Spring 5-15-2020

Pillars of the Nutrition Transition: The Global Impacts of Ultra-Processed Foods and Beverages on Overweight and Obesity and National Nutrient Supplies

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Recommended Citation

Eaton, Jacob, "Pillars of the Nutrition Transition: The Global Impacts of Ultra-Processed Foods and Beverages on Overweight and Obesity and National Nutrient Supplies" (2020). *Arts & Sciences Electronic Theses and Dissertations*. 2180.
https://openscholarship.wustl.edu/art_sci_etds/2180

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Pillars of the Nutrition Transition: The Global Impacts of Ultra-Processed Foods and Beverages on Overweight and Obesity and National Nutrient Supplies

by
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A dissertation presented to
The Graduate School
of Washington University in
partial fulfillment of the
requirements for the degree
of Doctor of Philosophy

May 2020
St. Louis, Missouri

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Acknowledgments

I am grateful for the mentorship of Lora Iannotti, who first took me on as a research assistant after a long conversation about food and nutrition in Cap-Haitien, Haiti, now six years past. Since then, she's provided steadfast support and made sure I don't use too many subjective statements about the state of the global food systems. Thanks to Doug Luke for convincing me that R was the best route and providing the guidance for the multi-level models that follow. I am thankful for the feedback and support of the rest of my committee.

I am indebted (not literally, praise be) to the financial support of the Brown School and to McDonnell International Scholars Academy. The former changed the direction of my life after my whim of an application to the MPH program back in 2013. The latter allowed me to complete this dissertation during an extra year after I decided to more or less entirely change course in the third year of my PhD – and provided tremendous travel and learning opportunities throughout. Without the social and emotional support of Karishma Furtado, Jessica Levy, Jenny Shutek, Sara Malone, Ellis Ballard, Natalicio Serrano, and Melissa Chapnick, this would have been much harder to write. My deepest gratitude and love for Kasey Miller - for your joy, for being a sounding board, a shoulder, and the impetus to pack up my St. Louis life to finish this dissertation from a noisy but light-filled California apartment. Our plans never turn out as tasty as reality.

Jake Eaton

San Francisco, California

May 2020

ABSTRACT OF THE DISSERTATION

Pillars of the Nutrition Transition: The Global Impacts of Ultra-Processed Foods and Beverages Overweight and Obesity and National Nutrient Supplies

by

Jacob Eaton

Doctor of Philosophy in Public Health Sciences

Washington University in St. Louis, 2020

Assistant Professor Lora Iannotti, Chair

Malnutrition in some form impacts nearly one-third of the global population. Across the world, countries are undergoing the "nutrition transition" from traditional and largely unprocessed diets to Western-style, energy-dense diets. At the same time, rates of overweight and obesity and diet-related chronic diseases continue to climb. Ultra-processed foods (UPF), sugar-sweetened beverages (SSB), and vegetable oils are three of the foods driving the nutrition transition. This dissertation calculates changes in the global food supply between 1961 and 2013 and quantifies the influence of UPF and SSB (as measured through sales) on national nutrient supplies between 2005 and 2013 and trends in adult and child and adolescent BMI, overweight, and obesity between 2005 and 2015. Globally, the fatty acid (FA) supply has grown larger and more heavily weighted towards omega-6 FA, while growing less diverse as a result of vegetable oil production. UPF and SSB sales are associated with country nutrient supplies that are higher in calories, carbohydrates, and total fat. Sales also predict increases in average BMI for most groups and increases in overweight and obesity prevalence for some groups. This national-level analysis strengthens the argument for global and national level regulation of UPF and SSB.

Chapter 1: Introduction

Background and Significance

Malnutrition and the nutrition transition

Malnutrition impacts nearly one-third of the global population. Among all risk factors in the global burden of disease, malnutrition ranks the highest.[1] Nearly every country is experiencing a substantial public health threat caused by some form of malnutrition, and many countries are facing a triple burden in the form of a high prevalence of undernutrition, nutrient deficiency, and overweight and obesity.[2,3] As the global economy grows, much of the world is experiencing a "nutrition transition" – significant shifts in dietary consumption and energy expenditure which come as countries move from traditional and mostly unprocessed diets to Western-style, energy-dense diets.

As the nutrition transition progresses within a country, rates of undernutrition (such as stunting, wasting, or underweight) tend to decrease, and overweight and obesity tend to increase. Between 1990 and 2011, the global prevalence of childhood stunting [height-for-age Z score (HAZ) of - 2 or lower] decreased 35%, from 40% to 26%. Between 1980 and 2011, the global age-standardized prevalence of obesity (BMI ≥ 30 kg/m^2) nearly doubled, from 6.4% to 12.0%. As the most recent Lancet report on overweight and obesity cautions, "not only is obesity increasing, but no national success stories have been reported in 33 years."

Indeed, there is little evidence for national food systems in which decreasing rates of undernutrition are not accompanied by increasing rates of overweight and obesity. One likely reason is that as nutrient availability and food diversity increase, so too does higher consumption of energy-dense foods. Western-style, energy-dense diets are characterized by higher consumption of three food categories in particular: vegetable oils, higher-fat meats, and ultra-processed foods.[4] While a wealth of epidemiological research and nutrition interventions have focused on these foods at the individual level, an understanding of how these foods have changed dietary supplies at the global and country-level represents a gap in the literature on nutrition and food systems: What has been the impact of the global growth on these pillars of the nutrition transition on national food and nutrient supplies? Do they have identifiable impacts on overweight and obesity at the country level?

Vegetable oils: the first pillar in the nutrition transition

In the popular imagination, the nutrition transition begins with increased consumption of meat within a country. Far more common, however, is an increase in the production or import and consumption of vegetable oils, due to their inexpensiveness, portability, and durability – as well as palatability and robust marketing schemes.[4] Reasons for this are myriad, but the history of nutrition and dietary guidelines offers one leading cause. A series of studies conducted in the 1950s and 1960s showed that diets high in polyunsaturated fatty acids (PUFA) and low in saturated fat were associated with a reduction in cardiovascular mortality.[5–7] Vegetable oils, which are low in saturated fat and high in PUFA, were promoted as a healthy alternative to cooking fats like butter and lard.[8] Over the past half-century, as the global land devoted to vegetable oil production has tripled and prices have dropped, consumption of vegetable oils per capita has increased more than any other food group, with 80% coming from soybean, palm, and canola.[9,10]

Growing epidemiological evidence, however, suggests that this shift in dietary fat preferences has had unintended consequences on global diets and human health. Humans likely evolved in environments in which the ratio of the two main PUFA – *n-6 ('omega-6)* and *n-3 (omega-3)* was balanced close to 1:1.[11–13] Today, that ratio in industrialized countries is estimated to be between 6:1 and 20:1 – to the vast extent a result of vegetable oil consumption.[14,15] Higher *n*-6:*n-3* FA acids ratios are associated with a range of adverse health outcomes. The ratio of *n-6*:*n-3* fatty acids in the diet, for example, may serve as a better predictor of cardiovascular disease (CVD) than saturated fat consumption.[16,17] Higher *n*-6:*n-3* ratios are further associated with an increased risk of obesity,[18] mortality from CVD,[16,17,19], and multiple forms of cancer,[20–23] as well as exacerbating the symptoms of a range of other health conditions including asthma, Crohn's disease, and rheumatoid arthritis.[24]

Vegetable oils high in PUFA (such as soybean) are less stable than saturated fats. When these oils are heated over 180°C for frying, they undergo oxidation, forming a range of secondary byproducts such as aldehydes. Consumption or inhalation of these lipid-oxidation products is associated with increased risk of cancer and cardiovascular disease.[25–27] Studies conducted in varied contexts has shown that much of the cooking oil used by restaurants and street vendors have levels of oxidation products exceeding accepted toxicological ranges.[28,29]

Vegetable oils have played a substantial role in increasing *n-6*:*n-3* ratios, although to what extent has not been analyzed on a global level. Their growth represents the largest increase in calories and fat than any other food group over the past half-century.[10] Unlike meat, which has also grown substantially in the global food supply, vegetable oils lack protein and micronutrients, which are still less available in low-and-middle-income countries. Moreover, they now form an "invisible fat"[30] which comprises a significant portion of ultra-processed foods.

Ultra-processed foods and sugar-sweetened beverages are becoming the central pillar in the nutrition transition

As staple cereals and oil crops have grown in production, their price has decreased. In concert with the development of advanced food processing techniques, low vegetable oil prices underpin a global food environment increasingly dominated by ultra-processed foods (UPF).[31] Ultra-processed foods are products made from processed substances extracted or refined from whole foods. These include oils, hydrogenated oils and fats, flours and starches, variants of sugar, and some remnants of animal foods – with little or no whole foods included.[31] UPF are now entrenched in the global food system: in some high-income countries, they comprise over 50% of all calories consumed,[32] and consumption are growing across low- and middle-income countries (LMICs) as well.[33]

Individual-level epidemiological analyses have shown how ultra-processed foods are changing individual dietary patterns – increasing calories, fat, and sugar consumed. These studies are based on national level dietary surveys and have lacked standard methodology for classifying food products according to the processing level. Euromonitor collects data on the sales of processed foods and sugar-sweetened beverages from 2005;[34] researchers have used descriptive statistics to delineate their prominence within individual countries and spread globally.[35–37] However, this data set has not been used to test whether and how-ultra processed foods have changed nutrient availability or impacted levels of overweight and obesity.

Sugar-sweetened beverages are drinks with added sugar. The vast majority of SSB are carbonates (or soda), with a small percentage of fruit-like drinks, energy drinks, or sweetened coffee and tea.[34] SSB comprise a smaller but still significant portion of the global diet – close to 5 oz per day, on average, with substantially higher consumption in adults between age 20-39 (8 oz), and in children .[38] Less data are available for children, but in some high-income contexts, children age 2-19 consume more calories from SSB than adults.[39] Using nationally representative dietary surveys, Singh et al.[38] found consumption is highest between ages 20 and 39, on average, 0.94 8-oz servings/day for women and 1.04/8oz servings per day for men. Consumption is also estimated to be higher in upper-middle countries (0.80 servings per day), and in lower-middle-income countries (0.59 servings per day) than in high-income countries (0.51 servings per day) and low-income countries (0.35 servings per day).

