)	12.44 (2.89)***	12.01 (2.90)***
ASIA	-2.20 (1.14)*		-1.61 (1.12)	-1.61 (1.12)
CEE	-1.94 (0.48)***		-1.68 (0.51)***	-1.68 (0.51)***
LAC	-3.97 (0.49)***		-4.09 (0.65)***	-4.09 (0.65)***
MENA	-3.98 (0.52)***		-3.35 (0.55)***	-3.35 (0.55)***
S-ASIA	-7.26 (1.00)***		-6.08 (1.08)***	-6.08 (1.08)***
SSA	-4.03 (0.49)***		-3.47 (0.81)***	-3.47 (0.81)***
Female	0.48 (0.04)***	0.48 (0.04)***	0.48 (0.04)***	0.06 (0.31)
Age	-0.04 (0.01)***	-0.04 (0.008)***	-0.04 (0.01)***	-0.10 (0.04)***
Age^2	0.00 (0.00)***	0.00 (0.00)***	0.00 (0.00)***	0.00 (0.00)***
ln(Y)		0.93 (0.18)***	0.19 (0.26)	0.24 (0.27)
Female × ln(Y)				0.04 (0.04)
Age × ln(Y)				0.01 (0.00)
Age^2 × ln(Y)				0.00 (0.00)***
ln(P)		-3.73 (1.59)***	-4.32 (1.88)**	-7.16 (2.29)***
Female × ln(P)				-0.13 (0.14)
Age × ln(P)				0.20 (0.06)***
Age^2 × ln(P)				0.00 (0.00)***
Adjusted R^2	0.34	0.18	0.36	0.37

Dependent variable is saturated fat intake in % energy/d. Robust standard errors (clustered by country) are in (parenthesis). **p*≤0.10; ***p*≤0.05; ****p*≤0.01. East and Southeast Asia (ASIA), Central and Eastern Europe (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), and Sub-Saharan Africa (SSA). Y is real GDP per capita, purchasing-power-parity adjusted. P is an inflation adjusted price index for meats, dairy products and eggs, and oils and fats.

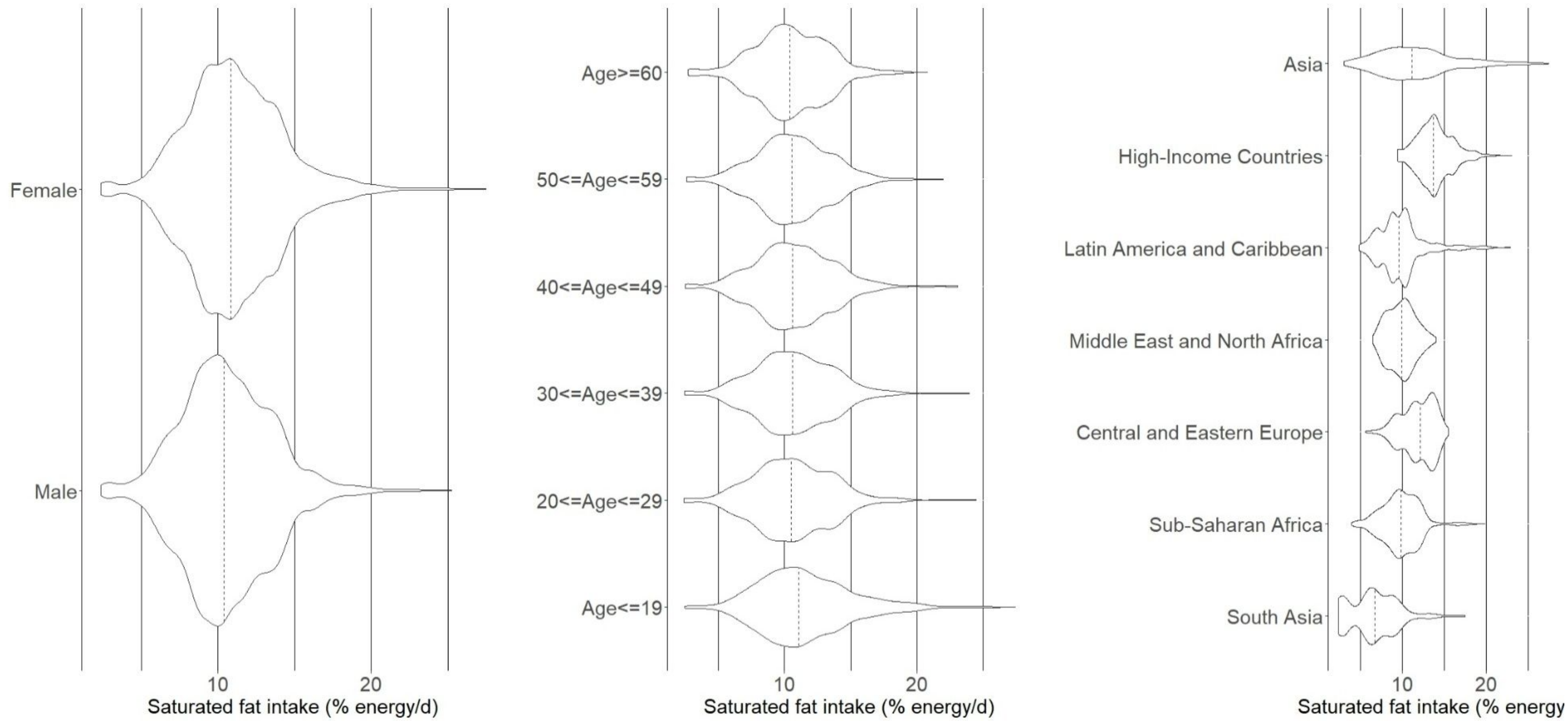

Figure 1. Comparison of percentage energy from saturated fat among individuals in sex, age, and country-specific strata globally and across world regions. Note that *n* = 7,040 (160 countries × 44 demographic subgroups). Female *n* = 3,520; male *n* = 3,520.

Age categories: Age<=19 *n* = 1,920; Age>=60 *n* = 2,560; for all other age groups *n* = 640; Regions: South Asia *n* = 308; Sub-Saharan Africa *n* = 1,892; Central and Eastern Europe *n* = 1,188; Middle East and North Africa *n* = 704; Latin America and Caribbean *n* = 1,276; High-Income Countries *n* = 1,056; Asia *n* = 616.

Source: Global Dietary Database, 2018.

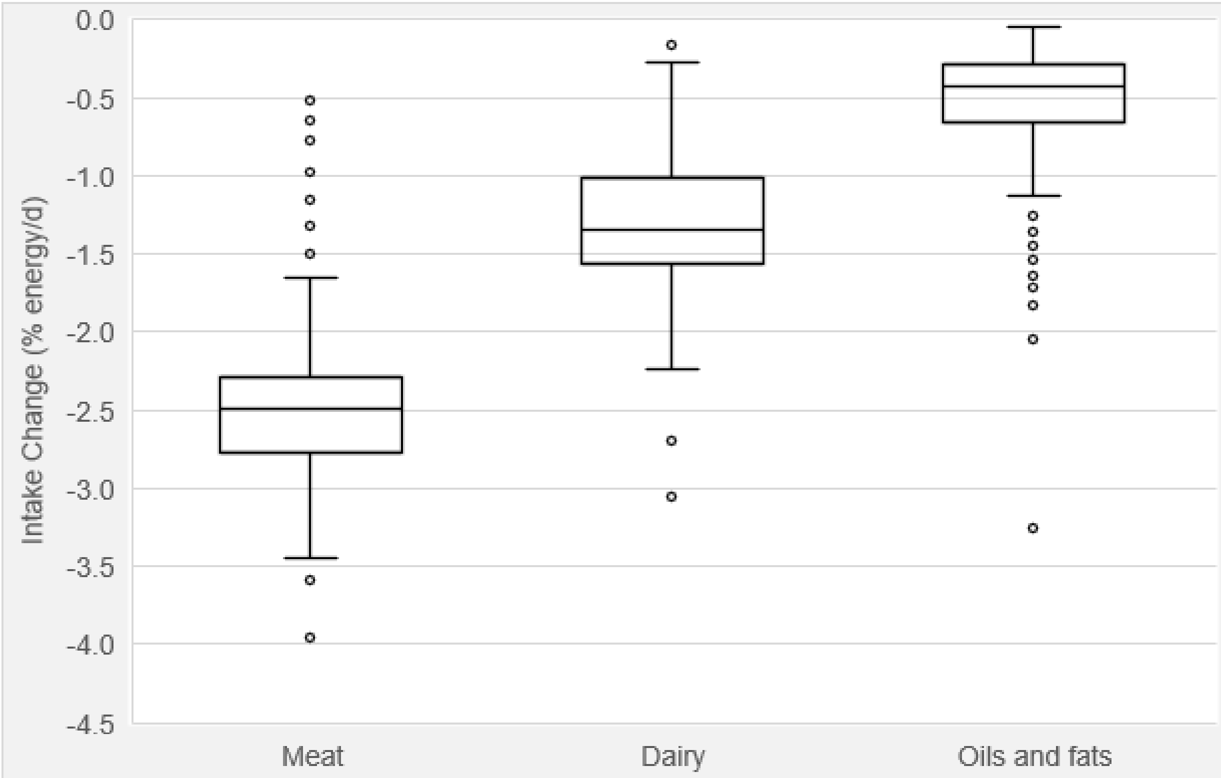

Figure 2. Change in saturated fat intake when prices double for each food category. Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR, error bars are min and max values, and data points are outliers.

Figure 3. Change in saturated fat intake when prices double for each food category by region and age. Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR and error bars are min and max values.

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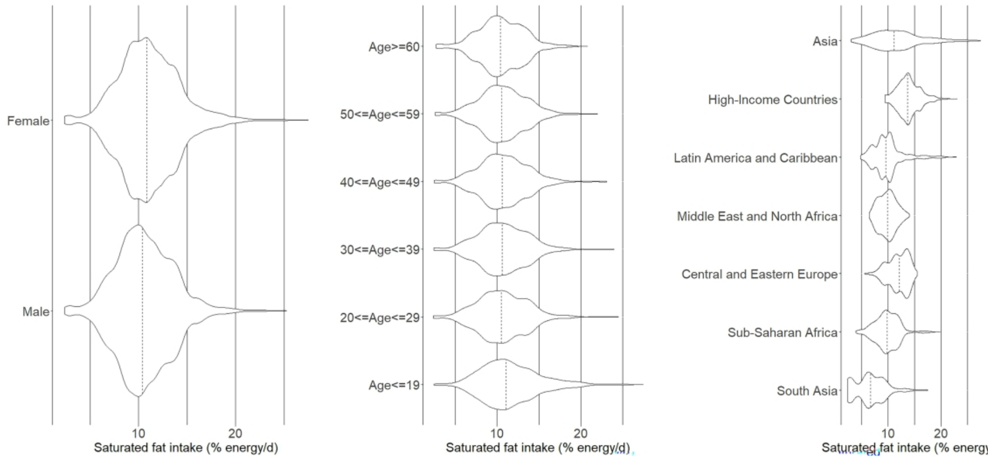

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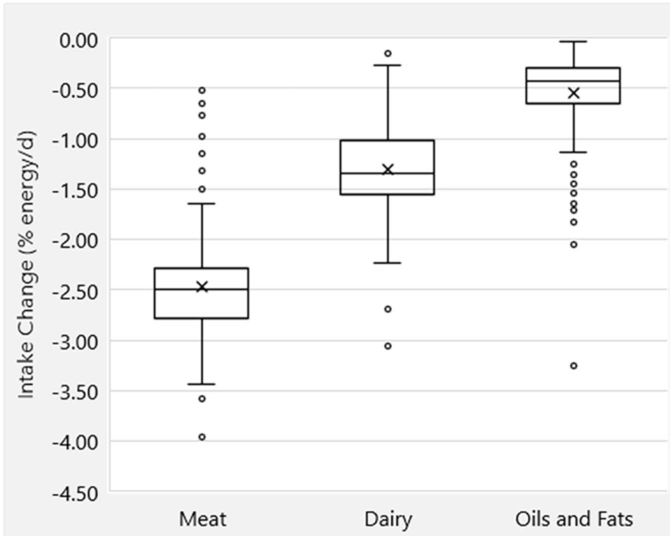

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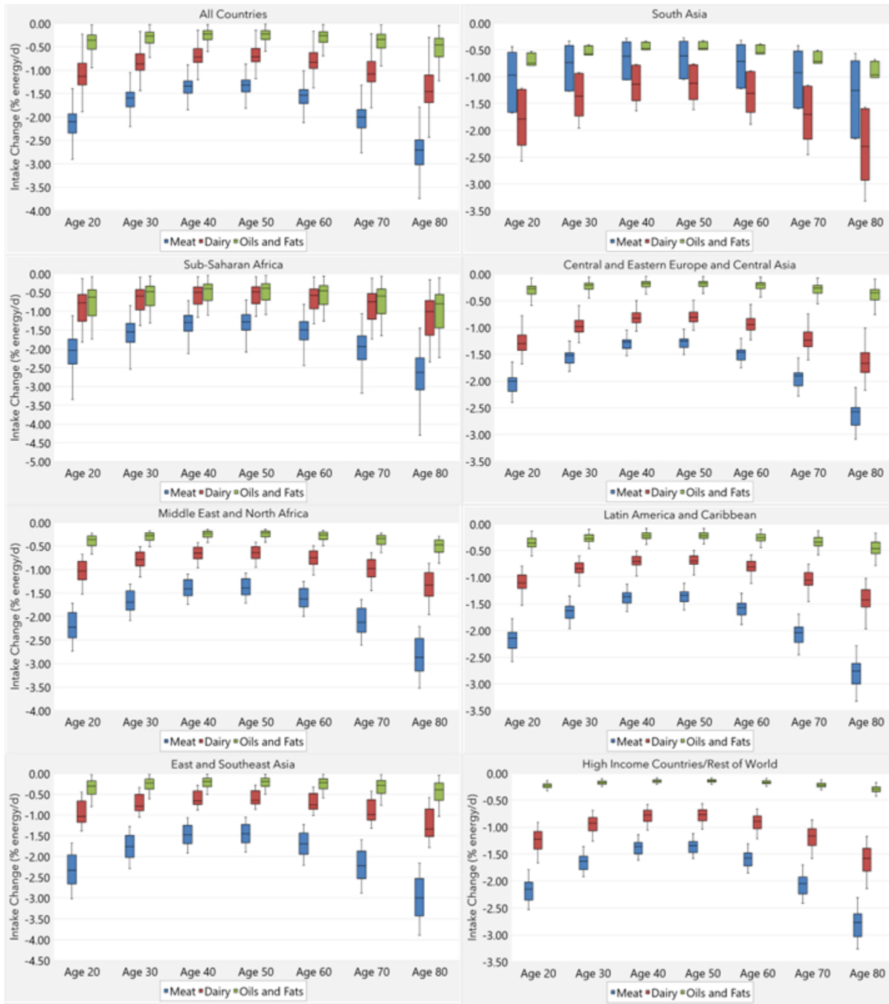

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Supplemental Appendix

Supplemental Table 1. Countries included in study by defined region

Region	Countries
Southeast Asia, East Asia, and High-Income Asia Pacific (ASIA) 14 countries	Brunei Darussalam, Cambodia, China, Fiji, Indonesia, Japan, Laos, Malaysia, Myanmar, Philippines, Singapore, South Korea, Thailand, and Vietnam.
Central Europe, Eastern Europe, and Central Asia (CEE) 27 countries	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Macedonia, Moldova, Mongolia, Montenegro, Poland, Romania, Russia, Serbia, Slovak Republic, Slovenia, Tajikistan, and Ukraine.
Latin America and the Caribbean (LAC) 29 countries	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, St. Lucia, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, and Uruguay.
Middle East and North Africa (MENA) 17 countries	Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, Turkey, United Arab Emirates, and West Bank and Gaza.
South Asia (S-ASIA) – 7 countries	Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.
Sub-Saharan Africa (SSA) 43 countries	Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo DR, Congo, Côte d'Ivoire, Djibouti, Equatorial Guinea, Eswatini, Ethiopia Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, Sudan, Tanzania, Togo, and Uganda.
High Income/Rest of World (HIC) 24 countries	Australia, Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and United States.

