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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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ABSTRACT

Objective When considering proposals to improve diets, it is important to understand how factors like price and income can affect saturated fat (SF) 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 Programme and income data from the World Development Indicators Databank (World Bank).

Results Intake differences due to price were highly significant, with a 1% increase in price associated with a 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 1% 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 heterogeneous 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 comparisons across the primary contributing food categories, which included the price of meat, dairy, and oils and 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, a 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-income and middle-income countries, and very low SF intake is associated with higher risk of haemorrhagic stroke, potentially due to increased cerebral vascular fragility.[3 4]

Governments and international organisations have proposed economic interventions to improve diets and health outcomes.[5–8] The associated intake and health responses from the taxation of unhealthy foods have 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 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 (ie, 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 is there any 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 (GDD) 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 Programme, 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 the assessment of the relationships between 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 per cent of total energy per day (% energy/d) for a representative individual was obtained from the 2018 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 on individual-based dietary intakes for key food and nutrient categories at the national and subnational levels. GDD intake estimates are based on the results of existing surveys (1248 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 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 Programme (ICP) were used to derive an 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 SF 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 savoury 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 well-being. PPPs are spatial price deflators that make it possible to compare expenditures across economies.[31] PLIs are PPPs standardised to a common currency (generally the US 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 allows 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 online supplemental table 1 by geographical region (see the online supplemental file 1): East Asia, Southeast Asia, and 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) (seven countries); Sub-Saharan Africa (SSA) (43 countries) and high-income/rest of world (HIC) (24 countries). HIC is an aggregation of HIC 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 online supplemental file 1 for a more detailed discussion of the price, expenditure and income data by geographical 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 semilog functional form that has been proven to be consistent with economic theory and rational consumer behaviour.[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 semilog relationship allowed for a better assessment of subgroup effects on intake responsiveness. Also, it has been shown that semilog 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 (ie, 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.[19 20]

Let q_{gC} represent the % energy/d from SF 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:

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

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 with food overall. Note that equation (1) does not include higher-order income and price effects (eg, 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.

Using equation (1), we estimated intake demand using a procedure that allowed for error correlations among observations from the same country (ie, country-clustered errors).[37] 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 was easily derived. Defining the conditional expenditure share and price for the ith 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, the relationships between q_{gC} and p_{iC} were derived using the estimate of 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

The descriptive statistics for the variables used in the model are shown in table 1. The mean SF intake across all observations was 10.83% energy/d and ranged from 2.39 to 27.48. PPP-adjusted 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]

Violin plots for SF intake by sex, age and region based on all observations (n=7040) are shown in figure 1. Violin plots use kernel densities to visualise 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 corresponded 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 and 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 SF intake

Table 1 Descriptive statistics for study variables

Variable	Measure	Mean	SD	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

Note that n=7040 (160 countries×44 demographic subgroups); n=160 for the GDP and price index.
*5-year intervals apply to age ≥ 10. Younger age groups include age ≤ 1, 2, 5, and 8.
ASIA, East and Southeast Asia; CEE, Central and Eastern Europe and Central Asia; GDP, gross domestic product; HIC, high-income countries/rest of world; LAC, Latin America and Caribbean; MENA, Middle East and North Africa; PPP, purchasing power parity; S-ASIA, South Asia; SF, saturated fat; SSA, Sub-Saharan Africa.

occurred in the Philippines (27.48) among female infants (<1 year old), while the overall minimum occurred in Nepal (2.39) among 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 among female infants to 9.45% energy/d in Portugal among males, aged 95 years and older.[26]

Estimation results

We first estimated the model using intake values at the country level (ie, intake averaged over all demographic subgroups, n=160) (see online 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), the 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

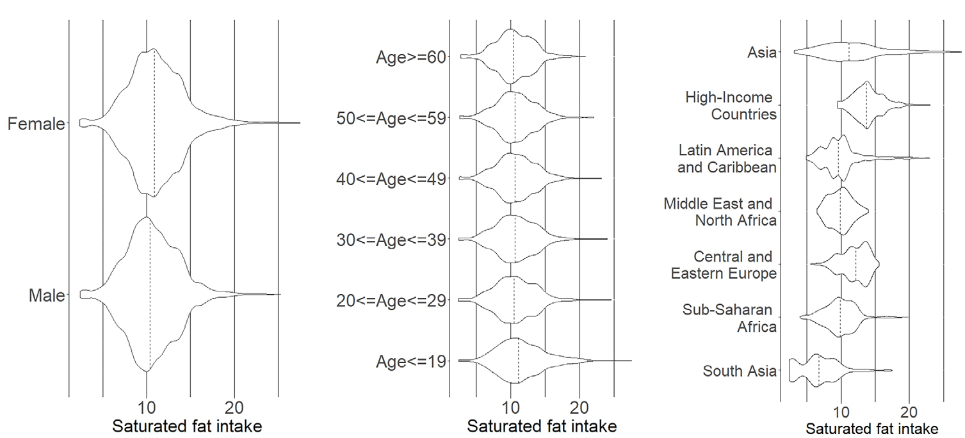

Figure 1 Comparison of percentage energy from saturated fat among individuals in sex, age and country-specific strata globally and across world regions. Note that n=7040 (160 countries×44 demographic subgroups). Female: n=3520 and male: n=3520. Age categories: age ≤19, n=1920; age ≥60, n=2560 and for all other age groups, n=640. Regions: South Asia, n=308; Sub-Saharan Africa, n=1892; Central and Eastern Europe, n=1188; Middle East and North Africa, n=704; Latin America and Caribbean, n=1276; high-income countries n=1056 and Asia, n=616. Source: Global Dietary Database, 2018.