Health Outcomes, Intervention Research, and Gaps in the Evidence Base

The impacts of high UPF consumption on health are well documented in both children and adults, including adverse lipid profiles,[40], increased obesity[32,41–43], and a wide range of other non-communicable diseases (NCDs).[44] Data from 19 European countries shows a significant positive association between household availability of UPF and prevalence of obesity among adults.[32]After adjusting for confounders including national income, physical activity, and smoking, each percentage point increase in household availability of UPF resulted in an increase of 0.25 percentage points in obesity prevalence. A similar trend is seen across Latin America, where each 20-kg increase in average annual sales per capita of UPF (which ranged from 40kg to 200kg depending on country and year) was associated with an increase of 0.28kg/m^2 in age-standardized BMI scores.[42]

The same trend is seen in individual studies. In Brazil, adults in the highest quintile of UPF consumption showed significantly higher body-mass-index (0.94 kg/m2; 95% CI: 0.42,1.47) and higher odds of being obese (OR=1.98; 95% CI: 1.26,3.12) compared with those in the lowest quintile of consumption[43] In a small cohort study in Brazil with 345 children of low socioeconomic status, mean percentage intake of UPF was 42.6% at preschool age (3-4 years) and 49.2% at school (7-8 years).[40] Ultra-processed food consumption at preschool age was a significant predictor of a higher increase in total cholesterol and LDL cholesterol.

To date, no studies have examined specifically how UPF impact the consumption of the *n-6:n-3* ratio. One study in France, however, included average *n*-3 and *n*-6 consumption across four quartiles, with the lowest quartile consuming less than 11% UPF as total percentage of their diet, and the highest consuming greater than 23%. Looking specifically at *n*-6, there was no significant difference in mean daily consumption, which was 9.6, 9.53, 9.56, and 9.75 in quartiles 1-4, respectively. Difference in mean daily consumption of *n*-3 fatty acids was significant at the $p<0.0001$ level: 1.56, 1.44, 1.35, and 1.21 in quartiles 1-4, respectively. Calculating the *n-6:n-3* ratio shows that the ratio increases in each quartile, from 6.2 in quartile 1, 6.6 in quartile 2, 7.1 in quartile 3, and 8.1 in quartile 4.

Evidence on the harmful health impacts of SSB is also highly consistent. High intake of SSB is associated with an increased risk of type 2 diabetes mellitus, coronary heart disease, hypertension, and overweight and obesity.[45,46] Meta-analyses show that body weight increases in direct proportion to calories consumed from SSB, with odds ratio of being overweight or obese 1.5 times higher in the highest consuming adults.[47] In children, the odds ratio may be as high as 2.5.[46]

To date, the largest gaps in the evidence base center on the unit of analysis. The vast majority of research is focused on individual-level associations. While these provide the most accurate calculations of associations between diet and health, building the evidence base at the country-level may help to more effectively make the case for national or global level interventions. The literature here is relatively scant. Food Balance Sheets have been used to calculate homogeneity in the global food supply,[48] calculate associations between food supply diversity and country rates of undernutrition and overweight and obesity,[49] and in smaller-scale studies, assess the fatty-acid supply in some developing countries.[50]

One global analysis found that sales of UPF and SSB are associated with increases in male but not female BMI.[51] That study did not assess children and adolescents less than 19 years, nor did it control for country energy supply, which has been shown to be the primary driver of overweight and obesity.[52,53] Two smaller analyses have similarly found associations between UPF sales and obesity, one in Latin America using sales from EuroMonitor,[42] another in 19 European countries using Household Budget Surveys.[32]

Theories and Frameworks: Reductionist, Evolutionary, and Transdisciplinary

The reductionist approach to nutrition, in which a comprehensive understanding of how food nutrients and other bioactive compounds affect human metabolism and health, has enabled substantial strides in addressing forms of undernutrition over the past several decades. This increased knowledge, however, has led to little improvements in the prevalence of diet-related chronic diseases such as obesity, type 2 diabetes, osteoporosis, cardiovascular disease, or cancer. This failure has led some to propose that it is the reductionist approach to nutrition which has hampered the nutrition community's ability to halt these epidemics.[54–56]

For example, the traditional diet-heart hypothesis, which predicts that replacing saturated fat with vegetable oils rich in linoleic acid will reduce cardiovascular deaths, is most emblematic of the failures of reductionist paradigms. In 50 years, the hypothesis has never been causally demonstrated in a randomized control trial, while several systematic reviews and meta-analyses suggest no or even an inverse association.[57] Even food-based approaches, which examine the relationship between food groups and health, are far from convincing. The "healthfulness" of any food results from both food structure and nutrient density. Food synergy describes how the absorption and metabolism of many nutrients is influenced by interaction between the constituents of food within the food matrix. Food processing can positively or negatively impact this matrix, but most epidemiological research has not taken food processing into account.[58]

Evolutionary approaches to nutrition have been posed as one countermeasure to the inductive approach taken by nutritional epidemiology. These approaches build upon the hypothesis that because human genetic constitution has changed little over the past 40,000 years, while food systems have changed dramatically in the past 200, many individuals now eat diets that are misaligned to human health.[59] Humans evolved eating diets that were highly diverse and nutrient dense, in contrast to modern food systems in which staple cereals, oil crops, and UPF comprise a majority of calories.

Using the *Ethnographic Atlas*, a compendium of anthropological writing on hunter-gatherer tribes, Cordain et al. estimated that hunter-gatherer groups consumed a majority of dietary calories from animal-source foods (between 45-65%), with the remainder comprised of wild plants, tubers, and fruits. On average, these groups consumed relatively equal energy ratios of protein (19-35%) to carbohydrates (22-40%).[60] Although limitations to this analysis have been well-described,[61] the numbers were corroborated in a subsequent study using more reliable quantitative surveys of modern hunter-gatherer groups.[62] The estimates were also validated in a study of Australian Aboriginals who re-adopted traditional hunting and gathering practices after living in urban areas.[63,64]

Kuipers et al. used nutritional databases of East African plant and animal foods to construct models of diets based on hypothesized subsistence strategies. Their analysis found similar macronutrient ratios, with the earliest humans consuming a range of 25-29% of total energy from protein, 39-40% from carbohydrates, and 30-39% from fat.[11] Still, modern research of hunter-gatherers shows humans have thrived with drastically different dietary intakes, even at extremes. The traditional Inuit diet consisted almost entirely of seal and whale meat, with high fat, moderate protein, and almost no carbohydrate.[65] In contrast, Kitavan islanders in Papua New Guinea subsisted on a diet close to 70% carbohydrates, mostly in the form of tubers and fruit.[66] What unites these eating patterns is higher dietary quality: abundant consumption of micronutrient dense foods, predominantly from ASF, fruits, and vegetables.

Absent are any form of ultra-processed food, particularly those derived from the main staple crops grown today.

While there is broad agreement that UPF have negative impacts on human health, there is substantially more ambiguity regarding vegetable oils. Seen through the lens of genome-nutrition divergence, however, vegetable oils represent a novel and possibly harmful food group, with dietary impacts that are difficult to isolate. Beyond an important energy source, fatty acids play a vital role in a multitude of bodily functions. Omega-6 (n-6) and omega-3 (n-3) fatty acids cannot be produced by the body and must be obtained through diet. Sufficient consumption of n-3, particularly DHA and EPA, is necessary for cognitive development in infants.[67,68] In adults, deficiencies in n-3 are associated with increased risk of mental disorders and increased consumption has been shown to positively impact inflammation, hypertension, and hyperlipidemia.[69]

The ideal ratio of n-6 to n-3 fatty acids is still a subject of debate. Archaeological evidence indicates that the transition from early hominids to modern humans occurred in an East African ecosystem rich in n-3 and low in n-6 fatty acids.[70–72] Estimates place the ratio of n-6:n-3 fatty acids consumed by early humans at 1:1, substantially lower than the current estimated intake of 10:1 in the United States.[73,74] Although n-6 is critical to a variety of biological processes, greater consumption is not necessarily better. High n-6:n-3 ratios increases the risk for pathogenesis of chronic diseases including cancer and autoimmune disorders.[19] Individuals in which tissue levels where n-6 and n-3 acids are balanced are also at higher risk of coronary heart disease.[75,76]

Ultimately, evolutionary approaches in nutrition provide a framework for hypothesis generation but should not be dogmatic in the prescriptive nature that is often the case when academic research filters into “fad diets.” The rise in “paleo,” “primal,” and “keto” diets is illustrative of the ways that nutrition research is often taken to extremes within the general public. However, the perspective of evolution can better inform transdisciplinary approaches to nutrition. Given the multifactorial nature of malnutrition, creating and sustaining enabling policy environments for nutrition-oriented action will require transdisciplinary approaches. The nutrition community has likely been overly focused on identifying the role of specific nutrients in food and disease, while neglecting broad dietary patterns and their cultural, economic, and political antecedents. It could be argued that this is one of the reasons that nutrition transition was so late to be recognized within the public health community, and why effective policies and interventions to address diet-related disease have been relatively scarce, save in the instance of single-nutrient deficiencies.

Nutrition is embedded within wide social and political contexts. While the disciplinary foundations of nutrition research rest in the nutrition sciences, epidemiology and biostatistics, psychology, and consumer behavior, transdisciplinary approaches must allow a greater role for history, economics, sociology, anthropology, policy analysis, and political science – among others.[77] These approaches can "enhance the intellectual coherence, practical utility, and societal benefit of population nutrition research."[77] While this proposed project draws from all of these in some measure, we focus heavily on the history of and policy within the global food system to place vegetable oils and ultra-processed foods within context.

Food Systems and Policy

It is well known that population diets have begun shifting towards increased consumption of UPF and SSB, as well as 'out-of-home' foods – i.e. fast food or street food – which are often unhealthy.[41,78,79] In tackling this issue, the majority of population nutrition research has focused on how to change the behavior of individuals[77] or 'nudge' food environments to be healthier within a predefined area – as in the case of removing soda products from schools.[80] Yet a wealth of literature from a range of disciplines has advocated for upstream approaches to tackling the problem of unhealthy food systems.[56,81–86]

These food systems have changed dramatically over the past century. The Green Revolution of the mid-20th century helped to avert famine through low- and middle-income countries by rapidly increasing agricultural yields. As a result of these progams, famine and hunger have decreased. However, despite widespread micronutrient fortification and supplementation programs, micronutrient deficiencies have dropped far less in comparison.[87] A likely reason is that although calorie yields continue to increase around the world, global food supplies have grown increasingly homogenous. Over the past fifty years, national per capita food supplies have expanded in

calories, protein, and fat. A larger proportion of those nutrients come from energy-dense foods (namely animal products, vegetable oils, and sugars).[48] As a result, "the increase in homogeneity worldwide portends the establishment of a global standard food supply, which is relatively species-rich in regard to measured crops at the national level, but species-poor globally."[64(p401)] The increase in demand for UPF is one possible driver of this homogeneity, but how UPF sales have influenced dietary supply diversity is not yet understood.

Increasingly, understanding and intervening in the role of agribusiness and transnational food corporations has been highlighted as the most effective – but least understood – method for impacting population nutrition by changing food environments.