Income, Price, and Expenditure Data Across Countries

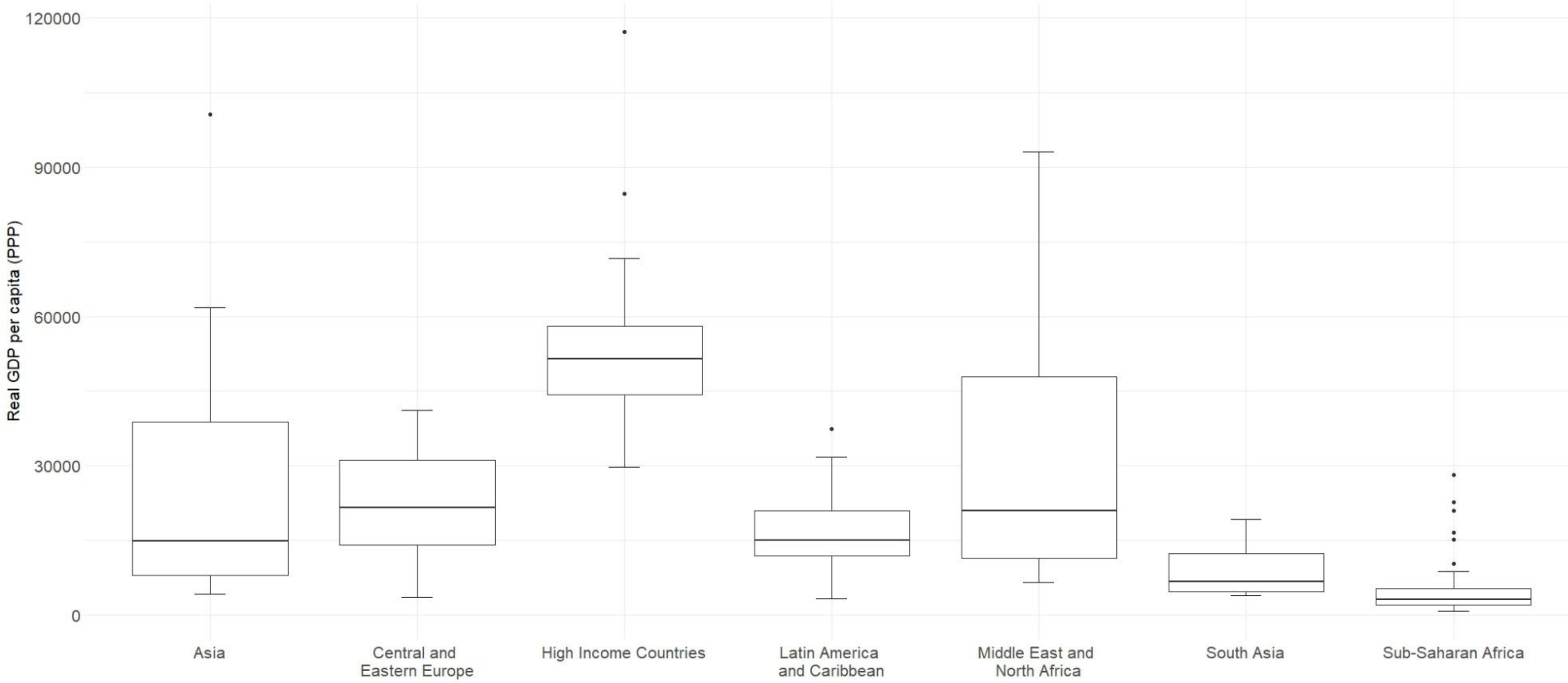
Supplemental Figures 1 – 3 contain box plots by region for the country-specific explanatory variables.

Supplemental Figure 1 shows real GDP per capita (PPP) for the seven regions in our study. The highest GDP region is High-Income Countries, which is unsurprising. The median income for High-Income Countries was $51,432 per person. In contrast, Sub-Saharan Africa had the smallest real GDP per capita, with a median value of $3,147.

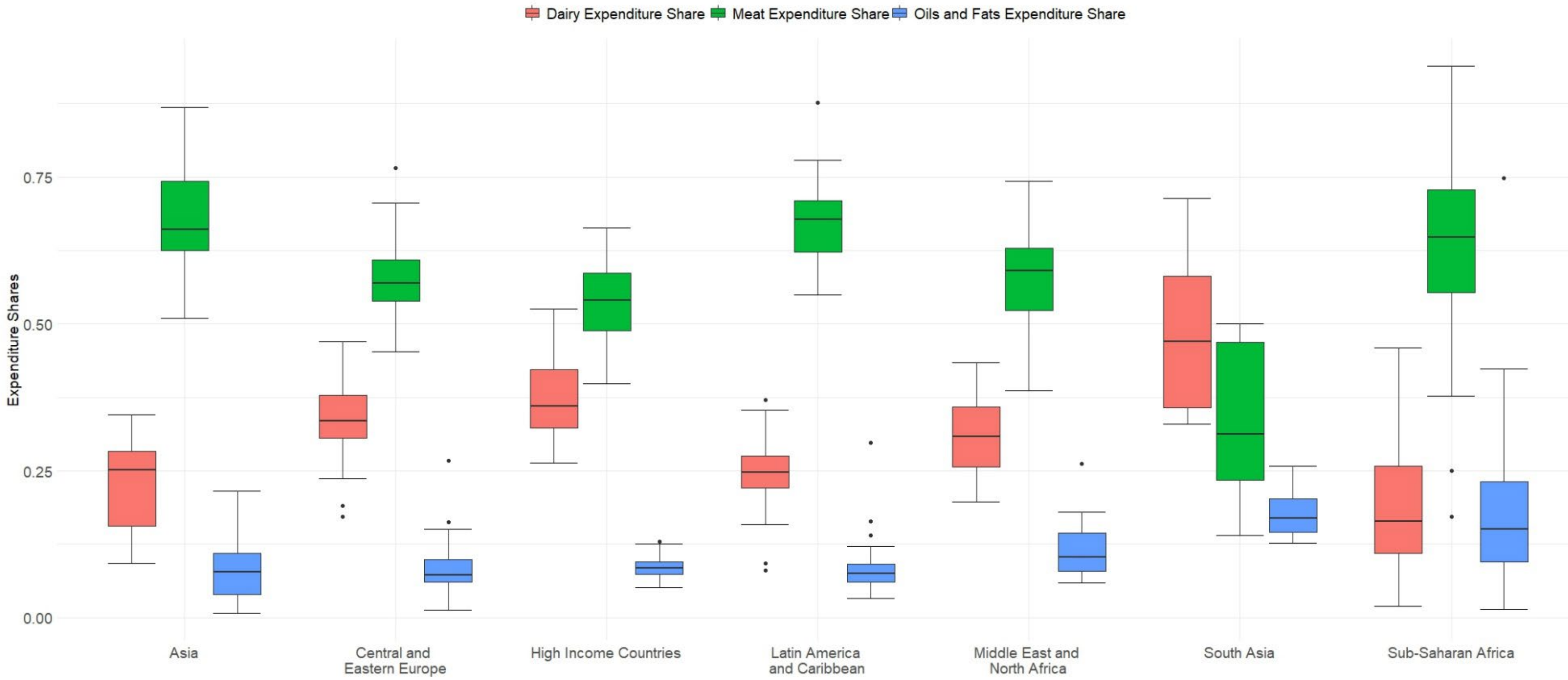
Supplemental Figure 2 shows expenditure shares for the contributing food categories: meats, dairy, and oils and fats by region. Food expenditure shares were derived from the World Bank International Comparison Program (ICP) which allows for global spending comparisons by standardizing expenditures to a common currency (U.S. Dollars). Across regions, meat expenditures were the highest food expenditure category, except for South Asia. In South Asia, the median dairy food expenditure share was the highest at 0.47 and the interquartile range (IQR) was 0.34 to 0.60. Asia, Latin America and Caribbean, and Sub-Saharan Africa were the regions with the highest median expenditures for meats at 0.65 and an IQR from 0.55 to 0.74. South Asia has the lowest meat expenditure share at 0.31 with an IQR from 0.16 to 0.48. Apart from South Asia, dairy expenditure shares represented the second highest expenditure shares across regions. Oils and fats account for the smallest share of food expenditures compared to the other food categories for all regions.

Supplemental Figure 3 shows the price indexes for meat, dairy, and oil and fats, and the weighted average price index (weighted based on the expenditures in Supplemental Figure 2) by region. The weighted average food price index is the sum of each price index times the expenditure share for the corresponding food category. Most regions exhibit relatively similar values across price index categories and shorter "whiskers" include Central and Eastern Europe, Middle East and North Africa, and South Asia. Alternatively, some regions (High-Income Countries, Latin America and Caribbean, and Sub-Saharan Africa) exhibit a greater range between the IQR and maximum and minimum values and greater variation in prices. For example, in the Latin American and Caribbean region, the dairy price index has a median value of 134.49 and IQR of 98.60 to 156.59. In contrast, the Central and Eastern Europe region has a dairy price index median value of 86.58 and IQR range of 75.84 to 93.50.

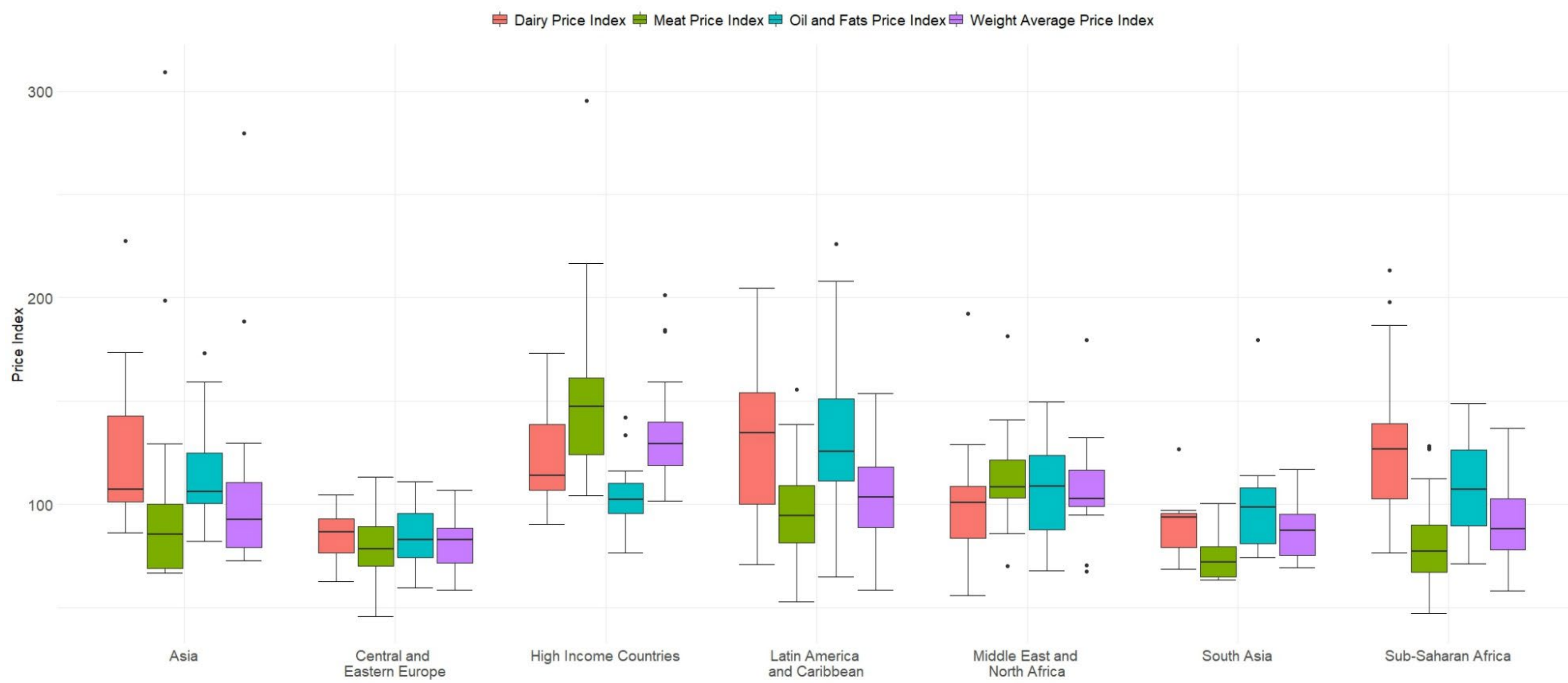
Supplemental Figure 1. Real GDP Per Capita (PPP) by Region



Supplemental Figure 2. Food Expenditure Shares by Region



Supplemental Figure 3. Price Indexes for each Food Category and Weighted Average by Region



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CHEERS 2022 Checklist

Topic	No.	Item	Location where item is reported
Title			
	1	Identify the study as an economic evaluation and specify the interventions being compared.	Examining the influence of price and income on global saturated fat intake: evidence from 160 countries
Abstract			

Topic	No.	Item	Location where item is reported
	2	Provide a structured summary that highlights context, key methods, results, and alternative analyses.	Introduction When considering proposals to improve diets, it is important to understand how factors like price and income can affect saturated fat intake and demand. This is even more important when considering economic interventions on a global scale. In this study, we examine and estimate the influence of price and income on intake across 160 countries, by age and sex, and derive sensitivity measures (elasticities) that vary by age, sex, and geographic region. Methods Secondary data were used for this analysis. Intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank). We estimated intake responsiveness to income and prices, accounting for differences by world region, age, and sex. Results Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. Results indicated that the highest price sensitivity was due to meat consumption. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were e 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Intake differences due to income were insignificant. Conclusion The results of this study show heterogeneous associations among prices and intake within and across countries. Policymakers should consider these heterogenous effects as they address global nutrition and health challenges.
Introduction			

Topic	No.	Item	Location where item is reported
Background and objectives	3	Give the context for the study, the study question, and its practical relevance for decision making in policy or practice.	To help address these knowledge gaps, this investigation assessed how price and country income relate to SF intake. We used nationally representative intake estimates from the 2018 Global Dietary Database to estimate how per capita income and prices jointly relate to SF intake by age and sex globally. Since nutrients are found in food, examinations of nutrient demand must consider food source demand, with price and income as explanatory variables.(15-17) Using price and expenditure data from the World Bank International Comparison Program, we constructed a global price series based on three food categories: meat, dairy, and oils and fats. This series sufficiently explained SF intake differences across countries and allowed for assessing the relationships of per capita income and price in each food category.
Methods			
Health economic analysis plan	4	Indicate whether a health economic analysis plan was developed and where available.	No. This does not apply.
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	Secondary data were used for this analysis. Intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank). We estimated intake responsiveness to income and prices, accounting for differences by world region, age, and sex.
Setting and location	6	Provide relevant contextual information that may influence findings.	Global study - 160 countries.
Comparators	7	Describe the interventions or strategies being compared and why chosen.	Economic analysis using secondary data. This does not apply.

Topic	No.	Item	Location where item is reported
Perspective	8	State the perspective(s) adopted by the study and why chosen.	• It is generally understood that affordability is an important driver of food demand, underscoring the importance of income and prices in dietary choices. Research has confirmed significant associations among income, prices, and food demand. What is missing, however, is a better understanding of how price and income influence actual nutrient intake, particularly on a global scale, and how price and income relationships could vary by demographics within and across countries.
Time horizon	9	State the time horizon for the study and why appropriate.	2017-2018
Discount rate	10	Report the discount rate(s) and reason chosen.	N/A
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	N/A
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	N/A
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	See 5.
Measurement and valuation of resources and costs	14	Describe how costs were valued.	Income values were in $US.
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	Prices were indexes where World = 100.

Topic	No.	Item	Location where item is reported
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	To estimate SF intake demand, we used a semi-log functional form that has been proven to be consistent with economic theory and rational consumer behavior.(25, 26) Many studies have used a double-log form.(27) However, a problem with the double-log form is that significant intake differences across subgroups can be lost in log conversions. A semi-log relationship allowed for a better assessment of subgroup effects on intake responsiveness.
Analytics and assumptions	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	Econometric analysis assuming country clusters.
Characterising heterogeneity	18	Describe any methods used for estimating how the results of the study vary for subgroups.	Econometric analysis assuming country clusters.
Characterising distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. Results indicated that the highest price sensitivity was due to meat consumption. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were e 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Intake differences due to income were insignificant.
Characterising uncertainty	20	Describe methods to characterise any sources of uncertainty in the analysis.	Not applicable
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communities, or stakeholders (such as clinicians or payers) in the design of the study.	N/A
Results			

Topic	No.	Item	Location where item is reported
Study parameters	22	Report all analytic inputs (such as values, ranges, references) including uncertainty or distributional assumptions.	See Results
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	See Results
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable.	N/A
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	N/A
Discussion			
Study findings, limitations, generalisability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could affect patients, policy, or practice.	Discussion
Other relevant information			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	End of manuscript
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	End of manuscript

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Examining the influence of price and income on global saturated fat intake: evidence from 160 countries

Abstract

Introduction

When considering proposals to improve diets, it is important to understand how factors like price and income can affect saturated fat intake and demand. This is even more important when considering economic interventions on a global scale. In this study, we examine and estimate the influence of price and income on intake across 160 countries, by age and sex, and derive sensitivity measures (price elasticities) that vary by age, sex, and geographic region.