Table 2 Saturated fat intake estimates using country and demographic (sex and age) level data (n=7040)

	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

The dependent variable is saturated fat intake in % energy/d. Robust SEs (clustered by country) are in parenthesis; *p≤0.10; **p≤0.05 and ***p≤0.01. 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.
ASIA, East and Southeast Asia; CEE, Central and Eastern Europe; LAC, Latin America and Caribbean; MENA, Middle East and North Africa; S-ASIA, South Asia; SSA, Sub-Saharan Africa.

log of price was associated with lower SF intake by 4.33 percentage points.

Since the intake variable was measured as a per cent, it is important to clarify the difference between a percentage point change and a per cent 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 twofold increase), suggested a price elasticity of about −0.40. That is, SF intake declines by 0.40% for every 1% 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 (eg, 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 online 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 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 twofold increase in price (IQR: −2.29 to −2.78). Assuming mean intake as the base, this implied a price elasticity of about −0.23 (ie, a 0.23% decline for every 1% 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),

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.

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 responsiveness 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 with dairy prices, and diary prices compared with 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 groups 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 twofold 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 well-being as measured by per-capita income. In contrast, differences due to food prices were highly significant. Globally, a 1% increase in prices was estimated to decrease SF intake by about 0.40%. Across regions, the meat-price sensitivity of SF intake was relatively high, except for S-ASIA where the 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 reducing SF intake would be more effective through

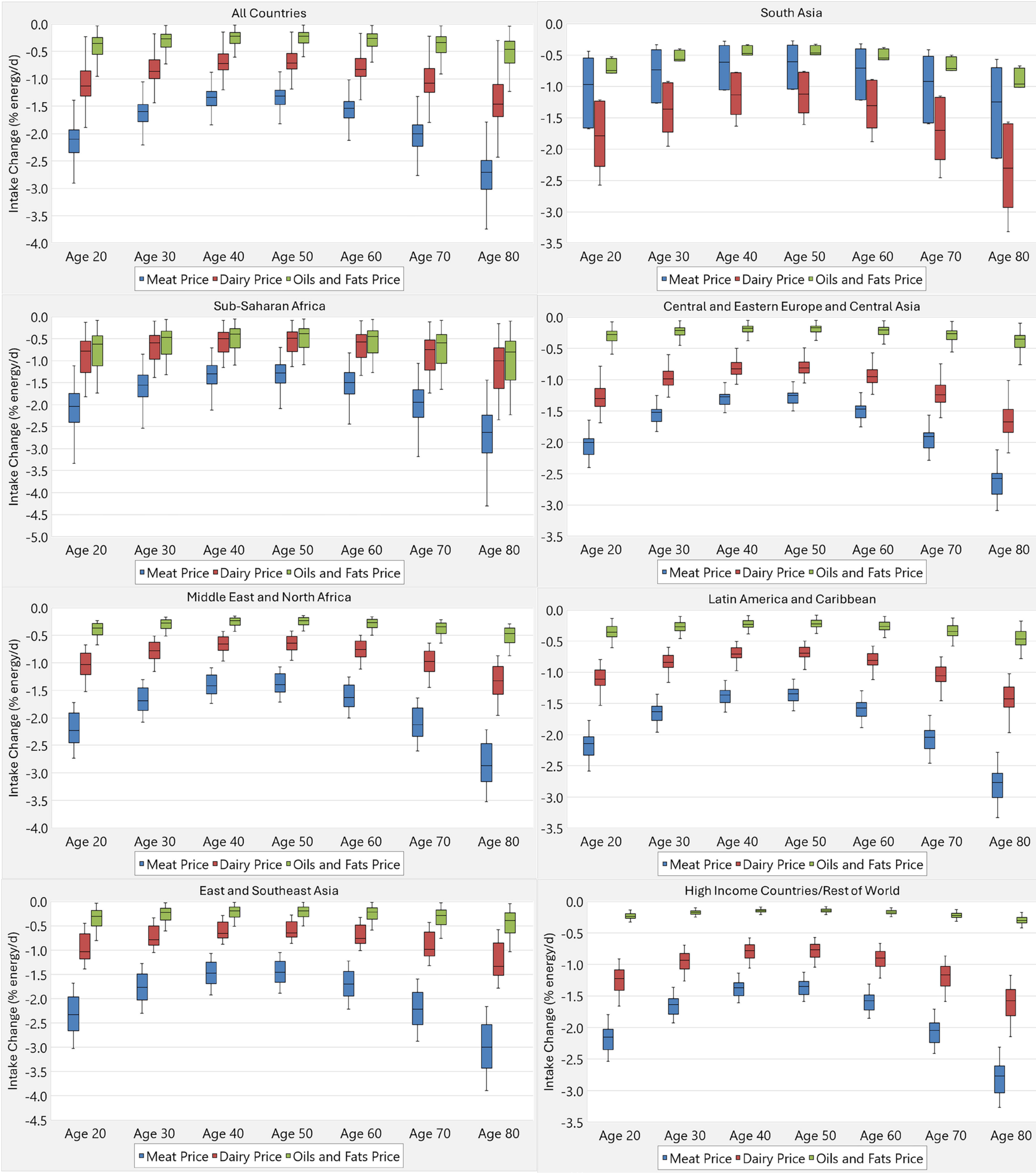

Figure 3 Change in saturated fat intake when prices double for each food category by select region and age. Intake change values measure the change in % energy/d from saturated fat. Boxes denote the median value and IQR, and error bars are min and max values.

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 twofold increase in meat prices (ie, 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.[38 39] A similar outcome was observed from the

Danish fat tax experience that targeted dairy and vegetable fat sources.[40]

The findings in this study can help to inform strategies that counter worsening diets. However, our modelling 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.[19 20]

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 effectiveness of price interventions would be limited in most countries but provide evidence of where interventions would be most effective if implemented (meat vs 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.

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