However, like many upstream interventions, this is an upstream battle. Food and drink industries are known to use similar tactics and strategies to tobacco companies to undermine public health interventions[44] – as in the case of Coca-Cola funding a range of research on how physical activity prevents obesity, or in cases where they lobby voters against proposed soda taxes.[88] Such approaches to public health hinge on neoliberal paradigms that cast public health problems as issues of individual consumption choices. Understanding how the aggressive manufacture and marketing of UPF and SSB (through the proxy of sales) helps to illustrate how precisely the growth in these foods has changed national dietary supplies. It thereby makes a stronger case for various forms of upstream intervention.

Finally, the fact that no country has yet to adequately tackle the crisis of obesity highlights the global gap in effective policies for preventing the global rise in BMI.[89] Although Mexico's preliminary success in reducing SSB consumption (with small impacts on weight) offers an important case study,[90] more research is needed on the feasibility and effectiveness of implementing similar taxes across contexts.

There is almost no research on the taxing of UPF. Given the multifactorial nature of overweight and obesity, effective solutions are likely to be transdisciplinary in nature, requiring significant coordination across many players throughout the global food system.

Purpose of the study:

This project aims to better understand the impact of two pillars of the nutrition transition – vegetable oils and ultra-processed food – on the global nutrient landscape and on obesity between countries and over time. It first takes a historical perspective to understand the antecedents of the rise of the modern vegetable oil industry. By applying an evolutionary lens, it argues that vegetable oils, the first pillar of the nutrition transition, are better considered as an ultra-processed food. It then bridges reductionist and food-based approaches by analyzing how these products of industry have shaped national nutrient supplies and how their growth is associated with rising levels of overweight and obesity. Emphasizing a transdisciplinary perspective, it does so through the following aims and research questions:

Specific Aims and Research Questions

Aim 1: To investigate, through an evolutionary framework, the historical trends of the rapid increase in vegetable oils in the 20th century and their impact on national supply levels of fatty acids

RQ 1: How have national dietary guidelines, food processing practices, and agricultural policies shaped global agricultural practices around vegetable oil?

RQ 2: How has the global and national distribution of FA changed over time?

RQ 3: How do current country supply levels of fatty acids compare with evolutionary fatty acid ratios and dietary reference intakes?

Aim 2: To analyze the association between ultra-processed food sales, sugar-sweetened beverage sales, and country-level nutrient supplies

RQ 1: What is the association between UPF sales and national level dietary supplies of fatty-acids and the omega-6:omega-3 fatty acid ratio?

RQ 2: What is the association between UPF sales, SSB sales, and national supplies of total energy, carbohydrates, and sugar?

RQ 3: Is there an association between sales of ultra-processed foods and country level food supply dietary diversity as measured by the share of calories supplied by non-staple foods?

Aim 3: To assess the associations between ultra-processed food sales, sugar-sweetened beverage sales, and obesity at the national level

RQ 1: What is the association between UPF and SSB sales and obesity at the national level between 2004-2018?

RQ 2: What is the association between edible oil sales and obesity at the national level between 2004-2018?

RQ 3: Do the effects differ between different country income groups?

The proposed dissertation will pursue these three specific aims and the association research questions within the three-paper model. By answering these questions and each specific aim, this research will contribute to a fuller understanding of how the nutrition transition has developed over time. By highlighting national and regional trends in the availability of fatty acids and food sources of fatty acids, and by applying an evolutionary framework to national FA supplies, it will provide an alternative blueprint for national dietary guidelines and policies which may over-emphasize saturated fat reductions. Finally, it will provide the most comprehensive overview to date of the spread of ultra-processed foods and beverages and their impacts on national dietary supplies and obesity. It will allow policy makers to more strongly make a case for food systems - rather than individual - solutions to malnutrition.

Methods

Global food environments continue to change. Increasing agricultural yields have been instrumental in ensuring the global food supply is sufficient to meet caloric intake, but it has come at the cost of increasing homogeneity in food supplies, possibly altering nutrient supply to unfavorable levels, and creating in many areas a surplus of staple crops which underpin the ultra-processed food industry. This dissertation aims to characterize exactly how that nutrient supply has changed over time, paying specific attention to fatty acids due to their role in a range of health outcomes. As a complement to individual-level epidemiological analyses, it then seeks to understand if the growth in two pillars of the nutrition transition, ultra-processed foods and sugar-sweetened beverages, are associated at the country-level with rising rates of overweight and obesity. It seeks to accomplish these aims through the integration of evolutionary and food processing frameworks as a means of moving forward methods in paradigms in traditional population nutrition research.

To create a comprehensive picture of nutrient supply over time, we will combine data from the Food and Agriculture Organization and United States Department of Agriculture. Data on the nutrient composition of the food items contained in the FBS was obtained by matching individual food items in the United States Department of Agriculture's (USDA) FoodData Central database with those in FBS.[91] Where the FBS provide an aggregate category, and the USDA provides nutrient data for specific parts of food (for example, FoodData Central provides nutrient information for more than ten different cuts of beef, but not an aggregate "beef" category), we will calculate an average. For categories in which FBS record an aggregate category (i.e., "oilcrops – other," which includes linseed, castor oil, and hempseed oil, among others), we will weigh the nutrient profile according to global production values of the individual crops. If a food item was not available in the USDA FoodData Central, nutrient data will be obtained via the New Zealand Food Composition Database.[92]

Finally, because FBS numbers represent raw, unprocessed food items and nutrient data are generally available for only the edible portion of a foodstuff, we will use refuse factors from the USDA FoodData Central to calculate edible portions of available foods. The per capita available of every nutrient i in year t and country c can be expressed as:

$$N_{itc} = \sum_{f=1}^{96} N_{fitc}$$

Where f is the FBS food item, t ranges from 1961 to 2013.

Statistical Analysis: Longitudinal multi-level analyses will be used to estimate the effects of UPF and SSBs on nutrient supply (Aim 2) and average country BMI and prevalence of overweight and obesity for both adults and children and adolescents less than 19 (Aim 3). Models will be built and analyzed using the lme4[93] package in RStudio (1.2.1335) using a "bottom-up strategy."[94] In the first step, an unconditional growth model will be fit with year as the only level-1 predictor, and with country as the level-2 unit. In the second model, region, GDP, and urbanization will be included. To assess improvement in the model with the addition of UPF or SSB as predictors, each variable will be added separately to the basic covariates model. Improvement in model fit will be assessed in two ways: A likelihood ratio test, measured as χ^2, will be used to compare the addition of predictor variables to model fit. If the addition of UPF or SSB significantly improves model fit, interactions will be explored and tested. Marginal and conditional R-squared will be calculated (following the approach outlined in Nakagawa, 2012[95]) to assess further the impact of increasing covariates in the models. ***P***-values for individual variables are presented using the Kenward-Roger approximation for degrees of freedom,[96] which produces acceptable Type 1 error rates even at small sample sizes.[97] In order to maximize power because availability of calories is only available up to year 2013, and prevalence of insufficient physical activity is only available for 68 countries, we will run three models for each outcome, checking to see that UPF and SSB remained significant predictors.

Conclusion

Population nutrition research is changing. While individual level-epidemiological studies still carry high importance in understanding the causal links between nutrients, dietary patterns, and health outcomes, nutrition research is being increasingly pushed to adopt new methods and paradigms. The amount of nutrients in food is of course relevant, but the lack of any population wide solution to the growing epidemics of overweight and obesity demand new solutions. New solutions demand new analyses.

There is no definitive healthy diet. Indeed, with the exception of trans fats, health is determined when nutrients fall within a certain range – neither too high nor too low. However, the growth of vegetable oils and ultra-processed foods has produced a global food environment in which the consumption of certain nutrients falls outside the range of what may be optimal for human health. To date, how these two pillars of the nutrition transition and their impacts on global nutrient supply and obesity have not been assessed globally or over time.

Given that solutions to the rising obesity epidemic are likely to be political and governmentality – through agriculture, policy, and regulation – country-level analyses of the associations between food environments and obesity are critical to informing future debate. This dissertation serves to inform that debate by demonstrating the associations between vegetable oils and UPF, country nutrient supply, and obesity rates. These higher level-analyses will serve to inform national and global efforts to alter food environments, reduce disease, and improve population health.

Chapter 2: Refining Frameworks for Fats: Evolutionary, Industrial, and Ecological Perspectives on the Global Supply of Fatty Acids

Abstract

Intro: In the second half of the 20th century, per capita availability of vegetable oils increased more than any food group. This growth is consonant with national dietary guidelines, yet researchers continue to debate the health impacts of the fatty acids (FA) most commonly found in vegetable oils. Evolutionary theory suggests humans evolved in environments in which *n*-6 and *n*-3 consumption was balanced. Some analyses have found that the *n*-6:*n*-3 ratio has increased over the past century, but to date, few global analyses of FA are available.

Objectives: This study aimed to 1) Quantify global and national supplies of total fat and FA, including saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), *n*-6, *n*-3, and the *n*-6:*n*-3 ratio, from 1961-2013; 2) Benchmark national FA availability against nationally recommended intakes and hypothesized evolutionary ratios; and 3) Integrate evolutionary, ecological, and food processing frameworks to better characterize the global FA supply.

Methods: Ninety-six foods encompassing primary commodities and some processed commodities (i.e., vegetable oils) from the Food and Agriculture Organization's Food Balance Sheets (FBS) were matched to food items in the United States Department of Agriculture Food Composition Database to calculate national energy and nutrient supplies between 1961 and 2013.

Results: Availability of *n*-6 FA increased by 85%, from 8.4 to 15.8 g per person per day. Availability of *n*-3 increased by 107%, from 0.89 to 2.03 g per person per day. The global *n*-6:*n*-3 ratio decreased 10.7%, from 8.9:1 to 7.9:1 and ranged from 3.6:1 to 35.6:1 across countries. Compared to a hypothesized evolutionary ratio of 1:1 *n*-6:*n*-3, the global FA supply is heavily weighted towards *n*-6 FA. However, supply levels in a majority of countries fall into the inadequate range for both *n*-6 and *n*-3.

Discussion: Contrary to many hypotheses, the *n*-6:*n*-3 ratio has decreased over the past six decades, largely a result of growth in *n*-3 rich soybean, rapeseed, and other vegetable oils. Compared to the hypothesized evolutionary ratio, the global average of 9.6:1 remains high. In the absence of epidemiological consensus of healthy FA intake, applying processing frameworks to vegetable oils illustrates that overconsumption (and use in ultra-processed foods) and toxic byproducts formed in oil heating are equally important factors when considering the health impacts of FA.