Methods

Secondary data were used for this analysis. Saturated fat intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank). We estimated intake responsiveness to income and prices, accounting for differences by world region, age, and sex.

Results

Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Price elasticities varied with age but not sex. Intake differences due to income were insignificant when regional binary variables were included in the analysis.

Conclusion

The results of this study show heterogeneous associations among prices and intake within and across countries. Policymakers should consider these heterogenous effects as they address global nutrition and health challenges.

Strengths and Limitations of this Study

- We derived detailed estimates of how price and income influence saturated fat intake across 160 countries, by age and sex.
- The strength of our analysis is the large country coverage, which is rarely seen in food and nutrition demand research, allowing for comparisons across population subgroups within and across countries.
- Our price and income measures were at the country level and could not account for within-country differences across population subgroups.
- The global price series used in this study was limited to primary contributing food categories and did not include, for instance, processed food prices.

INTRODUCTION

While nutritional guidelines call for reductions in saturated fat (SF), the literature is not clear and remains controversial on the causal link between SF intake and cardiovascular disease risk and other health-related outcomes.(1-3) Studies note that different food sources of SF may have different relationships with risk, for example with higher risk for red meats and their fats, generally neutral relationships for dairy foods and their fats, and protective associations for plant oils.(4) In addition, low SF intake has been associated with higher mortality risk in studies comprising mostly low- and middle-income countries, and very low SF intake is associated with higher risk of hemorrhagic stroke, potentially due to increased cerebral vascular fragility.(3, 4)

Governments and international organizations have proposed economic interventions to improve diets and health outcomes.(5-8) Associated intake and health responses from the taxation of unhealthy foods has been the subject of many studies.(9-12) For instance, studies have considered the effectiveness of economic interventions to reduce the consumption of sugar-sweetened beverages (SSBs) and calorically dense foods across countries and cities over the past decade. However, the effectiveness of these economic interventions in reducing intake and improving health varies widely.(9, 13, 14) For instance, taxation in a particular jurisdiction could increase cross-border shopping (i.e., purchasing outside of the jurisdiction) or substitutions for unhealthy, untaxed alternatives.(9, 13)

In considering these proposals to improve diets, it is important to understand how factors like price and income influence SF intake and demand.(6, 15-17) Sensitivity to prices of SF-source foods could vary by per capita income, age, sex, educational attainment, etc. This relationship may also vary by world region, given differing cultural preferences, with important implications for health policy interventions.(18-20) However, to-date, no evidence exists on the global income and price sensitivity of SF intake, nor potential variation by important demographic characteristics. Other than a few noted exceptions, global assessments of SF intake have been limited, particularly when considering price and income effects.(21, 22)

To help address these knowledge gaps, this investigation assessed how price and country income relate to SF intake. We used nationally representative intake estimates from the 2018 Global Dietary Database to estimate how per capita income and prices jointly relate to SF intake by age and sex globally. Since nutrients are found in food, examinations of nutrient demand must consider food source demand, with price and income as explanatory variables.(23-25) Using price and expenditure data from the World Bank International Comparison Program, we constructed a global price series based on three food categories: meat, dairy, and oils and fats. This series sufficiently explained SF intake differences across countries and allowed for assessing the relationships of per capita income and price in each food category.

METHODS

Data and sources

We used secondary data sources for the analysis. SF intake data measured in percent of total energy per day (% energy/d) for a representative individual was obtained from the 2018 Global Dietary Database (GDD). The GDD, maintained by the Global Nutrition and Policy Consortium at Tufts Friedman School of Nutrition Science and Policy provides comprehensive and comparable dietary intakes for major foods and nutrients in 185 countries and territories. The GDD was developed using systematic searches of available survey data of individual-based dietary intakes for key food and nutrient categories at the national and subnational level. GDD intake estimates are based on the results of existing surveys (1,248 in total), representing 188

countries and approximately 99% of the global population. It is the first database to provide estimates of daily consumption levels by food or nutrient category and contains representative individual intake data by age (0-1 year, 1-2 years, 2-5 years, and then by increments of 5 years to age 97.5) and sex.(26) The GDD also disaggregates individual intakes by three education levels and residence (urban and rural). The GDD data estimation process included extensive communication with researchers and government authorities and large subnational surveys, when other options were are unavailable (27, 28). For details on the GDD coverage, data methodology, and data collection, see:
https://www.globaldietarydatabase.org/methods/summary-methods-and-data-collection.

National food expenditure and price data from the World Bank International Comparison Program (ICP) were used to derive a SF price series. Although our intake measure is comprehensive and inclusive of all food sources, the price series used for the analysis was limited to the primary contributing food categories: meats, dairy, and oils and fats. The price series for the *meats* category in the ICP database is an aggregation of the following: beef and veal; pork; lamb, mutton, and goat; poultry; and other meats and meat preparations. *Dairy* – fresh milk; preserved milk and other milk products; cheese and curd; and eggs and egg-based products. *Oils and fats* – butter and margarine; and other edible oils and fats (29). Although saturated fat is readily found in a wide array of foods, these categories have been identified as major contributors to saturated fatty acids in diets.(30) While other foods, such as sweet and savory snacks, also contribute and are included in our SF intake variable, global price series for these food categories are not widely available.

The ICP is a global initiative that estimates purchasing power parities (PPPs) and price level indices (PLIs) across countries, which allows for global comparisons of spending and economic wellbeing. PPPs are spatial price deflators that make it possible to compare expenditures across economies.(31) PLIs are PPPs standardized to a common currency (generally the U.S Dollar) or indexed to a global average or base country.(32) The most recent ICP data round (2017) included comparative prices and expenditure data from 176 participating economies.(32)

For income, we used 2018 PPP-adjusted, gross domestic product (GDP) per capita from the World Development Indicators (WDI) database. Because differences in currency values and exchange rates do not always consistently reflect price-level differences across countries, PPP-adjusted GDP allowed for cross-country comparisons because overall price disparities across countries are taken into account.(33)

The analysis was limited to the 160 countries represented in all three databases (GDD, ICP, and WDI), which are listed in Supplementary Table 1 by geographic region (see the Supplemental Appendix): East Asia, Southeast Asia, and the Asian Pacific (Asia) (14 countries); Central and Eastern Europe and Central Asia (CEE) (27 countries); Latin America and Caribbean (LAC) (29 countries); Middle East and North Africa (MENA) (17 countries); South Asia (S-Asia) (7 countries); Sub-Saharan Africa (SSA) (43 countries), and High-Income/Western Countries (HIC) (24 countries). HIC is an aggregation of high-income countries in the Western hemisphere, Australia, and New Zealand, with the addition of a few surrounding islands. Countries without data in any of the three databases were excluded.

See the Supplemental Appendix for a more detailed discussion of the price, expenditure, and income data by geographic region.

Patient and public involvement

We used secondary data for this study. All data are publicly available and did not require direct patient involvement in the study design or implementation.

Model and estimation

To estimate SF intake demand, we used a semi-log functional form that has been proven to be consistent with economic theory and rational consumer behavior.(34, 35) Many studies have used a double-log form.(36) However, a problem with the double-log form is that significant intake differences across subgroups can be lost in log conversions. A semi-log relationship allowed for a better assessment of subgroup effects on intake responsiveness. Also, it has been shown that semi-log models contain the necessary information for obtaining, for instance, reliable measures of consumer welfare and the underlying preference structure of consumers.(34) Prior studies have also used a demand-system approach, primarily due to the adding-up property when using expenditure data (i.e., expenditures on all food categories "add up" to total food expenditures), which results in the error terms being correlated across equations specific to each food category. Since this relationship does not exist with individual intakes, particularly when the correspondence between purchases and intakes is not one to one, we can estimate intake demand for a single food or nutrient category separately.(37, 38)

Let q_{gC} represent the % energy/d from saturated fat for demographic subgroup g (g: sex and age) in country C and let p_C represent the price level index for the contributing food categories in country C. Let Y_C and P_C represent real per capita income and the food price level index, respectively, in country C. Given these terms, the following model was used to estimate the relationship between intake, income, and prices:

$$q_{gC} = \beta_0^* + \beta_1^* \ln(Y_C) + \beta_2^* \ln\left(\frac{p_C}{P_C}\right) + u_{gC}. \quad (1)$$

The β_k^* terms [$k = \{0,1,2\}$] are parameters to be estimated and u_{gC} is a random error term. Note that the price term is defined by the price of contributing food categories (p_C) relative to overall food prices (P_C). Thus, the model discounts any price differences across countries due to differences in overall food prices and implicitly accounts for the cross-price effects of other foods. For instance, if dairy prices were the same in two countries, but overall food prices differed, intake would be greater in the country with the higher food-price level since dairy is *relatively* cheaper when compared to food overall. Note that equation (1) does not include higher order income and price effects (e.g., quadratic income and price-income interactions). In preliminary analysis, these higher-order terms were highly insignificant, which implied that price or income responsiveness did not depend on the level of per-capita income level.

Using equation (1), we estimated intake demand using a procedure that allowed for error correlations among observations from the same country (i.e., country-clustered errors).(39) To account for differences in preferences across countries due to cultural differences or other related factors, we included regional binary variables in the analysis (ASIA, CEE, LAC, MENA, S-ASIA, and SSA). We accounted for age and sex by allowing these factors to have a direct effect on intake, as well as an additional effect through income and prices. Thus, the beta terms (β_k^*) were expanded to account for age and sex interactions: $\beta_k^* = f(sex, age)\forall k$. Further disaggregations (education level and residence) were not considered due to estimation concerns resulting from negligible differences in SF intake across these factors. Although we used a single price index (p_C) to represent the three food categories (meats, dairy, and oils and fats), intake responsiveness with respect to the price of each food category were easily derived. Defining the conditional expenditure share and price for the *i*th food category in country *C* as s_{iC} and p_{iC}, respectively, p_C is as follows: $p_C = \sum_i s_{iC} p_{iC}$. Thus, relationships between q_{gC} and p_{iC} were derived using the estimate on the price term in equation (1) $\left(\beta_2^*\right)$ and the conditional expenditure share s_{iC} as follows: $\frac{\partial q_{gC}}{\partial p_{iC}} = \frac{\partial q_{gC}}{\partial p_C}\frac{\partial p_C}{\partial p_{iC}} = \frac{\beta_2^*}{p_C} s_{iC}$.

RESULTS

Descriptive statistics and SF intake overview

Table 1 shows the descriptive statistics for the variables used in the model. Mean SF intake across all observations was 10.3% energy/d and ranged from 2.39 to 27.28. PPP-adjust real GDP per capita ranged from \$780 to \$117,245 (mean = \$22,226). The deflated price index $\left(\frac{p_C}{P_C}\right)$ ranged from 0.71 to 1.40 (mean = 1.00). Mean values for the region and sex variables reflect the country and subgroup representation in the data.(26, 33)

Figure 1 contains violin plots for SF intake by sex, age, and region based on all observations (*n* = 7,040). Violin plots use kernel densities to visualize the distribution of intake. The width of the violin plot corresponded to the probability of an observation taking a specific value of SF intake and the vertical black line in each violin plot corresponds to the median value. In general, the violin plots showed that the distribution of SF is similar across age and sex subgroups, although there was greater variation across regions. Additionally, the presence of long right tails across most subgroups suggested the presence of outliers with very high values of SF intake.(26)

While the median value for SF intake was around 10.60 % energy/d, there were notable differences (Figure 1). Median SF intake was slightly higher in females (females = 10.88, males=10.40). Across regions, median SF intake was lowest in S-Asia (6.42) and highest in HIC (13.78). Overall, the maximum value for saturated fat intake occurred in the Philippines (27.48) amongst female infants (< 1 year old), while the overall minimum occurred in Nepal (2.39) amongst females between the ages of 20 and 25. Even within regions, notable differences occurred. In HIC, for instance, intake ranged from a high of 23.02 % energy/d in France amongst female infants to 9.45 % energy/d in Portugal amongst males, age 95 years and older.(26)

Estimation results

We first estimated the model using intake values at the country level (i.e., intake averaged over all demographic subgroups) (n = 160) (See Supplemental Table 2). Since our explanatory variables (price and income) were country specific and did not vary with demographic subgroups, it was useful to examine the significance of price or income without age and sex differences. The country-level analysis also revealed the importance of each variable in explaining global differences in SF intake. For instance, Model 1 showed that regional differences accounted for a large share of intake differences across countries (Adjusted R^2 = 0.39). When regional differences were not accounted for, both income (1.03, $p < 0.01$) (Model 2) and price (-3.90, $p < 0.05$) (Model 3) were significant. When regional differences were accounted for (Model 4), price was still significant (-4.33, $p < 0.05$), but income was insignificant. The negative price estimate was consistent with economic theory (higher prices being associated with lower intake) and indicated that a unit increase in the log of price was associated with lower SF intake by 4.33 percentage points.

Since the intake variable was measured as a percent, it is important to clarify the difference between a percentage point change and percent change. For instance, intake falling from 10.83 to 6.50 % energy/d, is a 4.33 percentage point decline, but a 40% decline: -4.33 ÷ 10.83). This distinction is important when considering elasticity relationships where both intake and prices are measured in percentage. Assuming mean intake (10.83 % energy/day) as the base, intake falling by 4.33 percentage points or 40% given a unit change in the log of price (a two-fold increase) suggested a price elasticity of about -0.40. That is, SF intake declines by 0.40% for every 1.0% increase in price, which indicates minimal price sensitivity and inelastic demand. Note that this result is based on a price increase across all food categories in the price series. As discussed later in this section, intake responsiveness to the price of a particular food category (e.g., dairy) was smaller.

Estimation results for the full model (Model 4) are reported in Table 2. Other than ASIA, SF intake was significantly lower in all regions relative to HIC intake. Intake also decreased with higher age (-0.10, $p < 0.01$), but this effect was less significant with older adults. Results (Model 4) indicated a price effect of -7.16 ($p < 0.01$), where the magnitude became smaller with age (0.20, $p < 0.01$), but then increased for older populations. There was no significant difference in the price effect by sex – and like the country-level analysis – the income effect on intake was insignificant when regional differences were considered. Consequently, we did not examine income effects in detail and the price-specific measures that follow are not specific to sex.

Intake responsiveness and food prices

Using the country-level estimates from Supplemental Table 2, we derived measures of aggregate intake change with respect to price changes specific to the food categories in the SF price series (meat, dairy, and oils and fats) (Figure 2). Note that our dependent variable is SF intake from all foods, including ultra-processed food. Thus, the price effects reported in this section measure how changes in the price of meat (e.g.) affect total SF intake, not just SF intake from meat. An increase in the meat price index resulted in the largest intake decrease: -2.47 percentage points from a two-fold increase in price (IQR: -2.29 to -2.78). Assuming mean intake as the base, this implied a price elasticity of about -0.23 (i.e., a 0.23% decline for every 1.0% increase in meat prices). The next highest intake decrease was in response to the dairy price index (-1.30 percentage points and IQR: -1.01 to -1.56), implying a price elasticity of -0.12. The results for oils and fats indicate the lowest intake response to a price change (-0.55 percentage point change and IQR: -0.29 to -0.65); the elasticity with respect to the price of oils and fats is about -0.06.

Using the estimates from Table 2, we assessed intake responsive by food category, age, and region (See Figure 3). Across regions, meat prices resulted in the largest variation in SF intake, with S-Asia being the only exception. In HIC, for instance, median SF intake reductions at age 40 were 1.37, 0.78, and 0.15 percentage points, for 1% higher prices of meat, dairy, and oils and fats, respectively. In contrast, intake reductions in S-Asia at age 40 were highest for dairy prices (1.14 percentage points) followed by meat prices (0.62 percentage points) and then the price of oils and fats (0.48 percentage points). However, the IQR overlap for meat and dairy in S-Asia suggested that intake responsiveness to these two prices was not significantly different.

Across regions, there were key differences in intake responsiveness with respect to price changes. In HIC, there was no IQR overlap, suggesting significantly higher intake responsiveness to meat prices when compared to dairy prices, and diary prices compared to the price of oils and fats. Similar patterns were observed for CEE, LAC, and MENA. In SSA, however, intake changes from meat prices were significantly larger, but the estimates for dairy and oils and fats prices show considerable IQR overlap.