Introduction

Few topics in the field of nutrition have garnered as much debate as the role of fatty acids human health and disease. For much of the 20th century, a substantial portion of academic and policy focus centered on the role of saturated fat in cardiovascular disease (CVD). Today, what was once a consensus is now widely debated.[17,58,98,99] In the past two decades, polyunsaturated fatty acids (PUFA), particularly *n*-6 and *n*-3, have been of interest for their role in non-communicable diseases (NCDs), including but not limited to CVD,[75,100,101] cancer,[20,21,100] and Alzheimer's disease.[102]

The *n*-6 and *n*-3 FA represent families of structurally similar FA with different sources in the human diet. The most physiologically important of these FA are docosahexaenoic acid *(DHA, 22:6n-3*), eicosapentaenoic acid (EPA, 20:5*n*-3), and arachidonic acid (ARA; 20:4*n*-6). DHA (found predominantly in seafood) and AA (animal-source foods, particularly chicken) are the predominant long-chain PUFA in the human brain and are vital for brain development.[103] DHA and EPA (also found in seafood) together have well-established benefits in cardiovascular[76,104] and cognitive health.[102,105] No dietary reference intake (DRI) exists, but expert groups and international bodies recommend intakes that range from 250 mg/day to >1000 mg/day.[106]

The human body can synthesize DHA from alpha-linolenic acid (ALA, 18:3*n*-3), the most widely available *n*-3 FA (found in high sources in flax oil but most abundantly available in soybean or rapeseed oil). However, conversion rates are extremely low – no higher than 1%.[107,108] The ratio between linoleic acid (LA18:2*n*-6) and ALA determines the extent to which ALA can be converted to DHA, as ALA and LA compete for the Δ6 desaturase enzyme.[109–111] In order to achieve adequate tissue levels of DHA and EPA, it is suggested that LA *n-6* consumption would have to be reduced to less than 2% of the global dietary supply.[112] Given the importance of vegetable oils in modern diets, this amounts to a problematic and controversial undertaking.

Vegetable oils in historical context

Seed- or fruit-derived fats - commonly known as vegetable oils - were almost entirely absent from human diets until the 20th century. Today, vegetable oils comprise the largest source of dietary fat in the global food supply.[4]

Since 1961, the global percentage of available calories from vegetable oil has increased by 140% - higher than any other food group.[10] Driving this growth is the continued expansion of soybean, palm, and rapeseed production, which today account for roughly 75% of all vegetable oil consumed.

The present-day ubiquity of vegetable oils has dramatically altered the FA amounts and proportions of modern diets. Today's diets are very different from those consumed just a century ago, and highly divergent from the proportions hypothesized to comprise early hominid diets. Consumption of LA increased sharply at the turn of the 20th century,[10,113] with the average proportion of dietary calories in the US diets LA tripling since 1900, a result of a ten-fold increase in soybean oil consumption.[8] Adipose tissue levels of LA in American adults have increased 140% since 1960 alone.[114] In contrast, the proportion of available calories from ARA, EPA, and DHA is suspected to have decreased, resulting in declines in EPA and DHA tissue status.[8] Similar trends have been documented across diverse contexts worldwide.[112,113]

Some hypothesize that the present-day mean intake of LA is discordant with genetically determined physiological requirements *for FA*.[59] Early humans are believed to have evolved in food environments rich in long-chain polyunsaturated fatty acids (PUFA) from lacustrine and marine sources, where *n*-6:*n*-3 FA consumption is estimated to have been 1:1.[11,15] Only with the adoption of agriculture and higher consumption of staple grains and oilcrops did ratios change dramatically. Pre-20th-century estimates are not available, but American diets in 1909 are estimated to have contained *n*-6 and *n*-3 at a ratio of 6:1, with only 25% of *n*-6 consumed through added fats or oils.[14] At present, the ratio of the average American diet is between 10-16:1, with over 60% of *n*-6 consumed through added fats or oils.[8,15]

This shift in dietary FA profiles can be traced, in large measure, to the interaction between global agribusiness expansion, agricultural policies, and national dietary guidelines enacted throughout 20th century.[84,115,116] In 1961, the American Heart Association issued the first advisory advocating for reductions in saturated fats due to the association between SFA and CVD.[117] An immediate and rapid increase in soybean oil consumption in US diets followed this announcement.[8] Avoiding SFA became – and to some extent remains - standard dietary advice across the globe. As a result, consumer demand for vegetable oils catalyzed production growth, first throughout North America and Europe, and later throughout much of the global south.[118,119] As the agribusiness sector grew more vertically integrated and began operating as food processors in addition to producers, oil crops grew more profitable.[120] The ability to "flex" crops – adding value to agricultural products by separating them into parts, usually oil and meal – allow agribusiness conglomerates to sell oilcrops as separate and more profitable products.[116] Profitability for growers in high-income countries by price supports and lower tariffs on vegetable oil trade.[121,122]

The increasing abundance of vegetable oils in the food supply continues to be viewed as preferable to the earlier prominence of animal-source (and saturated) fats.[123] Growing epidemiological evidence, however, suggests reasons to view this global dietary shift more cautiously. Bruno Latour uses the term *blackboxing* to describe how "when a matter of fact is settled, one need focus only on its inputs and outputs and not on its internal complexity."[124] Dietary advice, particularly the reductionist approach to nutrients, has often proceeded in this fashion.[55,125] The reversal of nutrition science's stance on the role of dietary cholesterol in CVD is emblematic of the way that the nutrition community has adjusted course as better evidence has become available. The role of SFA in CVD and other health outcomes has, in recent years, come under similar scrutiny.[6,126] In this study we do not seek to resolve these debates but rather, to re-frame epidemiological evidence as a product of social forces.

Objectives

Social scientists have challenged nutrition researchers to address the public's reluctance to trust dietary advice by providing recommendations that better translate to the way consumers engage with food.[127] New methods and frameworks are needed to both guide research and allow nutrition science to speak more effectively across disciplines.[77] The nutrient-level, reductionist approach to nutrition continues to be effective in reducing micronutrient deficiencies, but has failed to adequately address the multifactorial nature of diet-related NCDs.[54] Large-scale observational studies form the backbone of nutritional advice but are limited by the reliability of dietary assessment and recall.[58,128] Randomized controlled trials of single nutrients are challenging to translate into meaningful dietary advice.[127] Food processing classifications have emerged as one part of a growing methodological expansion in nutrition science.[37,58]

More considerable attention to food processing illuminates several issues in the global supply of FA. First, we apply an evolutionary framework to illustrate the importance of understanding FA as they relate to human evolutionary biology, rather than the limited perspective of 60 years of clinical evidence. We suggest that the degree of processing required to extract edible oil and render it fit for human consumption correlates negatively with an oil's overall nutritional value. Finally, we point to how the inexpensiveness of vegetable oils facilitates overconsumption - both as an added fat in cooking and fried foods and as a primary ingredient in ultra-processed foods. This paper contextualizes the global supply of vegetable oils with this aim in mind.

The specific aims of this study were three-fold:

1) To quantify global and national supplies of fats and fatty acids and their primary food sources between 1961 and 2013
2) To compare and contrast national FA availability with hypothesized evolutionary FA ratios and with global recommendations
3) Integrate evolutionary, ecological, and food processing frameworks to contextualize the global FA supply

Methods

We obtained food supply data from the Food Balance Sheets (FBS) of the Food and Agriculture Organization (FAO) of the United Nations. FBS provide a comprehensive picture of the pattern of a country's food supply for each year between 1961 and 2013. FBS include 96 primary commodities and several processed commodities (i.e., vegetable oils) available for human consumption. For each food commodity, FBS calculate available supply by adding domestic production and imports and subtracting for quantities exported, fed to livestock, used for seed, processed for non-food uses, and lost during storage and transportation. Each commodity is then divided by the total population of the country in which the FBS survey is conducted.[129]

We calculated the nutrient composition of FBS items by matching FBS items to foods listed in the United States Department of Agriculture's (USDA) FoodData Central database.[91] If the FBS provided a whole food item where the USDA provides nutrient data for specific parts (e.g., FoodData Central provides nutrient information for more than ten different cuts of beef, but not an aggregate "beef" category), we averaged all parts. For categories in which FBS record an aggregate category (i.e. "oilcrops – other," which includes linseed, castor oil, and hempseed oil, among others) but FAO production data records individual food items, global production values were obtained, and nutrient composition of the aggregate category was weighted to global production numbers. Where an analog was not available in the USDA FoodData Central, nutrient data was obtained via the New Zealand Food Composition Database.[92]

Because FBS numbers represent raw, unprocessed food items and nutrient data are generally available for only the edible portion of a foodstuff, refuse factors were obtained from USDA FoodData Central and used to calculate edible portions of available foods. The per capita available of every nutrient i in year t and country c can be expressed as:

$$N_{itc} = \sum_{f=1}^{96} N_{fitc}$$

Where f is the FBS food item, t ranges from 1961 to 2013.

Results: Trends in Global Vegetable Oil Production

In this section, we review trends in global FA availability between 1961-2013 to apply a historical perspective on the global food supply. We provide comparisons to Dietary Reference Intakes as a means of benchmarking.[130] Where not available (i.e., DHA), we use recommendations from the WHO.[131]

During the 20th century, consumers gradually shifted away from cooking with animal fats like lard and tallow to vegetable oils. Between 1961 (the first year in which global data is available from FAO) and 2013, vegetable oils nearly doubled as a percentage of the global calorie supply, from 5.1% to 9.4%. The percentage of available calories from animal fats fell from 3.2% to 2.1% over the same period.[10] Earlier data on vegetable oil production and consumption show more dramatic changes. Soybean oil availability in the United States increased from near-zero at the turn of the 20th century to over 23kg per person per year in 2013.[8,10] In Canada, where agronomists first altered the characteristics of the rapeseed crop (from which processors derive canola oil) to render it suitable for human or animal consumption, availability has grown from 0.43kg/person/year in 1961 to 15.2kg in 2013.[10] In Brazil, which now rivals the U.S. in global soybean production, the equivalent numbers for soybean oil are 0.27kg in 1961 and 13.54kg in 2013.[10,84]

Worldwide, production and consumption of vegetable oils have followed a similarly rapid rise, usually with one or two varieties rapidly increasing as a proportion of the dietary supply **(Figure 1).** Since FAO recording began, soybean oil availability has increased in the Americas to just below 300 kcal/capita/day.[10] In Asia, palm and rapeseed oils have risen at similar rates.[132,133] In Europe, sunflower oil is the predominant cooking fat, a result of expansion in production throughout Russia and Ukraine resulting from post-Soviet land reform.[134] Rapeseed availability has grown across regions, most notably throughout Oceania and to a lesser extent in Asia and Europe. Africa is the only region in which vegetable oil availability has held relatively even, remaining at levels substantially lower than other parts of the world. This reflects slow overall growth in the African agricultural sector, in part a result of the failure to prioritize the development of improved oil crop varieties suitable for the African climate.[135]