Results also indicated that middle-aged groups (age 40-60 years) were the least sensitive to price changes. This was consistent with expectations as the middle-aged often have higher incomes and may be less sensitive to price changes. Based on the "All Countries" estimates (upper left panel), the median intake response from a two-fold increase in meat prices was -2.10 percentage points (age 20), responsiveness then decreased to -1.32 percentage points by age 50, and then increased to -2.71 percentage points by age 80. There was a similar pattern for dairy and oils and fats prices, but the differences between age groups were not as large.

DISCUSSION

This investigation provides evidence on how differences in income and food prices might jointly influence SF consumption by sex and age across the spectrum of rich and poor countries. Both the country-level and disaggregated (age and sex) analysis indicated that intake differences due to income were insignificant. These results suggest that intake differences across countries are better explained by regional dissimilarities and not economic wellbeing as measured by per-capita income. In contrast, differences due to food prices were highly significant. Globally, a one-percent increase in prices was estimated to decrease SF intake by about 0.40%. Across regions, meat-price sensitivity of SF intake was relatively high, except for S-Asia where dairy price sensitivity of SF intake was higher. Within regions and by age, price sensitivity was lowest among middle-aged adults.

The higher sensitivity of SF intake to price changes in meat consumption suggests that fiscal policies focused on a reducing SF intake would be more effective through meat-price interventions. That said, the magnitudes of price sensitivity were small, indicating relatively inelastic demand. Thus, high taxes would be needed to reduce intake: for example, global findings suggest that a two-fold increase in meat prices (i.e., a 100% tax) is associated with decreased intake of only 2.47 percentage points. Our results are consistent with previous findings. Research has shown that fat taxes in Denmark, Hungary, and France had small and ambiguous effects on demand.(40, 41) A similar outcome was observed from the Danish fat tax experience that targeted dairy and vegetable fat sources.(42)

The findings in this study can help to inform strategies that counter worsening diets. However, our modeling cannot prove causality of price changes on intake, and thus our findings should be interpreted cautiously when informing interventions and evaluations. Furthermore, the invariability of price and income across demographic subgroups ignores differences within countries and may have affected results, although we address this issue, in part, with age and sex variable interactions. Although the lack of price data for other food categories limited our ability to parse out other intake-price relationships, to the degree that our derived SF price series based on meat, dairy, and oils and fats is representative of a “true” global SF price the aggregate price effects could be applied to other food categories.

The benefit of our analysis is the country coverage. While relationships between income, prices, and food choice have been studied, combining GDD, World Bank, and ICP data allowed for a global coverage rarely seen in food and nutrition research, allowing for comparisons across individuals in rich and poor countries and an examination of intake responsiveness by age and sex.(37, 38)

CONCLUSION

Our results provide novel global evidence on how income and prices influence SF intake by region, age, and sex. Our results confirm that the effectives of price interventions would be limited in most countries but provide evidence where interventions would be most effective if implemented (meat versus dairy or oils and fats; youth, young adults, and the elderly). These observed relationships can assist policymakers as they consider how pricing policies can be leveraged to tackle nutrition challenges.

Table 1. Descriptive statistics for study variables

Variable	Measure	Mean	Std. Dev.	Min	Max
SF intake	% energy/d	10.83	3.09	2.39	27.48
Female	Binary	0.50	0.50	0	1
Age	5-year intervals*	45.6	30.83	1	98
ASIA	Binary	0.09	0.29	0	1
CEE	Binary	0.17	0.37	0	1
HIC	Binary	0.15	0.36	0	1
LAC	Binary	0.18	0.39	0	1
MENA	Binary	0.10	0.30	0	1
S-ASIA	Binary	0.04	0.20	0	1
SSA	Binary	0.27	0.44	0	1
Real GDP per capita (PPP)	$/person	$22,226	$21,646	$780	$117,245
Deflated price	index (US=1)	1.00	0.12	0.71	1.40

SF is saturated fat. Note that n = 7,040 (160 countries × 44 demographic subgroups); n = 160 for the GDP and price index. East and Southeast Asia (ASIA), Central and Eastern Europe and Central Asia (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), Sub-Saharan Africa (SSA), and High-Income Countries/Rest of World (HIC). PPP is purchasing power parity.

Table 2 Saturated fat intake estimates using country and demographic (sex and age) level data (*n* = 7,040)

	Model 1	Model 2	Model 3	Model 4
Constant	14.64 (0.39)***	2.81 (1.73)	12.44 (2.89)***	12.01 (2.90)***
ASIA	-2.20 (1.14)*		-1.61 (1.12)	-1.61 (1.12)
CEE	-1.94 (0.48)***		-1.68 (0.51)***	-1.68 (0.51)***
LAC	-3.97 (0.49)***		-4.09 (0.65)***	-4.09 (0.65)***
MENA	-3.98 (0.52)***		-3.35 (0.55)***	-3.35 (0.55)***
S-ASIA	-7.26 (1.00)***		-6.08 (1.08)***	-6.08 (1.08)***
SSA	-4.03 (0.49)***		-3.47 (0.81)***	-3.47 (0.81)***
Female	0.48 (0.04)***	0.48 (0.04)***	0.48 (0.04)***	0.06 (0.31)
Age	-0.04 (0.01)***	-0.04 (0.008)***	-0.04 (0.01)***	-0.10 (0.04)***
Age^2	0.00 (0.00)***	0.00 (0.00)***	0.00 (0.00)***	0.00 (0.00)***
ln(Y)		0.93 (0.18)***	0.19 (0.26)	0.24 (0.27)
Female × ln(Y)				0.04 (0.04)
Age × ln(Y)				0.01 (0.00)
Age^2 × ln(Y)				0.00 (0.00)***
ln(P)		-3.73 (1.59)***	-4.32 (1.88)**	-7.16 (2.29)***
Female × ln(P)				-0.13 (0.14)
Age × ln(P)				0.20 (0.06)***
Age^2 × ln(P)				0.00 (0.00)***
Adjusted R^2	0.34	0.18	0.36	0.37

Dependent variable is saturated fat intake in % energy/d. Robust standard errors (clustered by country) are in (parenthesis). *$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$. East and Southeast Asia (ASIA), Central and Eastern Europe (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), and Sub-Saharan Africa (SSA). Y is real GDP per capita, purchasing-power-parity adjusted. P is an inflation adjusted price index for meats, dairy products and eggs, and oils and fats.

List of Figures

Contributorship statement

AA and AM contributed to the study conceptualization; JR, PS, JZ, FC, JEM VM, and DM contributed to data cu and data curation; AA and AM contributed to the methodology and economic analysis; AA, AM, JNY, DM contributed to writing (original draft); AA, AM, and JNY contributed to writing (review and editing); AA and AM are joint senior authors. Collaborators are listed in the supplemental appendix.

Competing interests

There are no competing interests for any author.

Funding

No funding organization contributed to this research.

Data sharing statement

The expenditure and price data are available in a public, open access repository managed by the World Bank. The intake data can be obtained from the Global Dietary Database (GDD) through a data user agreement. The GDD is maintained by the Global Nutrition and Policy Consortium at Tufts Friedman School of Nutrition Science and Policy.

Ethical statement

This study does not involve human participants.

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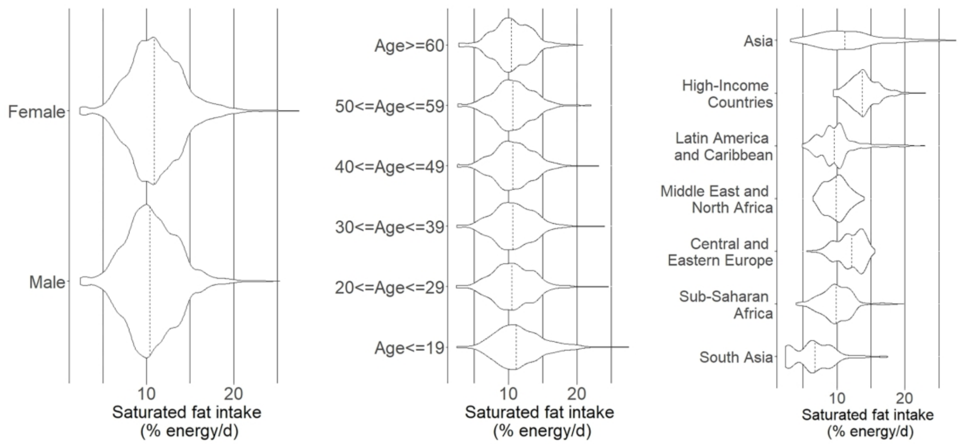

Figure 1. Comparison of percentage energy from saturated fat among individuals in sex, age, and country-specific strata globally and across world regions. Note that n = 7,040 (160 countries × 44 demographic subgroups). Female n = 3,520; male n = 3,520.
Age categories: Age<=19 n = 1,920; Age>=60 n = 2,560; for all other age groups n = 640; Regions: South Asia n = 308; Sub-Saharan Africa n = 1,892; Central and Eastern Europe n = 1,188; Middle East and North Africa n = 704; Latin America and Caribbean n = 1,276; High-Income Countries n = 1,056; Asia n = 616. Source: Global Dietary Database, 2018.

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Figure 2. Change in saturated fat intake when prices double for each food category.
Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR, error bars are min and max values, and data points are outliers.

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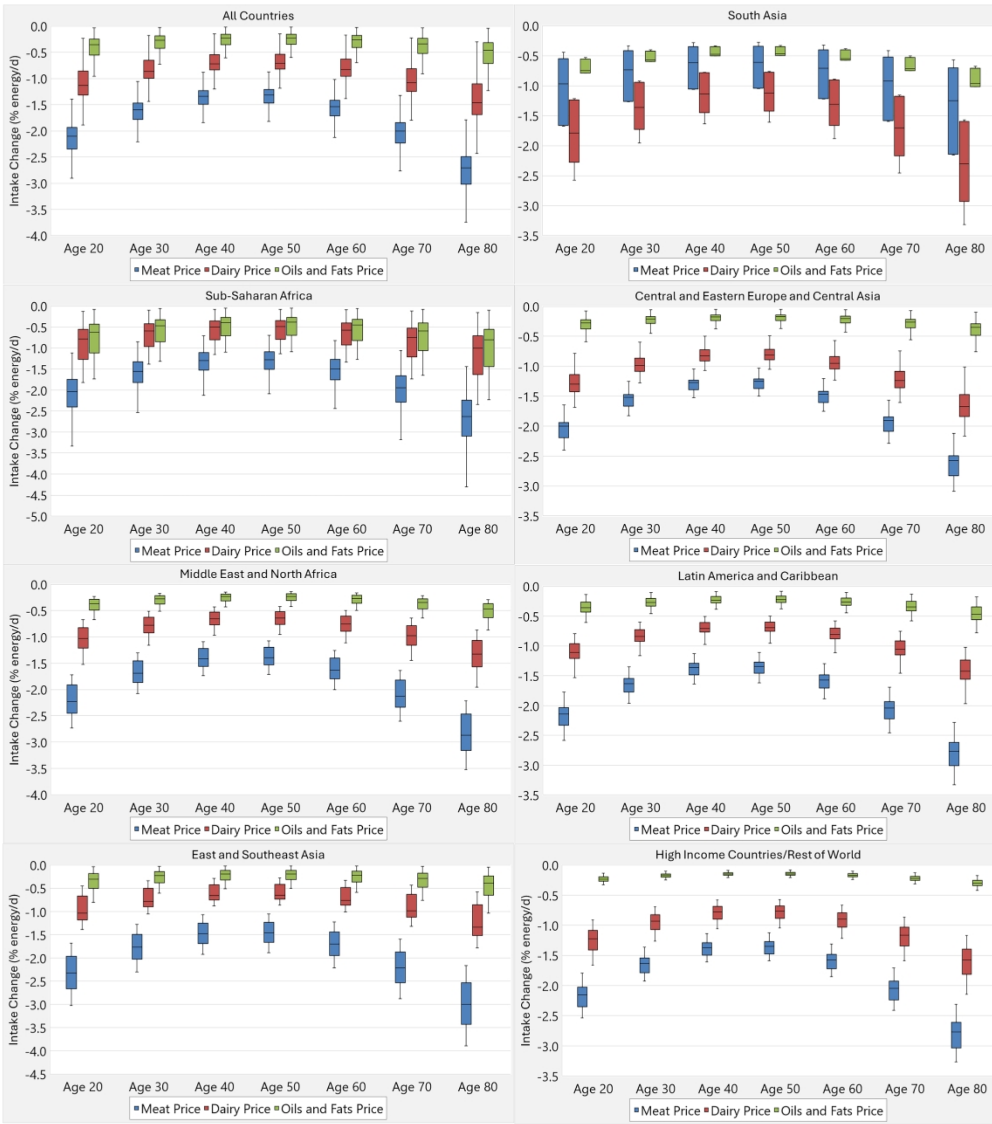


Figure 3. Change in saturated fat intake when prices double for each food category by select region and age. Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR and error bars are min and max values.

381x426mm (300 x 300 DPI)

Supplemental Appendix

Supplemental Table 1. Countries included in study by defined region

Region	Countries
Southeast Asia, East Asia, and High-Income Asia Pacific (ASIA) 14 countries	Brunei Darussalam, Cambodia, China, Fiji, Indonesia, Japan, Laos, Malaysia, Myanmar, Philippines, Singapore, South Korea, Thailand, and Vietnam.
Central Europe, Eastern Europe, and Central Asia (CEE) 27 countries	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Macedonia, Moldova, Mongolia, Montenegro, Poland, Romania, Russia, Serbia, Slovak Republic, Slovenia, Tajikistan, and Ukraine.
Latin America and the Caribbean (LAC) 29 countries	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, St. Lucia, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, and Uruguay.
Middle East and North Africa (MENA) 17 countries	Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, Turkey, United Arab Emirates, and West Bank and Gaza.
South Asia (S-ASIA) – 7 countries	Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.
Sub-Saharan Africa (SSA) 43 countries	Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo DR, Congo, Côte d'Ivoire, Djibouti, Equatorial Guinea, Eswatini, Ethiopia Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, Sudan, Tanzania, Togo, and Uganda.
High Income/Rest of World (HIC) 24 countries	Australia, Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and United States.

Supplemental Table 2. Saturated fat intake estimates using country level data (*n* = 160)

	Model 1	Model 2	Model 3	Model 4
Constant	13.66 (0.46)***	1.03 (1.75)	10.81 (0.23)***	12.05 (2.87)***
ASIA	-1.19 (0.76)			-0.66 (0.81)
CEE	-1.36 (0.63)**			-1.16 (0.67)*
LAC	-4.07 (0.62)***			-4.26 (0.74)***
MENA	-3.43 (0.73)***			-2.85 (0.77)***
S-ASIA	-7.41 (0.97)***			-6.34 (1.10)***
SSA	-4.07 (0.58)***			-3.65 (0.90)***
ln(Y)		1.03 (0.18)***		0.14 (0.26)
ln(P)			-3.90 (1.94)**	-4.33 (1.89)**
Adjusted R^2	0.39	0.16	0.02	0.41

Dependent variable is saturated fat intake measured in % energy/d. Robust standard errors are in (parenthesis). *$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$. East and Southeast Asia (ASIA), Central and Eastern Europe and Central Asia (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), and Sub-Saharan Africa (SSA). Y is real GDP per capita, purchasing-power-parity adjusted. P is an inflation adjusted price index for meats, dairy products and eggs, and oils and fats.

Income, Price, and Expenditure Data Across Countries

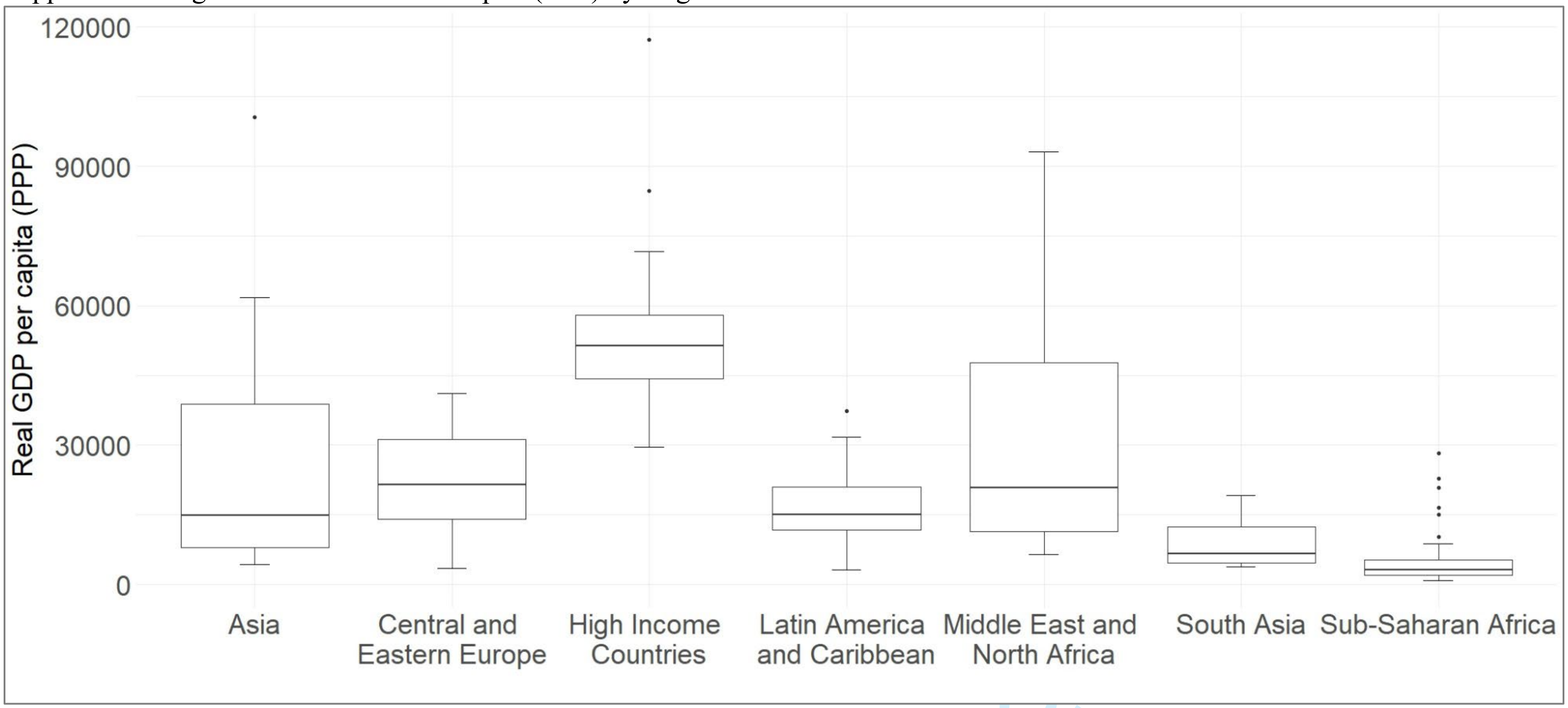
Supplemental Figures 1 – 3 contain box plots by region for the country-specific explanatory variables.

Supplemental Figure 1 shows real GDP per capita (PPP) for the seven regions in our study. The highest GDP region is High-Income Countries, which is unsurprising. The median income for High-Income Countries was $51,432 per person. In contrast, Sub-Saharan Africa had the smallest real GDP per capita, with a median value of $3,147.

Supplemental Figure 2 shows expenditure shares for the contributing food categories: meats, dairy, and oils and fats by region. Food expenditure shares were derived from the World Bank International Comparison Program (ICP) which allows for global spending comparisons by standardizing expenditures to a common currency (U.S. Dollars). Across regions, meat expenditures were the highest food expenditure category, except for South Asia. In South Asia, the median dairy food expenditure share was the highest at 0.47 and the interquartile range (IQR) was 0.34 to 0.60. Asia, Latin America and Caribbean, and Sub-Saharan Africa were the regions with the highest median expenditures for meats at 0.65 and an IQR from 0.55 to 0.74. South Asia has the lowest meat expenditure share at 0.31 with an IQR from 0.16 to 0.48. Apart from South Asia, dairy expenditure shares represented the second highest expenditure shares across regions. Oils and fats account for the smallest share of food expenditures compared to the other food categories for all regions.

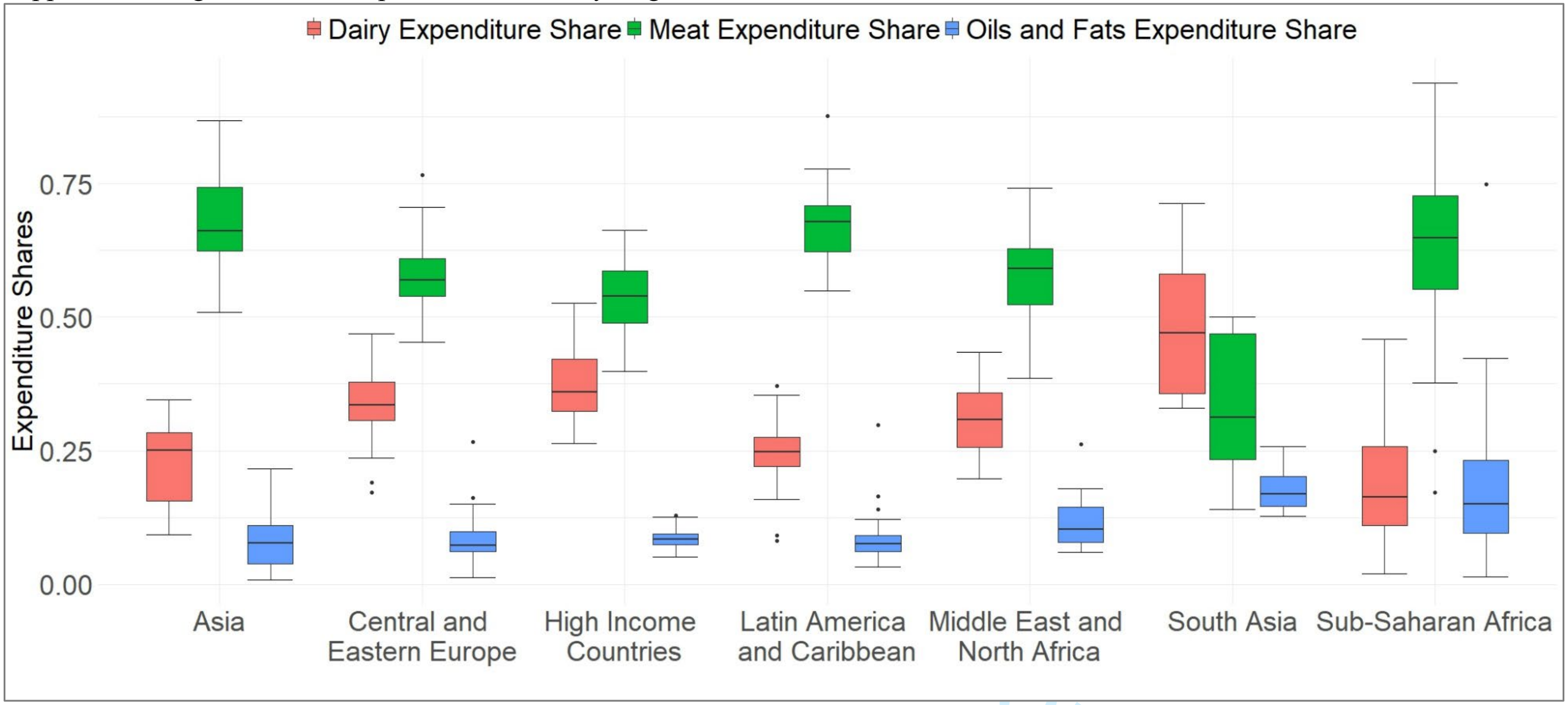
Supplemental Figure 3 shows the price indexes for meat, dairy, and oil and fats, and the weighted average price index (weighted based on the expenditures in Supplemental Figure 2) by region. The weighted average food price index is the sum of each price index times the expenditure share for the corresponding food category. Most regions exhibit relatively similar values across price index categories and shorter “whiskers” include Central and Eastern Europe, Middle East and North Africa, and South Asia. Alternatively, some regions (High-Income Countries, Latin America and Caribbean, and Sub-Saharan Africa) exhibit a greater range between the IQR and maximum and minimum values and greater variation in prices. For example, in the Latin American and Caribbean region, the dairy price index has a median value of 134.49 and IQR of 98.60 to 156.59. In contrast, the Central and Eastern Europe region has a dairy price index median value of 86.58 and IQR range of 75.84 to 93.50.

Supplemental Figure 1. Real GDP Per Capita (PPP) by Region



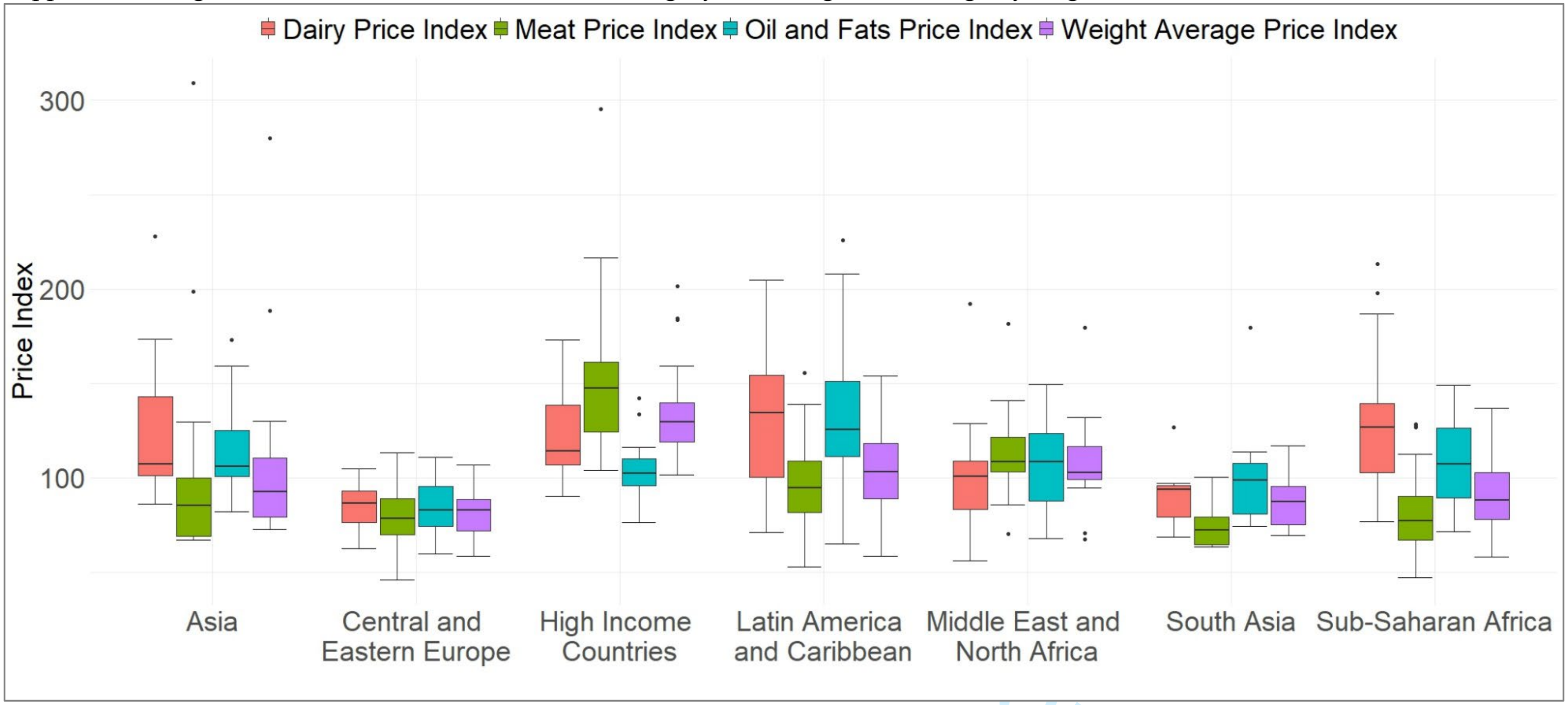
Source: Authors' estimates using income data from the World Bank Development Indicators.

Supplemental Figure 2. Food Expenditure Shares by Region



Source: Authors' estimates using income data from the World Bank International Comparison Program.

Supplemental Figure 3. Price Indexes for each Food Category and Weighted Average by Region



Source: Authors' estimates using income data from the World Bank International Comparison Program.

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CHEERS 2022 Checklist

Topic	No.	Item	Location where item is reported
Title			
	1	Identify the study as an economic evaluation and specify the interventions being compared.	Examining the influence of price and income on global saturated fat intake: evidence from 160 countries
Abstract			

Topic	No.	Item	Location where item is reported
	2	Provide a structured summary that highlights context, key methods, results, and alternative analyses.	Introduction When considering proposals to improve diets, it is important to understand how factors like price and income can affect saturated fat intake and demand. This is even more important when considering economic interventions on a global scale. In this study, we examine and estimate the influence of price and income on intake across 160 countries, by age and sex, and derive sensitivity measures (elasticities) that vary by age, sex, and geographic region. Methods Secondary data were used for this analysis. Intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank). We estimated intake responsiveness to income and prices, accounting for differences by world region, age, and sex. Results Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. Results indicated that the highest price sensitivity was due to meat consumption. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were e 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Intake differences due to income were insignificant. Conclusion The results of this study show heterogeneous associations among prices and intake within and across countries. Policymakers should consider these heterogenous effects as they address global nutrition and health challenges.
Introduction			

Topic	No.	Item	Location where item is reported
Background and objectives	3	Give the context for the study, the study question, and its practical relevance for decision making in policy or practice.	To help address these knowledge gaps, this investigation assessed how price and country income relate to SF intake. We used nationally representative intake estimates from the 2018 Global Dietary Database to estimate how per capita income and prices jointly relate to SF intake by age and sex globally. Since nutrients are found in food, examinations of nutrient demand must consider food source demand, with price and income as explanatory variables.(15-17) Using price and expenditure data from the World Bank International Comparison Program, we constructed a global price series based on three food categories: meat, dairy, and oils and fats. This series sufficiently explained SF intake differences across countries and allowed for assessing the relationships of per capita income and price in each food category.
Methods			
Health economic analysis plan	4	Indicate whether a health economic analysis plan was developed and where available.	No. This does not apply.
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	Secondary data were used for this analysis. Intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank). We estimated intake responsiveness to income and prices, accounting for differences by world region, age, and sex.
Setting and location	6	Provide relevant contextual information that may influence findings.	Global study - 160 countries.
Comparators	7	Describe the interventions or strategies being compared and why chosen.	Economic analysis using secondary data. This does not apply.

Topic	No.	Item	Location where item is reported
Perspective	8	State the perspective(s) adopted by the study and why chosen.	• It is generally understood that affordability is an important driver of food demand, underscoring the importance of income and prices in dietary choices. Research has confirmed significant associations among income, prices, and food demand. What is missing, however, is a better understanding of how price and income influence actual nutrient intake, particularly on a global scale, and how price and income relationships could vary by demographics within and across countries.
Time horizon	9	State the time horizon for the study and why appropriate.	2017-2018
Discount rate	10	Report the discount rate(s) and reason chosen.	N/A
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	N/A
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	N/A
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	See 5.
Measurement and valuation of resources and costs	14	Describe how costs were valued.	Income values were in $US.
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	Prices were indexes where World = 100.

Topic	No.	Item	Location where item is reported
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	To estimate SF intake demand, we used a semi-log functional form that has been proven to be consistent with economic theory and rational consumer behavior.(25, 26) Many studies have used a double-log form.(27) However, a problem with the double-log form is that significant intake differences across subgroups can be lost in log conversions. A semi-log relationship allowed for a better assessment of subgroup effects on intake responsiveness.
Analytics and assumptions	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	Econometric analysis assuming country clusters.
Characterising heterogeneity	18	Describe any methods used for estimating how the results of the study vary for subgroups.	Econometric analysis assuming country clusters.
Characterising distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. Results indicated that the highest price sensitivity was due to meat consumption. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were e 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Intake differences due to income were insignificant.
Characterising uncertainty	20	Describe methods to characterise any sources of uncertainty in the analysis.	Not applicable
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communities, or stakeholders (such as clinicians or payers) in the design of the study.	N/A
Results			

Topic	No.	Item	Location where item is reported
Study parameters	22	Report all analytic inputs (such as values, ranges, references) including uncertainty or distributional assumptions.	See Results
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	See Results
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable.	N/A
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	N/A
Discussion			
Study findings, limitations, generalisability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could affect patients, policy, or practice.	Discussion
Other relevant information			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	End of manuscript
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	End of manuscript

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How prices and income influence global patterns in saturated fat intake by age, sex, and world region: a cross-sectional analysis of 160 countries

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How prices and income influence global patterns in saturated fat intake by age, sex, and world region: a cross-sectional analysis of 160 countries

Abstract

Objective

When considering proposals to improve diets, it is important to understand how factors like price and income can affect saturated fat intake and demand. In this study, we examine and estimate the influence of price and income on intake across 160 countries, by age and sex, and derive sensitivity measures (price elasticities) that vary by age, sex, and world region.