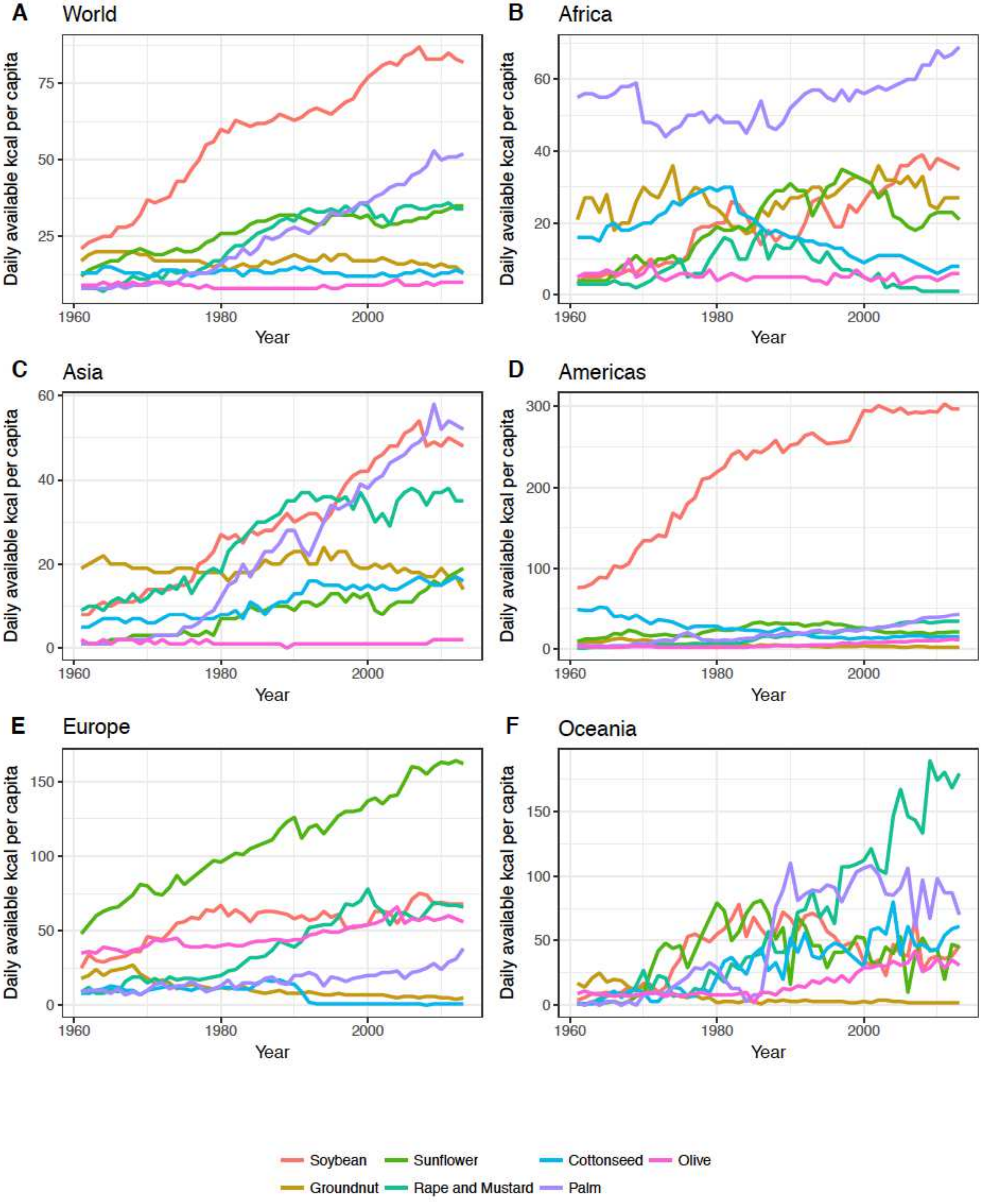

Figure 1: Growth in Vegetable Oil Availability By Region, 1961-2013

Omega-6: In 1961, global mean daily per capita availability was 8.4 g, varying from 20.2 g in North America to 4.8 g in South Asia. By 2013, global daily availability had risen 88% to 15.8 g per capita. Regionally, increases were the greatest in East Asia and Pacific (154%) and Latin America and Caribbean (122%) and lowest in Europe (46%) and Sub-Saharan Africa (49%). Aggregated by income classification, increases were highest in upper-middle-income countries (128%) and lowest in low-income countries (37%).

The largest increases have come from soybean oil, sunflower oil, and rapeseed oil (Figure 2). In 1961, 14% of the global availability of *n*-6 was from soybean oil; in 2013, it was 30%. The five highest sources of vegetable oil *n-6* – rapeseed, groundnut, cottonseed, sunflower, and soy – now account for just under 50% of the entire *n*-6 supply.

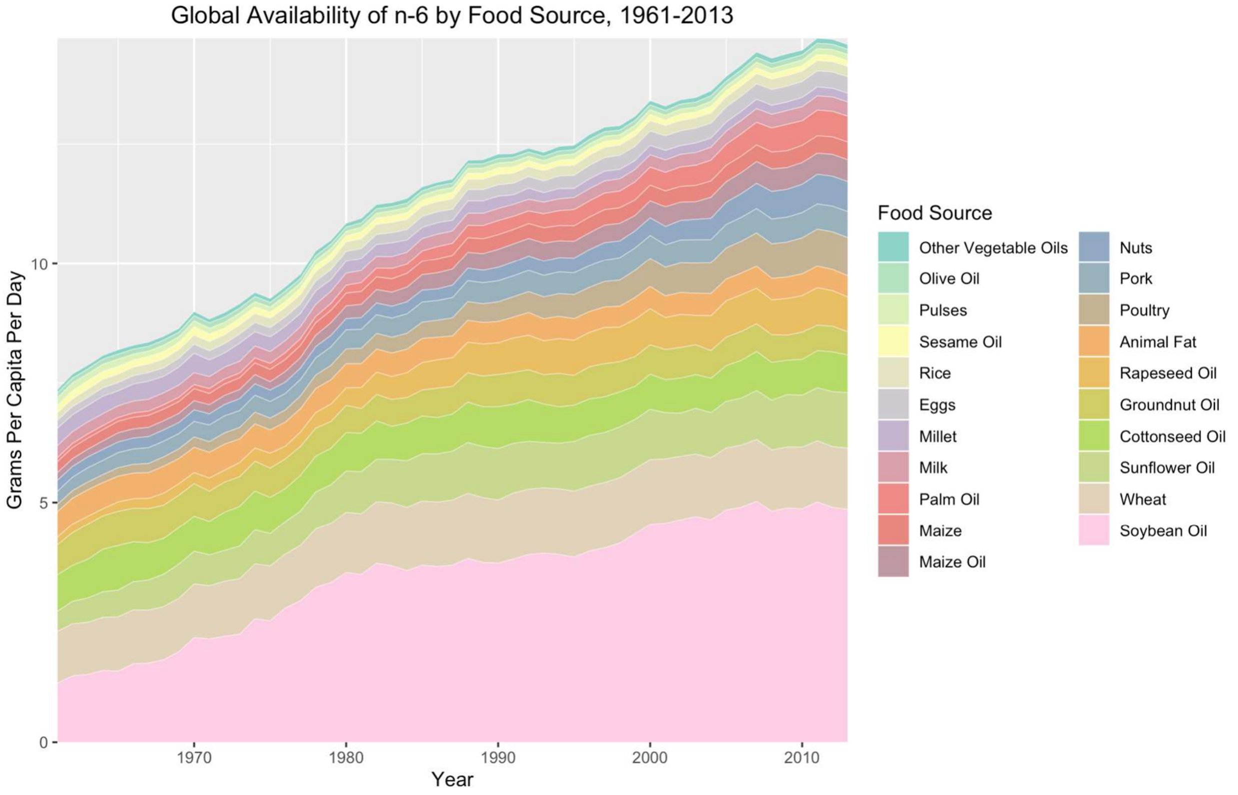

Figure 2: Global Availability of Omega-6 Fatty Acids, 1961-2013, By Source

Omega-3: The global mean per capita availability of omega-3 FA was 1.05 g in 1961. By 2013, availability had increased 89% to 1.98 g/p/d – nearly the same rate as *n*-6. Increases were highest in East and Pacific (158%) and North America (143%), and lowest in Europe (31.4%). While in 1961, soybean and rapeseed oils accounted for 23%

of the global *n*-3 supply, in 2013, they comprised 49%. Pork and milk accounted for a further 21% of 2013 *n*-3 levels, a slight reduction from the 27% they accounted for in 1961.

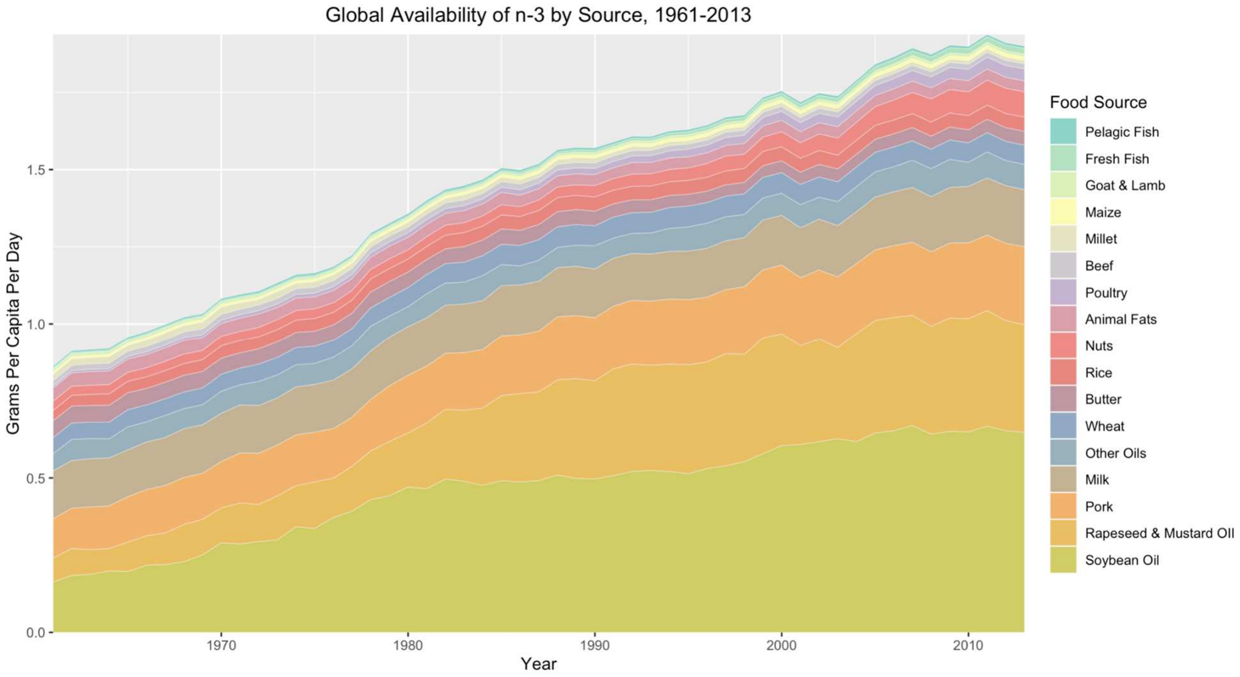

Figure 3: Global Availability of Omega-3 FA, 1961-2013, By Source

Omega-6:3 Ratio: In 1961, the global mean n-6:n-3 FA ratio was 10.4:1. In 2013, it had decreased by 7.7% to 9.6:1. Across nearly every region and income bracket, the ratio has decreased, if slightly, ranging from -17.6% in North America to -2.8% in the Middle East and North Africa. The only regional exception was a 16% increase, from 7.5 to 8.7, in Europe.

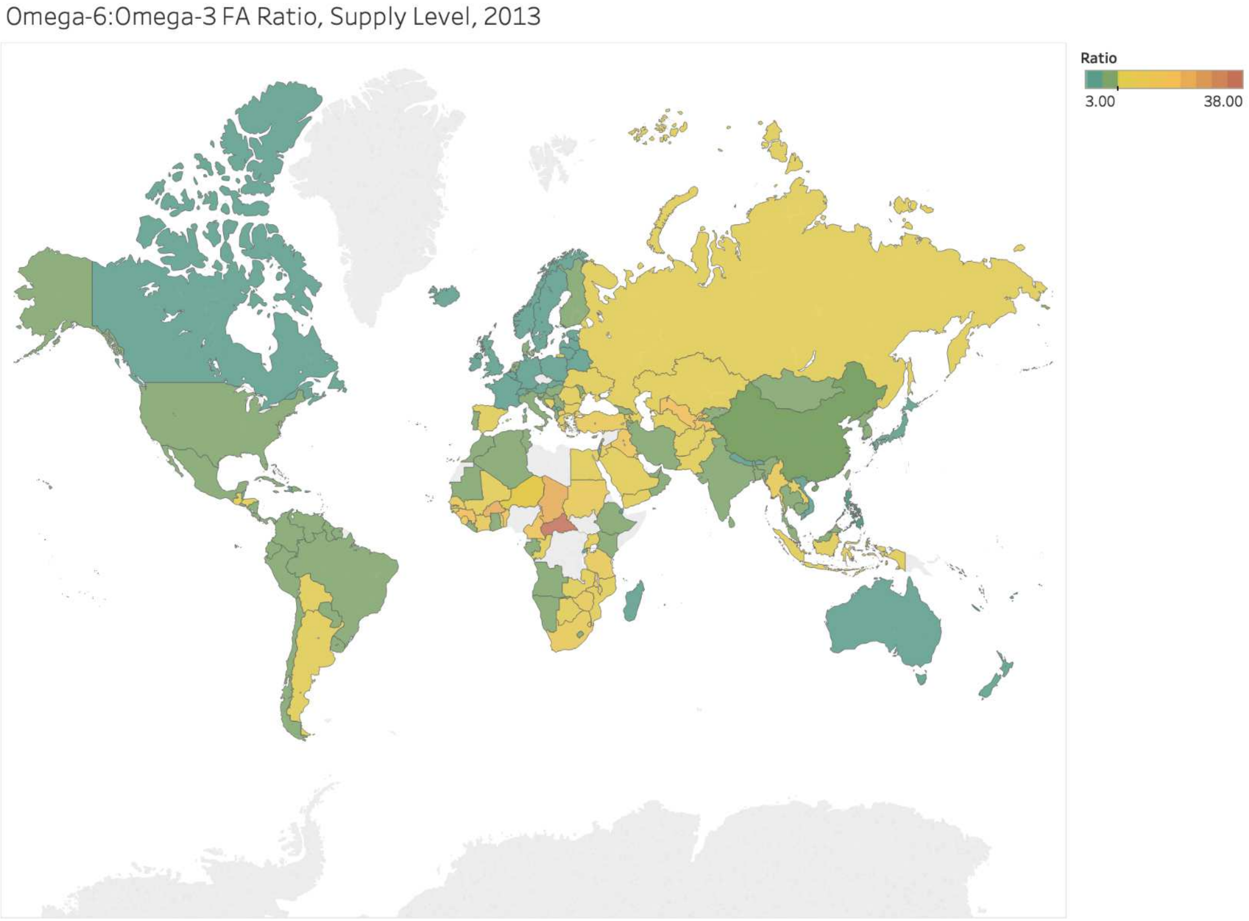

Figure 4: National Omega-6:Omega-3 FA Ratio in 2013

Regional disparities mask the variation at the country level. In 2013, the highest ratio was in Central Africa Republic (35.6:1), followed by Chad (26.0:1), Burkina Faso (24.6:1), and Guinea (23.8:1). Of the ten highest countries with available data, six are landlocked, and two (Iraq and Benin) have very small coastlines – suggesting the importance of seafood in balancing out *n*-6 availability. In contrast, many countries with the lowest ratios are also coastal countries with high fish landings, including Bahamas (3.6), Estonia (3.7), Japan (4.5), and Sweden (4.8).

Comparisons to Dietary Reference Intakes

Total Fat: Although there is no defined intake level at which potential adverse effects of total fat have been identified, the Acceptable Macronutrient Distribution Range (AMDR) for fats is as 20-35% of total energy.[130] In 2013 among the countries in which FAO FBS estimates were available, 42 countries fell below this threshold at the country food supply level. Most were low and lower-middle-income countries in Sub-Saharan Africa and South

Asia. The lowest levels were in Rwanda (7.7%), Madagascar (8.7%), and Laos (10.4%). In contrast, 20 countries exceeded the AMDR, most were high-income. The highest levels were observed in the United States (39.7%), Australia (40.1%), Austria (41.2%), and Samoa (43.4%).

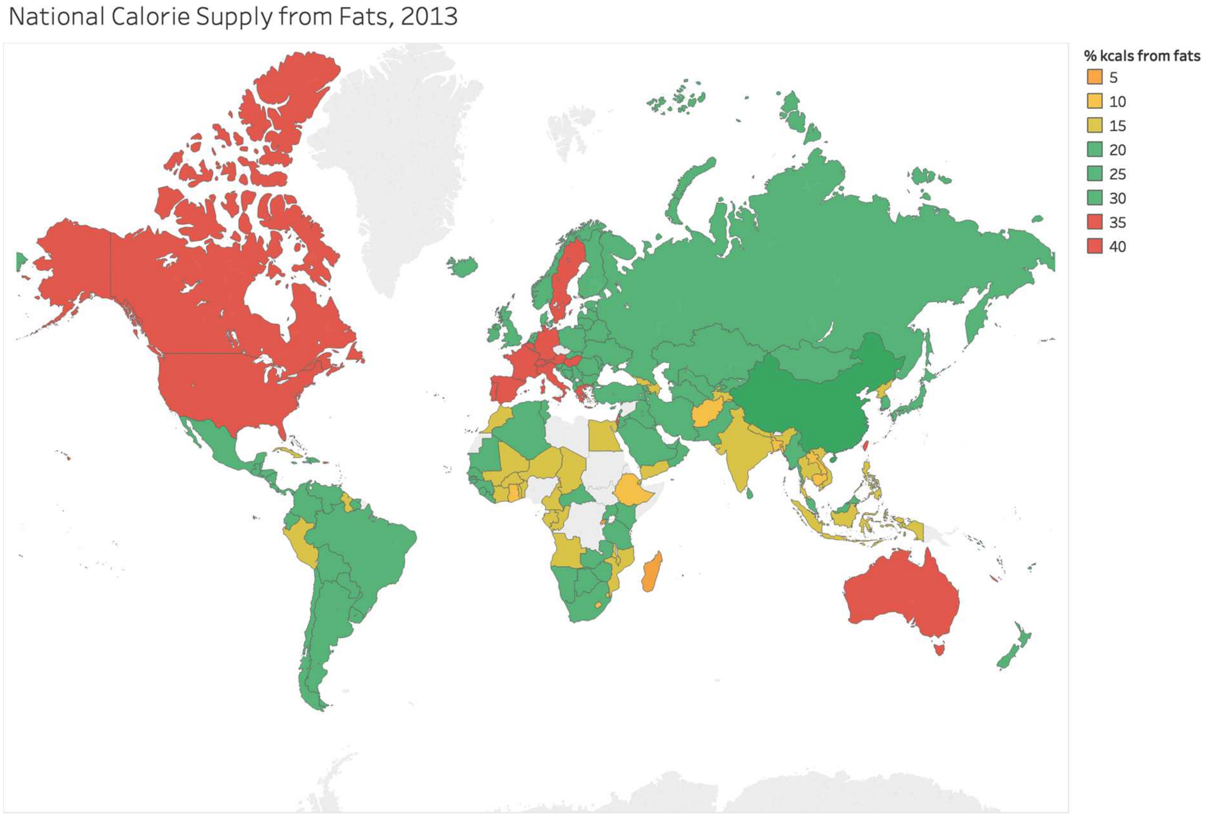

Figure 5: National Calorie Supply From Fats, 2013

Table 2.1: Trends in Omega-FA Availability, 1961-2013

	Omega-6				**Omega-3**				**Ratio**			
Region	**1961**	**1990**	**2013**	***%Δ 1961-2013***	**1961**	**1990**	**2013**	***%Δ 1961-2013***	**1961**	**1990**	**2013**	***%Δ 1961-2013***
East Asia And Pacific	5.5	11.1	14	***154.5***	0.78	1.67	2.01	***157.7***	8.4	7.7	7.9	**-6.0**
Europe	13.4	20.8	19.6	***46.3***	2.04	3.11	2.68	***31.4***	7.5	7.7	8.7	**16.0**
Latin American and Caribbean	7.2	12.6	16	***122.2***	1.01	1.89	2.2	***117.8***	8.9	8.2	7.7	**-13.5**
Middle East and North Africa	9.7	17.9	20.8	***114.4***	1.27	2.02	2.25	***77.2***	10.7	10.7	10.4	**-2.8**
North America	20.2	32.8	40.3	***99.5***	2.72	5.25	6.61	***143.0***	7.4	6.2	6.1	**-17.6**
South Asia	4.8	6.8	8.8	***83.3***	0.56	1.03	1.21	***116.1***	8.7	7.1	8	**-8.0**
Sub-Saharan Africa	7.8	9.6	11.6	***48.7***	0.57	0.96	0.99	***73.7***	15.4	11.7	13.1	**-14.9**
Income												
High	11.7	19.4	21.6	***84.6***	1.97	3.19	3.36	***70.6***	6.6	6.6	6.8	**3.0**
Upper-Middle	7.2	13.6	16.4	***127.8***	0.78	1.56	1.89	***142.3***	9.9	9.7	9.4	**-5.1**
Lower-Middle	5.9	8.8	11.3	***91.5***	0.54	0.99	1.13	***109.3***	12.2	10.2	10.7	**-12.3**
Low	7.9	8.9	10.8	***36.7***	0.54	0.87	0.88	***63.0***	16.2	12	14.2	**-12.3**
Global	8.4	13.3	15.8	***88.1***	1.05	1.79	1.98	***88.6***	10.4	9.2	9.6	**-7.7**

Omega-6: An intake level at which potential adverse effects of *n*-6 exist has not been identified. The AMDR of 5-10% of energy is based on a lack of evidence demonstrating long-term safety and human in vitro studies showing increased free-radical formation and lipid peroxidation (a precursor of atherosclerotic plaque) with higher *n*-6 intake. Adequate intake for adult males is 14-17g/day, 11-12 g/day for women, and 13g/day for pregnant and lactating women.