Design

We econometrically estimate intake responsiveness to income and prices across countries, accounting for differences by world region, age, and sex. Intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank).

Results

Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Price elasticities varied with age but not sex. Intake differences due to income were insignificant when regional binary variables were included in the analysis.

Conclusion

The results of this study show heterogeneous associations among prices and intake within and across countries. Policymakers should consider these heterogenous effects as they address global nutrition and health challenges.

Strengths and Limitations of this Study

- We compared price responsiveness across population subgroups (by age and sex) and across countries by world region.
- The analysis allowed for price elasticity comparison across primary contributing food categories that included the price of meat, dairy, and oils/fats.
- Price and income measures were at the country level and could not account for within-country price and income differences.
- The price series used in this study was limited to the primary contributing food categories and did not include, for instance, ultra processed foods.

INTRODUCTION

While nutritional guidelines call for reductions in saturated fat (SF), the literature is not clear and remains controversial on the causal link between SF intake and cardiovascular disease risk and other health-related outcomes.(1-3) Studies note that different food sources of SF may have different relationships with risk, for example with higher risk for red meats and their fats, generally neutral relationships for dairy foods and their fats, and protective associations for plant oils.(4) In addition, low SF intake has been associated with higher mortality risk in studies comprising mostly low- and middle-income countries, and very low SF intake is associated with higher risk of hemorrhagic stroke, potentially due to increased cerebral vascular fragility.(3, 4)

Governments and international organizations have proposed economic interventions to improve diets and health outcomes.(5-8) Associated intake and health responses from the taxation of unhealthy foods has been the subject of many studies.(9-12) For instance, studies have considered the effectiveness of economic interventions to reduce the consumption of sugar-sweetened beverages (SSBs) and calorically dense foods across countries and cities over the past decade. However, the effectiveness of these economic interventions in reducing intake and improving health varies widely.(9, 13, 14) For instance, taxation in a particular jurisdiction could increase cross-border shopping (i.e., purchasing outside of the jurisdiction) or substitutions for unhealthy, untaxed alternatives.(9, 13)

In considering these proposals to improve diets, it is important to understand how factors like price and income influence SF intake and demand.(6, 15-17) Sensitivity to prices of SF-source foods could vary by per capita income, age, sex, educational attainment, etc. This relationship may also vary by world region, given differing cultural preferences, with important implications for health policy interventions.(18-20) However, to-date, no evidence exists on the global income and price sensitivity of SF intake, nor potential variation by important demographic characteristics. Other than a few noted exceptions, global assessments of SF intake have been limited, particularly when considering price and income effects.(21, 22)

To help address these knowledge gaps, this investigation assessed how price and country income relate to SF intake. We used nationally representative intake estimates from the 2018 Global Dietary Database to estimate how per capita income and prices jointly relate to SF intake by age and sex globally. Since nutrients are found in food, examinations of nutrient demand must consider food source demand, with price and income as explanatory variables.(23-25) Using price and expenditure data from the World Bank International Comparison Program, we constructed a global price series based on three food categories: meat, dairy, and oils and fats. This series sufficiently explained SF intake differences across countries and allowed for assessing the relationships of per capita income and price in each food category.

METHODS

Data and sources

We used secondary data sources for the analysis. SF intake data measured in percent of total energy per day (% energy/d) for a representative individual was obtained from the 2018 Global Dietary Database (GDD). The GDD, maintained by the Global Nutrition and Policy Consortium at Tufts Friedman School of Nutrition Science and Policy provides comprehensive and comparable dietary intakes for major foods and nutrients in 185 countries and territories. The GDD was developed using systematic searches of available survey data of individual-based dietary intakes for key food and nutrient categories at the national and subnational level. GDD intake estimates are based on the results of existing surveys (1,248 in total), representing 188 countries and approximately 99% of the global population. It is the first database to provide estimates of daily consumption levels by food or nutrient category and contains representative individual intake data by age (0-1 year, 1-2 years, 2-5 years, and then by increments of 5 years to age 97.5) and sex.(26) The GDD also disaggregates individual intakes by three education levels and residence (urban and rural). The GDD data estimation process included extensive communication with researchers and government authorities and large subnational surveys, when other options were are unavailable (27, 28). For details on the GDD coverage, data methodology, and data collection, see: https://www.globaldietarydatabase.org/methods/summary-methods-and-data-collection.

National food expenditure and price data from the World Bank International Comparison Program (ICP) were used to derive a SF price series. Although our intake measure is comprehensive and inclusive of all food sources, the price series used for the analysis was limited to the primary contributing food categories: meats, dairy, and oils and fats. The price series for the *meats* category in the ICP database is an aggregation of the following: beef and veal; pork; lamb, mutton, and goat; poultry; and other meats and meat preparations. *Dairy* – fresh milk; preserved milk and other milk products; cheese and curd; and eggs and egg-based products. *Oils and fats* – butter and margarine; and other edible oils and fats (29). Although saturated fat is readily found in a wide array of foods, these categories have been identified as major contributors to saturated fatty acids in diets.(30) While other foods, such as sweet and savory snacks, also contribute and are included in our SF intake variable, global price series for these food categories are not widely available.

The ICP is a global initiative that estimates purchasing power parities (PPPs) and price level indices (PLIs) across countries, which allows for global comparisons of spending and economic wellbeing. PPPs are spatial price deflators that make it possible to compare expenditures across economies.(31) PLIs are PPPs standardized to a common currency (generally the U.S Dollar) or indexed to a global average or base country.(32) The most recent ICP data round (2017) included comparative prices and expenditure data from 176 participating economies.(32)

For income, we used 2018 PPP-adjusted, gross domestic product (GDP) per capita from the World Development Indicators (WDI) database. Because differences in currency values and exchange rates do not always consistently reflect price-level differences across countries, PPP-adjusted GDP allowed for cross-country comparisons because overall price disparities across countries are taken into account.(33)

The analysis was limited to the 160 countries represented in all three databases (GDD, ICP, and WDI), which are listed in Supplementary Table 1 by geographic region (see the Supplemental Appendix): East Asia, Southeast Asia, and the Asian Pacific (Asia) (14 countries); Central and Eastern Europe and Central Asia (CEE) (27 countries); Latin America and Caribbean (LAC) (29 countries); Middle East and North Africa (MENA) (17 countries); South Asia (S-Asia) (7 countries); Sub-Saharan Africa (SSA) (43 countries), and High-Income/Western Countries (HIC) (24 countries). HIC is an aggregation of high-income countries in the Western hemisphere, Australia, and New Zealand, with the addition of a few surrounding islands. Countries without data in any of the three databases were excluded.

See the Supplemental Appendix for a more detailed discussion of the price, expenditure, and income data by geographic region.

Patient and public involvement

We used secondary data for this study. All data are publicly available and did not require direct patient involvement in the study design or implementation.

Model and estimation

To estimate SF intake demand, we used a semi-log functional form that has been proven to be consistent with economic theory and rational consumer behavior.(34, 35) Many studies have used a double-log form.(36) However, a problem with the double-log form is that significant intake differences across subgroups can be lost in log conversions. A semi-log relationship allowed for a better assessment of subgroup effects on intake responsiveness. Also, it has been shown that semi-log models contain the necessary information for obtaining, for instance, reliable measures of consumer welfare and the underlying preference structure of consumers.(34) Prior studies have also used a demand-system approach, primarily due to the adding-up property when using expenditure data (i.e., expenditures on all food categories "add up" to total food expenditures), which results in the error terms being correlated across equations specific to each food category. Since this relationship does not exist with individual intakes, particularly when the correspondence between purchases and intakes is not one to one, we can estimate intake demand for a single food or nutrient category separately.(37, 38)

Let q_{gC} represent the % energy/d from saturated fat for demographic subgroup g (g: sex and age) in country C and let p_C represent the price level index for the contributing food categories in country C. Let Y_C and P_C represent real per capita income and the food price level index, respectively, in country C. Given these terms, the following model was used to estimate the relationship between intake, income, and prices:

$$q_{gC} = \beta_0^* + \beta_1^* \ln(Y_C) + \beta_2^* \ln\left(\frac{p_C}{P_C}\right) + u_{gC}. \qquad (1)$$

The β_k^* terms [$k = \{0,1,2\}$] are parameters to be estimated and u_{gC} is a random error term. Note that the price term is defined by the price of contributing food categories (p_C) relative to overall food prices (P_C). Thus, the model discounts any price differences across countries due to differences in overall food prices and implicitly accounts for the cross-price effects of other foods. For instance, if dairy prices were the same in two countries, but overall food prices differed, intake would be greater in the country with the higher food-price level since dairy is *relatively* cheaper when compared to food overall. Note that equation (1) does not include higher order income and price effects (e.g., quadratic income and price-income interactions). In preliminary analysis, these higher-order terms were highly insignificant, which implied that price or income responsiveness did not depend on the level of per-capita income level.

Using equation (1), we estimated intake demand using a procedure that allowed for error correlations among observations from the same country (i.e., country-clustered errors).(39) To account for differences in preferences across countries due to cultural differences or other related factors, we included regional binary variables in the analysis (ASIA, CEE, LAC, MENA, S-ASIA, and SSA). We accounted for age and sex by allowing these factors to have a direct effect on intake, as well as an additional effect through income and prices. Thus, the beta terms (β_k^*) were expanded to account for age and sex interactions: $\beta_k^* = f(sex, age)\forall k$. Further disaggregations (education level and residence) were not considered due to estimation concerns resulting from negligible differences in SF intake across these factors. Although we used a single price index (p_C) to represent the three food categories (meats, dairy, and oils and fats), intake responsiveness with respect to the price of each food category were easily derived. Defining the conditional expenditure share and price for the *i*th food category in country *C* as s_{iC} and p_{iC}, respectively, p_C is as follows: $p_C = \sum_i s_{iC} p_{iC}$. Thus, relationships between q_{gC} and p_{iC} were derived using the estimate on the price term in equation (1) (β_2^*) and the conditional expenditure share s_{iC} as follows: $\frac{\partial q_{gC}}{\partial p_{iC}} = \frac{\partial q_{gC}}{\partial p_C}\frac{\partial p_C}{\partial p_{iC}} = \frac{\beta_2^*}{p_C} s_{iC}$.

RESULTS

Descriptive statistics and SF intake overview

Table 1 shows the descriptive statistics for the variables used in the model. Mean SF intake across all observations was 10.3% energy/d and ranged from 2.39 to 27.28. PPP-adjust real GDP per capita ranged from \$780 to \$117,245 (mean = \$22,226). The deflated price index $\left(\frac{p_C}{P_C}\right)$ ranged from 0.71 to 1.40 (mean = 1.00). Mean values for the region and sex variables reflect the country and subgroup representation in the data.(26, 33)

Figure 1 contains violin plots for SF intake by sex, age, and region based on all observations (*n* = 7,040). Violin plots use kernel densities to visualize the distribution of intake. The width of the violin plot corresponded to the probability of an observation taking a specific value of SF intake and the vertical black line in each violin plot corresponds to the median value. In general, the violin plots showed that the distribution of SF is similar across age and sex subgroups, although there was greater variation across regions. Additionally, the presence of long right tails across most subgroups suggested the presence of outliers with very high values of SF intake.(26)

While the median value for SF intake was around 10.60 % energy/d, there were notable differences (Figure 1). Median SF intake was slightly higher in females (females = 10.88, males=10.40). Across regions, median SF intake was lowest in S-Asia (6.42) and highest in HIC (13.78). Overall, the maximum value for saturated fat intake occurred in the Philippines (27.48) amongst female infants (< 1 year old), while the overall minimum occurred in Nepal (2.39) amongst females between the ages of 20 and 25. Even within regions, notable differences occurred. In HIC, for instance, intake ranged from a high of 23.02 % energy/d in France amongst female infants to 9.45 % energy/d in Portugal amongst males, age 95 years and older.(26)

Estimation results

We first estimated the model using intake values at the country level (i.e., intake averaged over all demographic subgroups) (n = 160) (See Supplemental Table 2). Since our explanatory variables (price and income) were country specific and did not vary with demographic subgroups, it was useful to examine the significance of price or income without age and sex differences. The country-level analysis also revealed the importance of each variable in explaining global differences in SF intake. For instance, Model 1 showed that regional differences accounted for a large share of intake differences across countries (Adjusted R^2 = 0.39). When regional differences were not accounted for, both income (1.03, $p < 0.01$) (Model 2) and price (-3.90, $p < 0.05$) (Model 3) were significant. When regional differences were accounted for (Model 4), price was still significant (-4.33, $p < 0.05$), but income was insignificant. The negative price estimate was consistent with economic theory (higher prices being associated with lower intake) and indicated that a unit increase in the log of price was associated with lower SF intake by 4.33 percentage points.

Since the intake variable was measured as a percent, it is important to clarify the difference between a percentage point change and percent change. For instance, intake falling from 10.83 to 6.50 % energy/d, is a 4.33 percentage point decline, but a 40% decline: -4.33 ÷ 10.83). This distinction is important when considering elasticity relationships where both intake and prices are measured in percentage. Assuming mean intake (10.83 % energy/day) as the base, intake falling by 4.33 percentage points or 40% given a unit change in the log of price (a two-fold increase) suggested a price elasticity of about -0.40. That is, SF intake declines by 0.40% for every 1.0% increase in price, which indicates minimal price sensitivity and inelastic demand. Note that this result is based on a price increase across all food categories in the price series. As discussed later in this section, intake responsiveness to the price of a particular food category (e.g., dairy) was smaller.

Estimation results for the full model (Model 4) are reported in Table 2. Other than ASIA, SF intake was significantly lower in all regions relative to HIC intake. Intake also decreased with higher age (-0.10, $p < 0.01$), but this effect was less significant with older adults. Results (Model 4) indicated a price effect of -7.16 ($p < 0.01$), where the magnitude became smaller with age (0.20, $p < 0.01$), but then increased for older populations. There was no significant difference in the price effect by sex – and like the country-level analysis – the income effect on intake was insignificant when regional differences were considered. Consequently, we did not examine income effects in detail and the price-specific measures that follow are not specific to sex.

Intake responsiveness and food prices

Using the country-level estimates from Supplemental Table 2, we derived measures of aggregate intake change with respect to price changes specific to the food categories in the SF price series (meat, dairy, and oils and fats) (Figure 2). Note that our dependent variable is SF intake from all foods, including ultra-processed food. Thus, the price effects reported in this section measure how changes in the price of meat (e.g.) affect total SF intake, not just SF intake from meat. An increase in the meat price index resulted in the largest intake decrease: -2.47 percentage points from a two-fold increase in price (IQR: -2.29 to -2.78). Assuming mean intake as the base, this implied a price elasticity of about -0.23 (i.e., a 0.23% decline for every 1.0% increase in meat prices). The next highest intake decrease was in response to the dairy price index (-1.30 percentage points and IQR: -1.01 to -1.56), implying a price elasticity of -0.12. The results for oils and fats indicate the lowest intake response to a price change (-0.55 percentage point change and IQR: -0.29 to -0.65); the elasticity with respect to the price of oils and fats is about -0.06.

Using the estimates from Table 2, we assessed intake responsive by food category, age, and region (See Figure 3). Across regions, meat prices resulted in the largest variation in SF intake, with S-Asia being the only exception. In HIC, for instance, median SF intake reductions at age 40 were 1.37, 0.78, and 0.15 percentage points, for 1% higher prices of meat, dairy, and oils and fats, respectively. In contrast, intake reductions in S-Asia at age 40 were highest for dairy prices (1.14 percentage points) followed by meat prices (0.62 percentage points) and then the price of oils and fats (0.48 percentage points). However, the IQR overlap for meat and dairy in S-Asia suggested that intake responsiveness to these two prices was not significantly different.

Across regions, there were key differences in intake responsiveness with respect to price changes. In HIC, there was no IQR overlap, suggesting significantly higher intake responsiveness to meat prices when compared to dairy prices, and diary prices compared to the price of oils and fats. Similar patterns were observed for CEE, LAC, and MENA. In SSA, however, intake changes from meat prices were significantly larger, but the estimates for dairy and oils and fats prices show considerable IQR overlap.

Results also indicated that middle-aged groups (age 40-60 years) were the least sensitive to price changes. This was consistent with expectations as the middle-aged often have higher incomes and may be less sensitive to price changes. Based on the "All Countries" estimates (upper left panel), the median intake response from a two-fold increase in meat prices was -2.10 percentage points (age 20), responsiveness then decreased to -1.32 percentage points by age 50, and then increased to -2.71 percentage points by age 80. There was a similar pattern for dairy and oils and fats prices, but the differences between age groups were not as large.