Out of 179 countries for which data was available, 97 fell into the inadequate supply range <5%, 82 were in the adequate range of 5-10%, and 2 (the United States and Taiwan) exceeded the AMDR of 10%. When looking at absolute levels, 41 countries had mean availability levels below adequate intake for women at 11g/day, and 110 had mean availability below adequate intake for men at 17 g/day. The United States had the highest availability at 49.8 g/day, followed by Israel (38.1) and Taiwan (34.4).

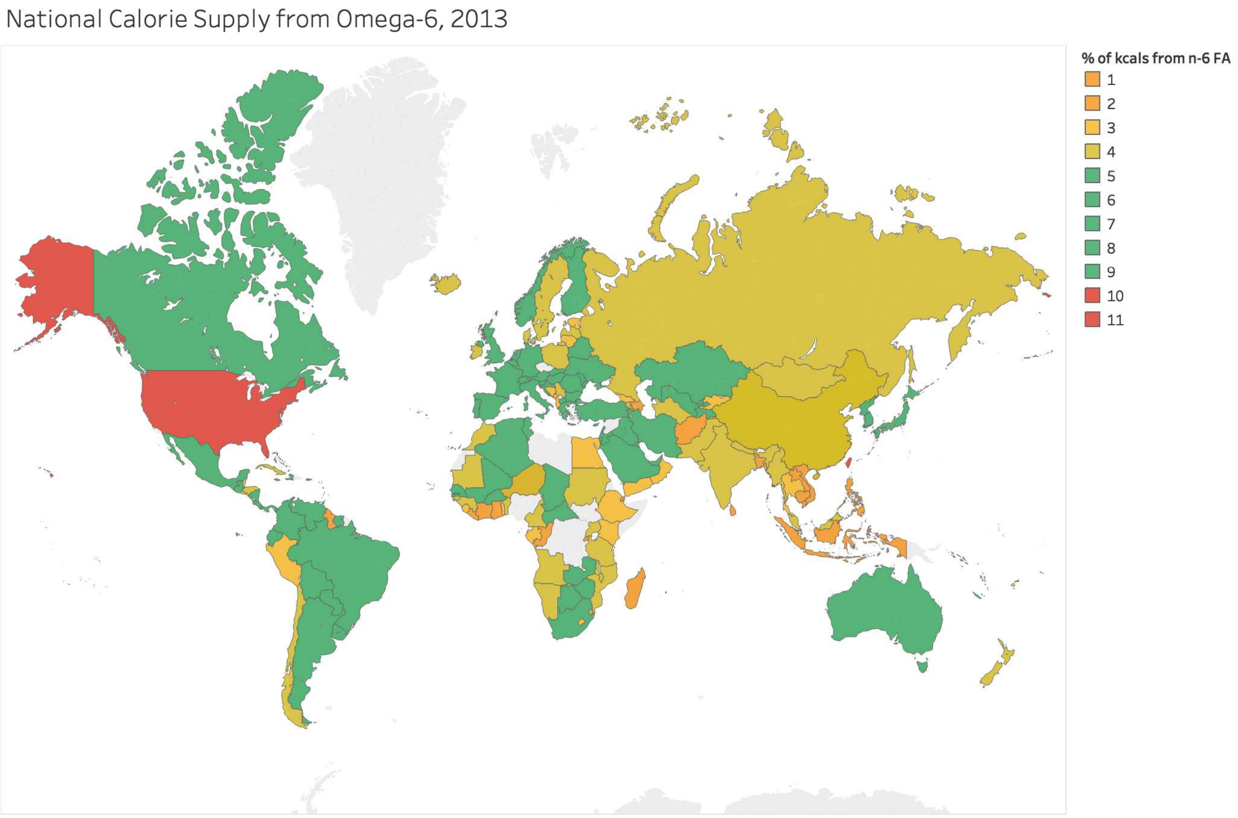

Figure 6: Percentage of National Calorie Supply from Omega-6, 2013

Omega-3: The AMDR for n-3 FA is 0.6-1.2% of energy. RDA is 1.6g per day in male adults, 1.1 g/day in female adults, 1.4g/day for pregnant women, and 1.3 g/day in lactating women. Although the DRI established an upper threshold in the AMDR, we have chosen to present *n-3* availability >1.2% of national energy supply in blue rather than red, as there is little evidence to indicate adverse effects of exceeding *n-3* consumption. Indeed, some estimates suggest increasing *n-3* intake to a minimum of 3.5g/day for a 2000-kcal diet if *n-6* consumption remains at current levels.[136]

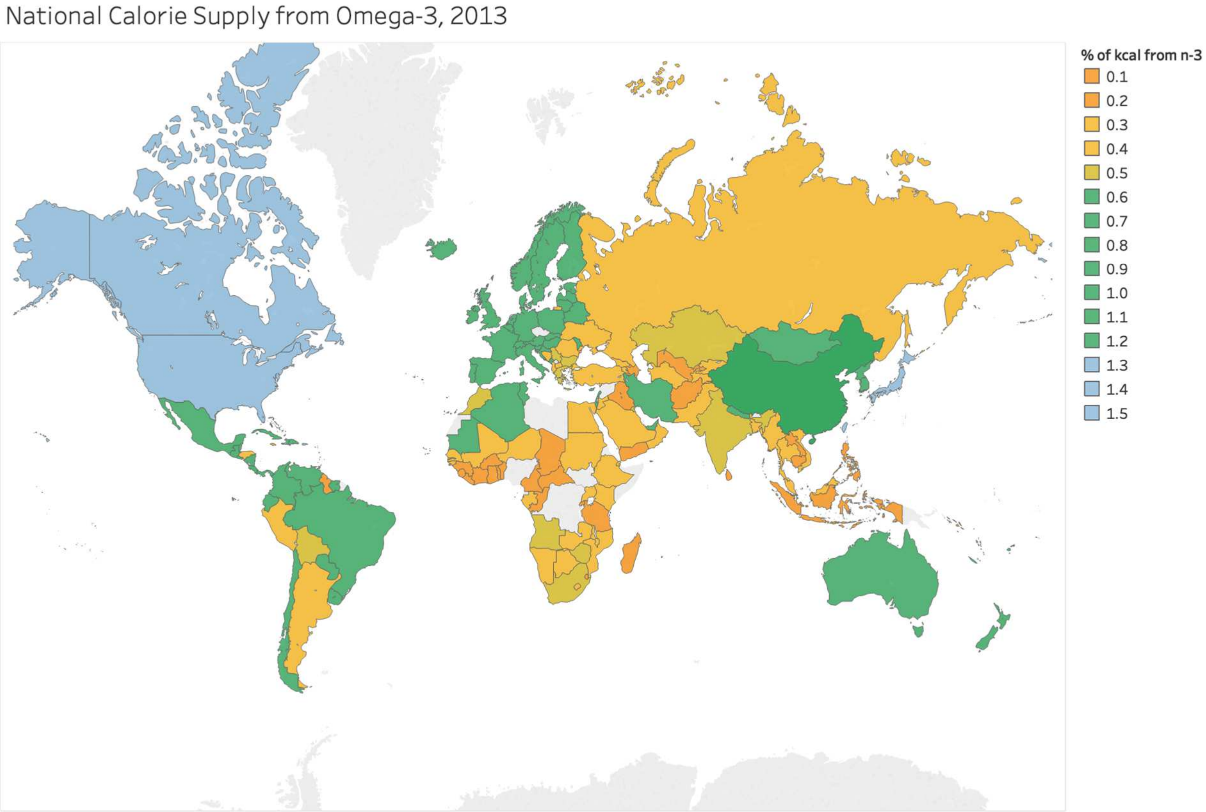

Figure 7: Percentage of National Calorie Supply From Omega-3. Note: Colors describe ranges between number selected and previous number, i.e. 0.0-0.1 is orange, 0.5-0.6 is green.

While 74 countries fall into the adequate AMDR, 99 had mean population availability lower than 0.6% of energy. Eight fell above the high range of the AMDR. No countries met an adequate *n*-3 level at the country supply level for men, and only 4 (Taiwan, Macao, United States, and Canada) met the threshold for pregnant women. Availability was lowest in Sri Lanka (0.14g/day), Solomon Islands (0.18g/day), and Guinea (0.19g/day). No country in Sub-Saharan Africa met adequate thresholds, and most of Southeast Asia and MENA also fell below AMDR.

DHA and EPA: There is no DRI for EPA and DHA. The WHO recommended adequate intake is 0.2-0.25g/day.[131] However, 1 g/day has been proposed as the amount at which the needs of nearly all healthy individuals would be met.[106] In our analysis, 101 of 181 countries failed to meet the 0.25 threshold, while only Maldives met the 1g/day threshold (due to substantial marine fish landings).