DISCUSSION

This investigation provides evidence on how differences in income and food prices might jointly influence SF consumption by sex and age across the spectrum of rich and poor countries. Both the country-level and disaggregated (age and sex) analysis indicated that intake differences due to income were insignificant. These results suggest that intake differences across countries are better explained by regional dissimilarities and not economic wellbeing as measured by per-capita income. In contrast, differences due to food prices were highly significant. Globally, a one-percent increase in prices was estimated to decrease SF intake by about 0.40%. Across regions, meat-price sensitivity of SF intake was relatively high, except for S-Asia where dairy price sensitivity of SF intake was higher. Within regions and by age, price sensitivity was lowest among middle-aged adults.

The higher sensitivity of SF intake to price changes in meat consumption suggests that fiscal policies focused on a reducing SF intake would be more effective through meat-price interventions. That said, the magnitudes of price sensitivity were small, indicating relatively inelastic demand. Thus, high taxes would be needed to reduce intake: for example, global findings suggest that a two-fold increase in meat prices (i.e., a 100% tax) is associated with decreased intake of only 2.47 percentage points. Our results are consistent with previous findings. Research has shown that fat taxes in Denmark, Hungary, and France had small and ambiguous effects on demand.(40, 41) A similar outcome was observed from the Danish fat tax experience that targeted dairy and vegetable fat sources.(42)

The findings in this study can help to inform strategies that counter worsening diets. However, our modeling cannot prove causality of price changes on intake, and thus our findings should be interpreted cautiously when informing interventions and evaluations. Furthermore, the invariability of price and income across demographic subgroups ignores differences within countries and may have affected results, although we address this issue, in part, with age and sex variable interactions. Although the lack of price data for other food categories limited our ability to parse out other intake-price relationships, to the degree that our derived SF price series based on meat, dairy, and oils and fats is representative of a "true" global SF price the aggregate price effects could be applied to other food categories.

The benefit of our analysis is the country coverage. While relationships between income, prices, and food choice have been studied, combining GDD, World Bank, and ICP data allowed for a global coverage rarely seen in food and nutrition research, allowing for comparisons across individuals in rich and poor countries and an examination of intake responsiveness by age and sex.(37, 38)

CONCLUSION

Our results provide novel global evidence on how income and prices influence SF intake by region, age, and sex. Our results confirm that the effectives of price interventions would be limited in most countries but provide evidence where interventions would be most effective if implemented (meat versus dairy or oils and fats; youth, young adults, and the elderly). These observed relationships can assist policymakers as they consider how pricing policies can be leveraged to tackle nutrition challenges.

Table 1. Descriptive statistics for study variables

Variable	Measure	Mean	Std. Dev.	Min	Max
SF intake	% energy/d	10.83	3.09	2.39	27.48
Female	Binary	0.50	0.50	0	1
Age	5-year intervals*	45.6	30.83	1	98
ASIA	Binary	0.09	0.29	0	1
CEE	Binary	0.17	0.37	0	1
HIC	Binary	0.15	0.36	0	1
LAC	Binary	0.18	0.39	0	1
MENA	Binary	0.10	0.30	0	1
S-ASIA	Binary	0.04	0.20	0	1
SSA	Binary	0.27	0.44	0	1
Real GDP per capita (PPP)	$/person	$22,226	$21,646	$780	$117,245
Deflated price	index (US=1)	1.00	0.12	0.71	1.40

SF is saturated fat. Note that n = 7,040 (160 countries × 44 demographic subgroups); n = 160 for the GDP and price index. East and Southeast Asia (ASIA), Central and Eastern Europe and Central Asia (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), Sub-Saharan Africa (SSA), and High-Income Countries/Rest of World (HIC). PPP is purchasing power parity.

Table 2 Saturated fat intake estimates using country and demographic (sex and age) level data (*n* = 7,040)

	Model 1	Model 2	Model 3	Model 4
Constant	14.64 (0.39)***	2.81 (1.73)	12.44 (2.89)***	12.01 (2.90)***
ASIA	-2.20 (1.14)*		-1.61 (1.12)	-1.61 (1.12)
CEE	-1.94 (0.48)***		-1.68 (0.51)***	-1.68 (0.51)***
LAC	-3.97 (0.49)***		-4.09 (0.65)***	-4.09 (0.65)***
MENA	-3.98 (0.52)***		-3.35 (0.55)***	-3.35 (0.55)***
S-ASIA	-7.26 (1.00)***		-6.08 (1.08)***	-6.08 (1.08)***
SSA	-4.03 (0.49)***		-3.47 (0.81)***	-3.47 (0.81)***
Female	0.48 (0.04)***	0.48 (0.04)***	0.48 (0.04)***	0.06 (0.31)
Age	-0.04 (0.01)***	-0.04 (0.008)***	-0.04 (0.01)***	-0.10 (0.04)***
Age^2	0.00 (0.00)***	0.00 (0.00)***	0.00 (0.00)***	0.00 (0.00)***
ln(Y)		0.93 (0.18)***	0.19 (0.26)	0.24 (0.27)
Female × ln(Y)				0.04 (0.04)
Age × ln(Y)				0.01 (0.00)
Age^2 × ln(Y)				0.00 (0.00)***
ln(P)		-3.73 (1.59)***	-4.32 (1.88)**	-7.16 (2.29)***
Female × ln(P)				-0.13 (0.14)
Age × ln(P)				0.20 (0.06)***
Age^2 × ln(P)				0.00 (0.00)***
Adjusted R^2	0.34	0.18	0.36	0.37

Dependent variable is saturated fat intake in % energy/d. Robust standard errors (clustered by country) are in (parenthesis). *$p\leq0.10$; **$p\leq0.05$; ***$p\leq0.01$. East and Southeast Asia (ASIA), Central and Eastern Europe (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), and Sub-Saharan Africa (SSA). Y is real GDP per capita, purchasing-power-parity adjusted. P is an inflation adjusted price index for meats, dairy products and eggs, and oils and fats.

List of Figures

Figure 1. Comparison of percentage energy from saturated fat among individuals in sex, age, and country-specific strata globally and across world regions. Note that *n* = 7,040 (160 countries × 44 demographic subgroups). Female *n* = 3,520; male *n* = 3,520.
Age categories: Age<=19 *n* = 1,920; Age>=60 *n* = 2,560; for all other age groups *n* = 640;
Regions: South Asia *n* = 308; Sub-Saharan Africa *n* = 1,892; Central and Eastern Europe *n* = 1,188; Middle East and North Africa *n* = 704; Latin America and Caribbean *n* = 1,276; High-Income Countries *n* = 1,056; Asia *n* = 616.
Source: Global Dietary Database, 2018.

Figure 2. Change in saturated fat intake when prices double for each food category. Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR, error bars are min and max values, and data points are outliers.

Figure 3. Change in saturated fat intake when prices double for each food category by select region and age. Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR and error bars are min and max values.

Contributorship statement

AA and AM contributed to the study conceptualization; JR, PS, JZ, FC, JEM VM, and DM contributed to data cu and data curation; AA and AM contributed to the methodology and economic analysis; AA, AM, JNY, DM contributed to writing (original draft); AA, AM, and JNY contributed to writing (review and editing); AA and AM are joint senior authors. Collaborators are listed in the supplemental appendix.

Competing interests

There are no competing interests for any author.

Funding

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Data sharing statement

The expenditure and price data are available in a public, open access repository managed by the World Bank. The intake data can be obtained from the Global Dietary Database (GDD) through a data user agreement. The GDD is maintained by the Global Nutrition and Policy Consortium at Tufts Friedman School of Nutrition Science and Policy.

Ethical statement

This study does not involve human participants.

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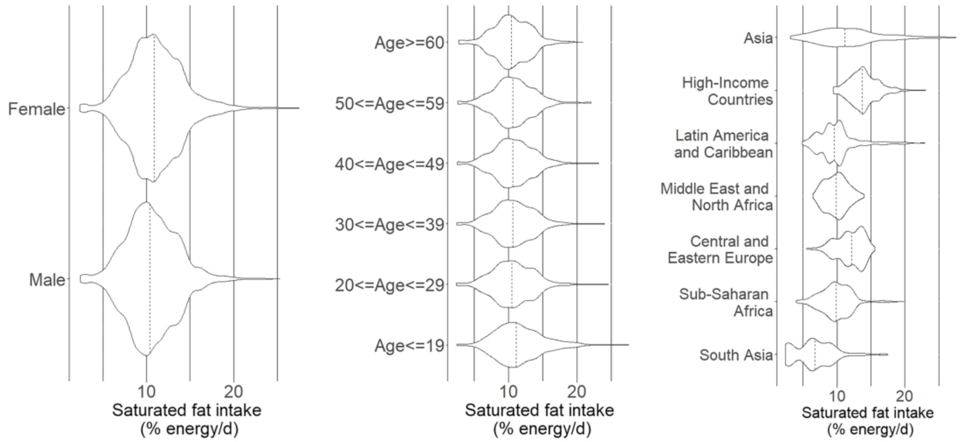

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203x101mm (300 x 300 DPI)

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Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR, error bars are min and max values, and data points are outliers.

145x94mm (300 x 300 DPI)

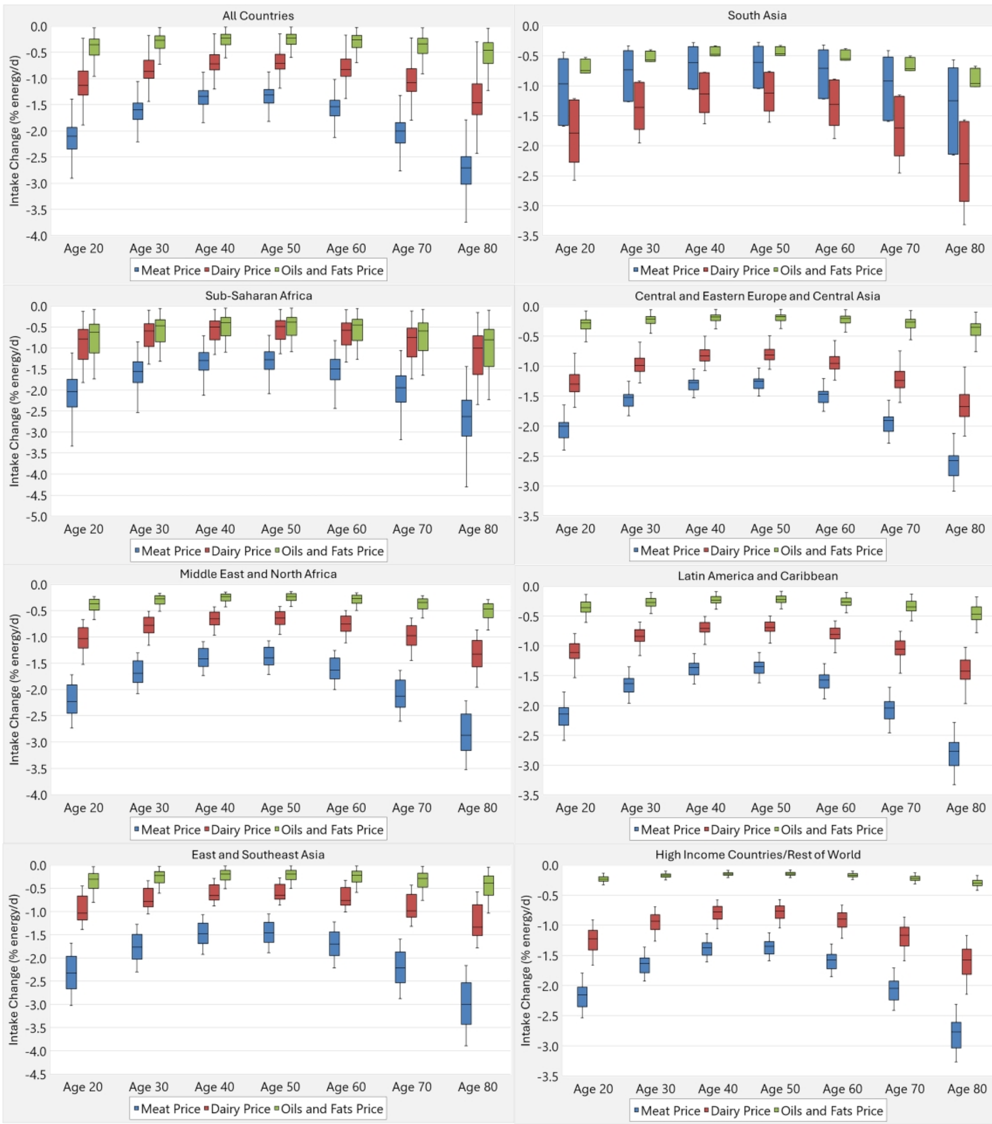


Figure 3. Change in saturated fat intake when prices double for each food category by select region and age. Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR and error bars are min and max values.

381x426mm (300 x 300 DPI)

Supplemental Appendix

Supplemental Table 1. Countries included in study by defined region

Region	Countries
Southeast Asia, East Asia, and High-Income Asia Pacific (ASIA) 14 countries	Brunei Darussalam, Cambodia, China, Fiji, Indonesia, Japan, Laos, Malaysia, Myanmar, Philippines, Singapore, South Korea, Thailand, and Vietnam.
Central Europe, Eastern Europe, and Central Asia (CEE) 27 countries	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Macedonia, Moldova, Mongolia, Montenegro, Poland, Romania, Russia, Serbia, Slovak Republic, Slovenia, Tajikistan, and Ukraine.
Latin America and the Caribbean (LAC) 29 countries	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, St. Lucia, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, and Uruguay.
Middle East and North Africa (MENA) 17 countries	Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, Turkey, United Arab Emirates, and West Bank and Gaza.
South Asia (S-ASIA) – 7 countries	Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.
Sub-Saharan Africa (SSA) 43 countries	Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo DR, Congo, Côte d'Ivoire, Djibouti, Equatorial Guinea, Eswatini, Ethiopia Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, Sudan, Tanzania, Togo, and Uganda.
High Income/Rest of World (HIC) 24 countries	Australia, Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and United States.

Supplemental Table 2. Saturated fat intake estimates using country level data (*n* = 160)

	Model 1	Model 2	Model 3	Model 4
Constant	13.66 (0.46)***	1.03 (1.75)	10.81 (0.23)***	12.05 (2.87)***
ASIA	-1.19 (0.76)			-0.66 (0.81)
CEE	-1.36 (0.63)**			-1.16 (0.67)*
LAC	-4.07 (0.62)***			-4.26 (0.74)***
MENA	-3.43 (0.73)***			-2.85 (0.77)***
S-ASIA	-7.41 (0.97)***			-6.34 (1.10)***
SSA	-4.07 (0.58)***			-3.65 (0.90)***
ln(Y)		1.03 (0.18)***		0.14 (0.26)
ln(P)			-3.90 (1.94)**	-4.33 (1.89)**
Adjusted R^2	0.39	0.16	0.02	0.41

Dependent variable is saturated fat intake measured in % energy/d. Robust standard errors are in (parenthesis). *$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$. East and Southeast Asia (ASIA), Central and Eastern Europe and Central Asia (CEE), Latin America and Caribbean (LAC), Middle East and North Africa (MENA), South Asia (S-ASIA), and Sub-Saharan Africa (SSA). Y is real GDP per capita, purchasing-power-parity adjusted. P is an inflation adjusted price index for meats, dairy products and eggs, and oils and fats.

Income, Price, and Expenditure Data Across Countries

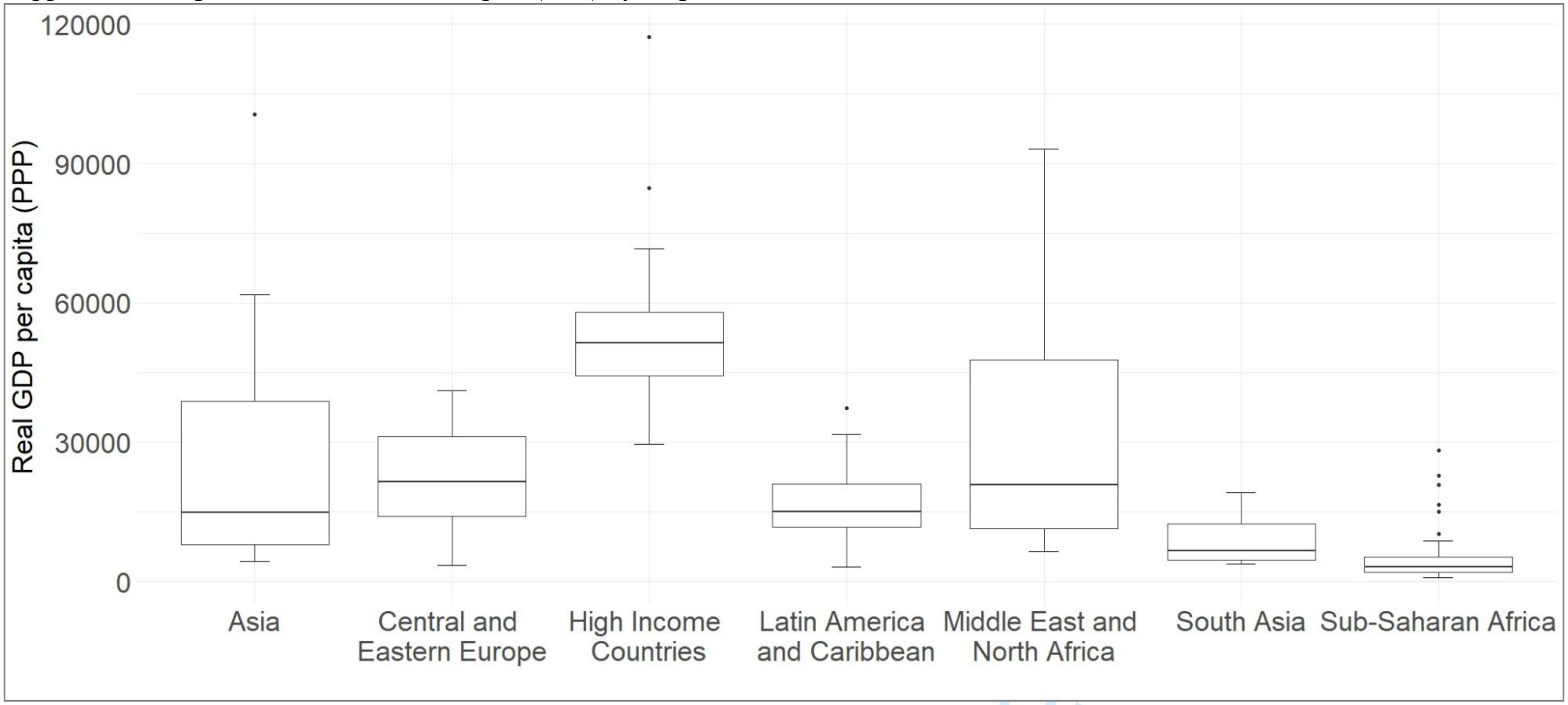
Supplemental Figures 1 – 3 contain box plots by region for the country-specific explanatory variables.

Supplemental Figure 1 shows real GDP per capita (PPP) for the seven regions in our study. The highest GDP region is High-Income Countries, which is unsurprising. The median income for High-Income Countries was $51,432 per person. In contrast, Sub-Saharan Africa had the smallest real GDP per capita, with a median value of $3,147.

Supplemental Figure 2 shows expenditure shares for the contributing food categories: meats, dairy, and oils and fats by region. Food expenditure shares were derived from the World Bank International Comparison Program (ICP) which allows for global spending comparisons by standardizing expenditures to a common currency (U.S. Dollars). Across regions, meat expenditures were the highest food expenditure category, except for South Asia. In South Asia, the median dairy food expenditure share was the highest at 0.47 and the interquartile range (IQR) was 0.34 to 0.60. Asia, Latin America and Caribbean, and Sub-Saharan Africa were the regions with the highest median expenditures for meats at 0.65 and an IQR from 0.55 to 0.74. South Asia has the lowest meat expenditure share at 0.31 with an IQR from 0.16 to 0.48. Apart from South Asia, dairy expenditure shares represented the second highest expenditure shares across regions. Oils and fats account for the smallest share of food expenditures compared to the other food categories for all regions.

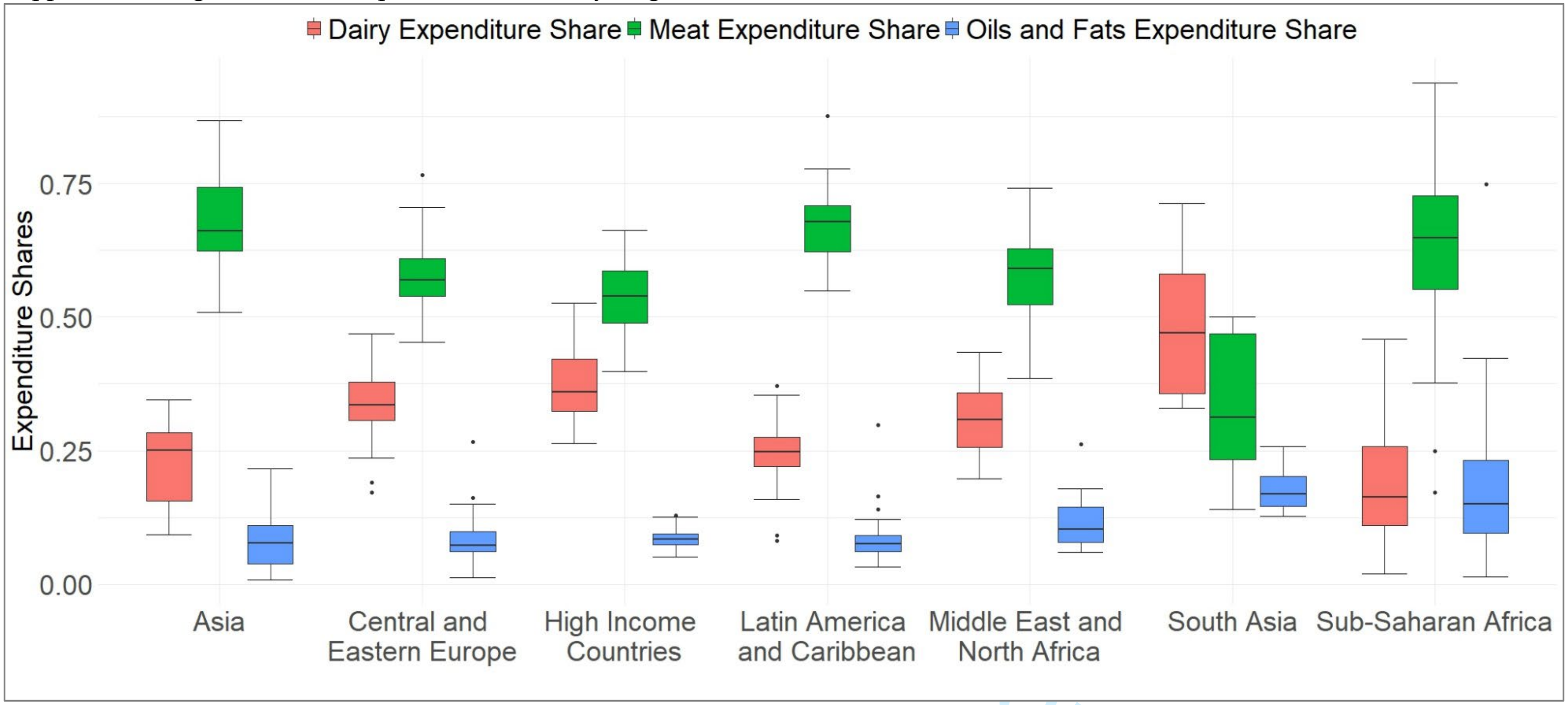
Supplemental Figure 3 shows the price indexes for meat, dairy, and oil and fats, and the weighted average price index (weighted based on the expenditures in Supplemental Figure 2) by region. The weighted average food price index is the sum of each price index times the expenditure share for the corresponding food category. Most regions exhibit relatively similar values across price index categories and shorter "whiskers" include Central and Eastern Europe, Middle East and North Africa, and South Asia. Alternatively, some regions (High-Income Countries, Latin America and Caribbean, and Sub-Saharan Africa) exhibit a greater range between the IQR and maximum and minimum values and greater variation in prices. For example, in the Latin American and Caribbean region, the dairy price index has a median value of 134.49 and IQR of 98.60 to 156.59. In contrast, the Central and Eastern Europe region has a dairy price index median value of 86.58 and IQR range of 75.84 to 93.50.

Supplemental Figure 1. Real GDP Per Capita (PPP) by Region



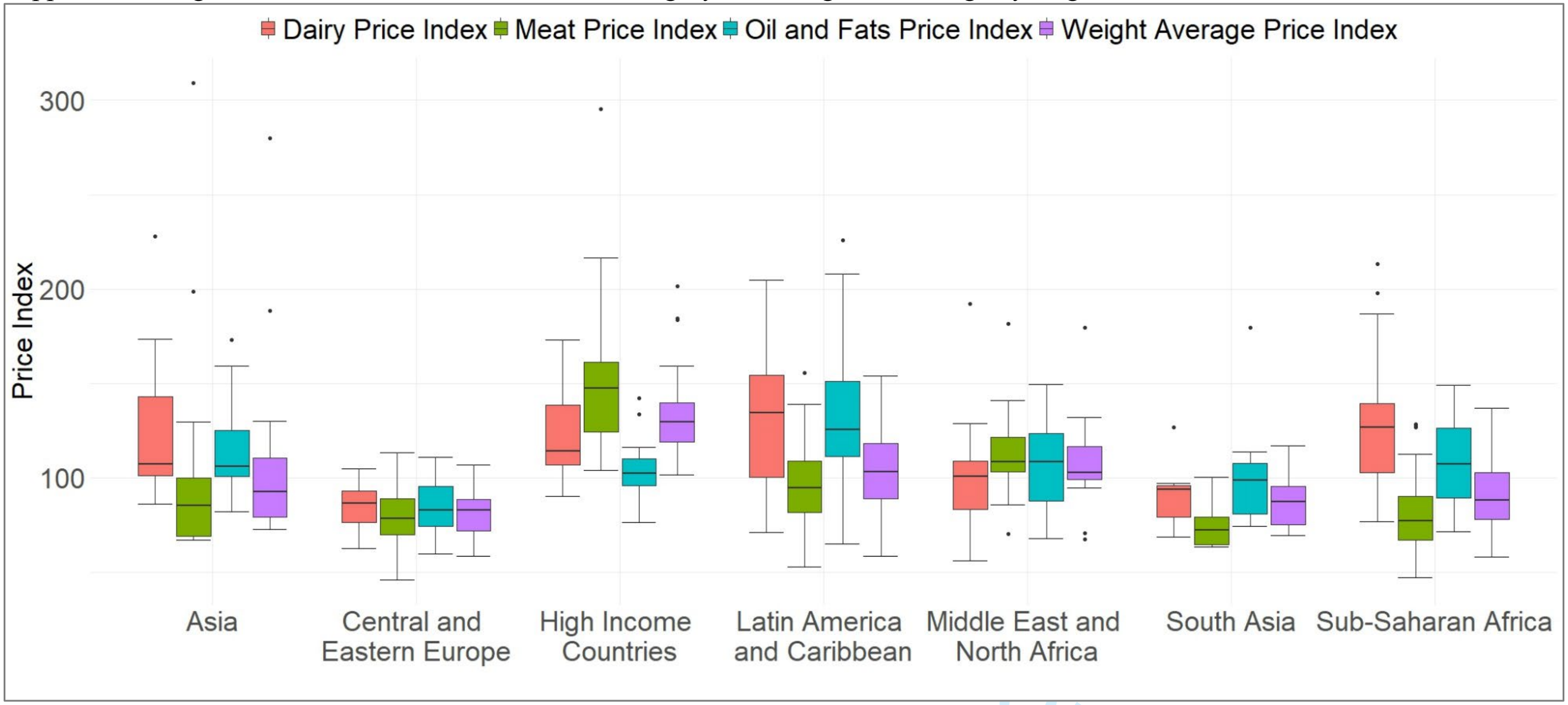
Source: Authors' estimates using income data from the World Bank Development Indicators.

Supplemental Figure 2. Food Expenditure Shares by Region



Source: Authors' estimates using income data from the World Bank International Comparison Program.

Supplemental Figure 3. Price Indexes for each Food Category and Weighted Average by Region



Source: Authors' estimates using income data from the World Bank International Comparison Program.

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CHEERS 2022 Checklist

Topic	No.	Item	Location where item is reported
Title			
	1	Identify the study as an economic evaluation and specify the interventions being compared.	Examining the influence of price and income on global saturated fat intake: evidence from 160 countries
Abstract			

Topic	No.	Item	Location where item is reported
	2	Provide a structured summary that highlights context, key methods, results, and alternative analyses.	Introduction When considering proposals to improve diets, it is important to understand how factors like price and income can affect saturated fat intake and demand. This is even more important when considering economic interventions on a global scale. In this study, we examine and estimate the influence of price and income on intake across 160 countries, by age and sex, and derive sensitivity measures (elasticities) that vary by age, sex, and geographic region. Methods Secondary data were used for this analysis. Intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank). We estimated intake responsiveness to income and prices, accounting for differences by world region, age, and sex. Results Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. Results indicated that the highest price sensitivity was due to meat consumption. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were e 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Intake differences due to income were insignificant. Conclusion The results of this study show heterogeneous associations among prices and intake within and across countries. Policymakers should consider these heterogenous effects as they address global nutrition and health challenges.
Introduction			

Topic	No.	Item	Location where item is reported
Background and objectives	3	Give the context for the study, the study question, and its practical relevance for decision making in policy or practice.	To help address these knowledge gaps, this investigation assessed how price and country income relate to SF intake. We used nationally representative intake estimates from the 2018 Global Dietary Database to estimate how per capita income and prices jointly relate to SF intake by age and sex globally. Since nutrients are found in food, examinations of nutrient demand must consider food source demand, with price and income as explanatory variables.(15-17) Using price and expenditure data from the World Bank International Comparison Program, we constructed a global price series based on three food categories: meat, dairy, and oils and fats. This series sufficiently explained SF intake differences across countries and allowed for assessing the relationships of per capita income and price in each food category.
Methods			
Health economic analysis plan	4	Indicate whether a health economic analysis plan was developed and where available.	No. This does not apply.
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	Secondary data were used for this analysis. Intake data by age, sex, and country were obtained from the 2018 Global Dietary Database. These data were then linked to global price data for select food groups from the World Bank International Comparison Program and income data from the World Development Indicators Databank (World Bank). We estimated intake responsiveness to income and prices, accounting for differences by world region, age, and sex.
Setting and location	6	Provide relevant contextual information that may influence findings.	Global study - 160 countries.
Comparators	7	Describe the interventions or strategies being compared and why chosen.	Economic analysis using secondary data. This does not apply.

Topic	No.	Item	Location where item is reported
Perspective	8	State the perspective(s) adopted by the study and why chosen.	• It is generally understood that affordability is an important driver of food demand, underscoring the importance of income and prices in dietary choices. Research has confirmed significant associations among income, prices, and food demand. What is missing, however, is a better understanding of how price and income influence actual nutrient intake, particularly on a global scale, and how price and income relationships could vary by demographics within and across countries.
Time horizon	9	State the time horizon for the study and why appropriate.	2017-2018
Discount rate	10	Report the discount rate(s) and reason chosen.	N/A
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	N/A
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	N/A
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	See 5.
Measurement and valuation of resources and costs	14	Describe how costs were valued.	Income values were in $US.
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	Prices were indexes where World = 100.

Topic	No.	Item	Location where item is reported
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	To estimate SF intake demand, we used a semi-log functional form that has been proven to be consistent with economic theory and rational consumer behavior.(25, 26) Many studies have used a double-log form.(27) However, a problem with the double-log form is that significant intake differences across subgroups can be lost in log conversions. A semi-log relationship allowed for a better assessment of subgroup effects on intake responsiveness.
Analytics and assumptions	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	Econometric analysis assuming country clusters.
Characterising heterogeneity	18	Describe any methods used for estimating how the results of the study vary for subgroups.	Econometric analysis assuming country clusters.
Characterising distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	Intake differences due to price were highly significant, with a one percent increase in price associated with lower SF intake (% energy/d) of about 4.3 percentage points. Results indicated that the highest price sensitivity was due to meat consumption. We also find significant differences across regions. In high-income countries, median (age 40) intake reductions were e 1.4, 0.8, and 0.2 percentage points, given a one-percent increase in the price of meat, dairy, and oils and fats, respectively. Intake differences due to income were insignificant.
Characterising uncertainty	20	Describe methods to characterise any sources of uncertainty in the analysis.	Not applicable
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communities, or stakeholders (such as clinicians or payers) in the design of the study.	N/A
Results			

Topic	No.	Item	Location where item is reported
Study parameters	22	Report all analytic inputs (such as values, ranges, references) including uncertainty or distributional assumptions.	See Results
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	See Results
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable.	N/A
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	N/A
Discussion			
Study findings, limitations, generalisability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could affect patients, policy, or practice.	Discussion
Other relevant information			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	End of manuscript
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	End of manuscript

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