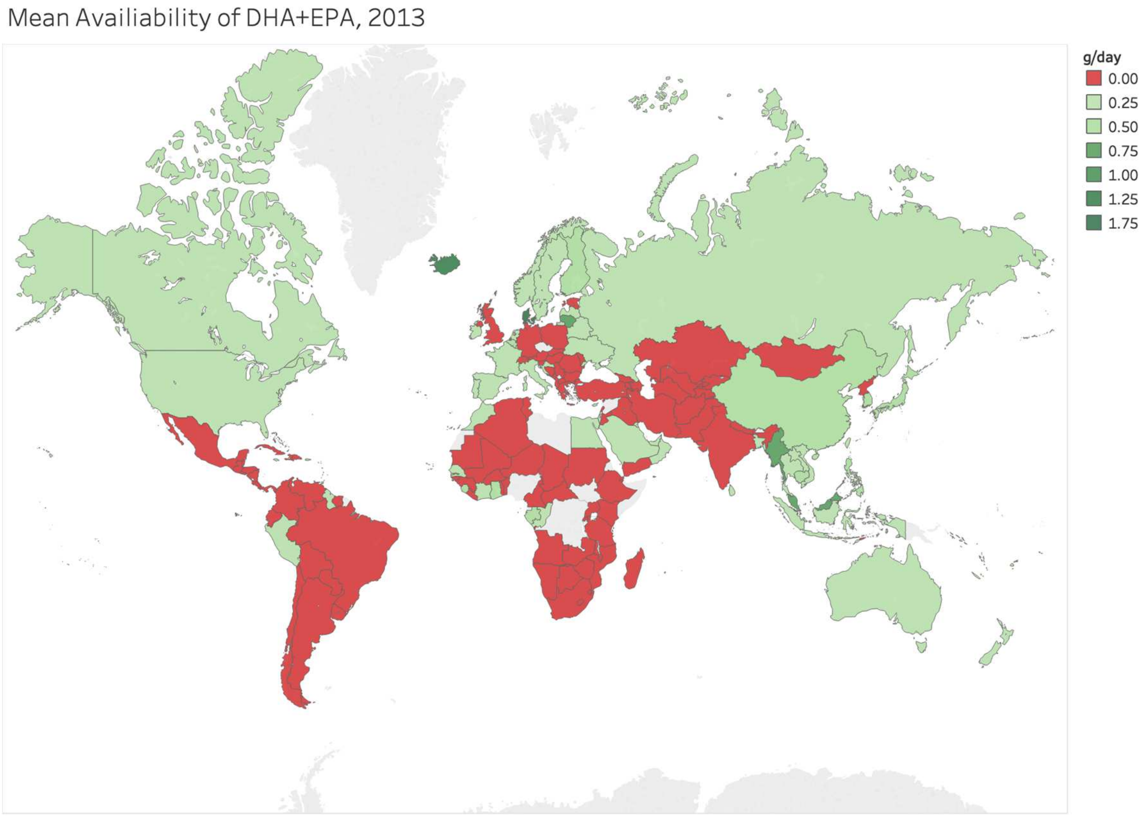

Figure 8: Mean Availability of DHA and EPA By Country, 2013

Discussion: Vegetable Oils Within a Holistic Nutrition Paradigm

Although the reductionist approach to FA is critical in understanding the intricacies of bioactive compounds, human metabolism, and their health impacts, the multifactorial nature and failure of traditional approaches to treat diet-related non-communicable disease demands new approaches. In particular, holistic paradigms which replace reductionism with considerations of public health, environmental sustainability, animal husbandry, ecology, and food processing are needed. We build upon Fardet and Rock's[54] approach by reviewing FA and vegetable oils from a more holistic perspective, including the interactions between FA nomenclature and marketing, dietary guidelines, food processing, and environmental sustainability.

Essential Fatty Acids and "Omega" Fatty Acid Nomenclature

In addition to the challenges of accounting for overall dietary context when examining the role of FA in disease, the nomenclature used to describe FA, drawing from clinical practice, is imprecise. In particular, the concept of an "essential" fatty acid may be misleading. LA and ALA are considered "essential" because they cannot be synthesized by humans in sufficient amounts to meet physiologic requirements.[137] This terminology dates to 1930 when lab studies demonstrated that deficiency of LA and ALA impaired growth in rats.[138] It has not been amended to account for a more nuanced understanding of the role EFA play in health. Cunnane has argued that standard nutrition sciences inaccurately applies the concept of "essentiality" to the symptoms arising from a lack of *de novo* synthesis of linoleate or alpha-linolenate. Terminology that accounts for this nuanced understanding of the body's capacity for FA synthesis and conservation, which are influenced by developmental age, nutritional context, and disease status, would be more useful.[110] Instead, "conditionally dispensable" or "conditionally indispensable" more accurately describe the body's needs for LA and ALA.

For example, despite the body's ability to convert ALA into DHA, rates are low - usually no higher than 1%.[107,108] This is particularly important for infants, who lack pre-formed tissue stores and draw more heavily on DHA for proper neurocognitive development. Although infants more efficiently convert ALA to DHA than adults, the necessity for DHA in this developmental window may be better described as "conditionally indispensable." In contrast, tissue linoleate stores in healthy adults are equivalent to roughly the average amount consumed in one year. With the body's ability to draw on these stores, LA could be described as "conditionally dispensable."

The more common usage of the "omega" terminology to refer to the *n*-6 and *n*-3 families, particularly in food marketing (e.g. "fish is rich in omega-3"), has obscured more considerable attention to the 23 fatty acids within the *n*-6 and *n*-3 families. This lack of resolution in nomenclature is seen throughout the marketing of "omega-3" enriched spreads, bread, and other "functional" foods, which include high-ALA oils such as flax.[139,140] Soy, canola, and flax oils are often promoted because of their high "omega-3" content compared to other vegetable oils or animal-fats, allowing ultra-processed products to make nutrient claims that based on DHA and EPA, which are functionally and biochemically distinct. Academic work can also be misleading on this front. The "Omega-3 Index," for example, has been proposed as a risk factor for death from coronary heart disease.[16] Combined levels of EPA and DHA in red blood cells of ≥ 8% show the highest protection from CVD, while ≤ 4% with the least.[16] More accurate terminology might refer to an "EPA+DHA Index," particularly given that foods high in these long-chain PUFA do not often overlap with foods high in ALA.

Vegetable Oil Production Trends and Health Considerations

Omega-FA dietary recommendations remain controversial, and various health associations are likely found for differing levels of consumption. Stark et al. posit that in order to achieve high blood levels of EPA+DHA (>8% in erythrocytes), total dietary PUFA must be <2% of total energy in order to minimize competition for Δ-6 desaturase.[112] We calculate that PUFA currently comprises 5.8% of total available energy across the globe, with substantial variation between countries.

Adequate consumption of EPA and DHA appears restricted to populations consuming large amounts of fish or within communities that traditionally hunt and gather. A systematic review of global *n*-3 FA status found 298 studies from 54 countries that measured tissue levels of EPA and DHA. North and South America had comparatively low levels: below 4% in erythrocytes in Canada, the United States, Brazil, and Guatemala. Tissue levels were higher, between 4-6% in Europe, China, and Australia.[112] The regions with the highest levels (>8%) included the Sea of Japan, Scandinavia, and several indigenous populations consuming high amounts of seafood.

This pattern is not limited to high-income countries. The Westernization of diets in LMICs is commonly associated with increased consumption of meat products and animal fats, but the nutrition transition most typically begins with increased production and importation of vegetable oils. Indeed, the global decrease in vegetable oil prices is the most proximate cause of the increase in consumption.[141–143] In the 1930s, 75% of the world's population had a total lipid consumption of less than 30g per capita per day.[132] In the past fifty years, available calories from vegetable oils alone have increased more than any other food product, from 113 kcal/capita/day in 1961 to 271 kcal in 2013, a growth of roughly 140%.[10] In higher-income countries, growth has been even more dramatic. In the United States, per capita availability of vegetable oils increased from 276 kcal/day to 689 kcal/day in the same time period, while animal-fats decreased from 199 to 101 kcal/day.[10]

The Brazilian Dietary Guidelines, the first national dietary guidelines to take into account food processing, state that if used in moderation in culinary preparations based on natural or minimally processed foods, oils and fats can contribute toward diverse diets without rendering them nutritionally unbalanced.[144] Though true, in addition to being a major source of calories in home-cooking, vegetable oils have become an integral component of ultra-processed foods. Among the highest sources of LA in American diets, for example, are grain-based desserts, salad dressings, and chips.[145]

There is evidence to suggest that vegetable oils consumed in such preparations encourage overconsumption. Flavor-nutrient satiety (FN-S) describes the process by which mammals learn about the energy content and satiating quality of foods, adjusting intake to fit energy needs. In mouse models, oils appear to encourage overconsumption more than any other food source. One explanation is that mammals have not evolved regulatory feedback mechanisms for concentrated fat sources.[146] Human studies show similar patterns concerning ultra-processed foods rich in vegetable oils, where processing impairs the brain's ability to sense nutrient content.[147] A likely further reason is the neutral flavor of most vegetable oils – a primary goal of oilseed processing - provides little sensory feedback to the brain.

Processing Gradients: Higher degrees of processing correlate with genome-nutrition divergent FA profiles

The NOVA system is currently the best-established framework for classifying foods based on the degree of processing, from natural and minimally-processed to ultra-processed foods.[148,149] Recent work by Fardet builds upon this system, using textural analyses to create a "technological index" based on physicochemical parameters, food composition, and nutritional indices.[150] However, this system does not offer the ability to make meaningful distinctions between vegetable oils. NOVA categorizes all oils as processed "industrial" products.[144,148] While the Brazilian Dietary Guidelines, the first national guidelines to incorporate the NOVA classification, recommend using oils in small amounts, there is no guidance on how consumers should differentiate between them.[144] A more detailed understanding of the industrial processes employed in oil-seed and oil-crop processing provides nuance absent within the current NOVA framework.

Most large-scale observational studies measure food intake by food groups, such as fruits, red meat, or dairy. These analyses continue to classify vegetable oils (save olive oil, and to a lesser extent, soybean and canola oils) as one group, usually juxtaposed with animal-source fats such as butter.[151] Too narrow an emphasis on saturated or unsaturated fats obscures other frameworks for evaluating differences between vegetable oils. Taking as our basis Stark et al.'s recommendation to minimize LA in the diet, we argue that incorporating food-processing perspectives and building upon NOVA classification provides an improved framework for differentiating between vegetable oils. LA content correlates with the level of processing required to bring oil from its fruit or seed crop to edible form. The high amounts of LA in modern diets are primarily a result of modern oil extraction methods. The most commonly consumed vegetable oils might better be considered ultra-processed products. The various vegetable oil production and processing methods are highlighted below, followed by a discussion of the nutritional considerations of oils through this processing perspective.

Extraction: Extraction is the initial stage in oil processing, where fats are separated from fruit or seed. For palm fruits and olives, mechanical pressing is sufficient to separate oil from the fruit.[152,153] The most common extraction method is through an expeller press, a screw-type machine in which oil from crushed fruits or seeds passes through small openings. Olive oil extracted using this method and kept from other refining techniques except filtration is labeled "extra-virgin." Virgin oils have higher phenol and tocopherol content, higher resistance to oxidation, and more favorably rated sensory characteristics.[154]

Animal-source fats are rendered by heating with dry heat or steam. After render, they can be subjected to any of the same refining and modification processes as vegetable oils. Because of the higher stability of saturated fats, however, this is not necessary for culinary use.[155] Before the development of modern extraction methods, animal fats were the preferred cooking fats because they could be rendered in home kitchens. At the turn of the 20th century, the average American consumed over 8kg of butter and 6 kg of lard per person per year - substantially more than any other fats.[8] All other crops with oil content below 20% (e.g., rapeseed, soybean, or cottonseed) are extracted using a solvent; usually, hexane or methylpentane.[156] After the seeds are ground, they are washed in the solvent, which releases the oils in the seed. Manufacturers then heat the oil solvent blend to boiling point to dissolve the solvent. The oil then moves to the filtering and refining stage.

Filtration and Refining: Filtering and refining change the sensory characteristics of the final oil product. The general goal is to remove flavor and color. The simplest method is to allow sediment to settle over days or weeks. Faster methods include the use of paper filters. While these are sufficient for locally produced vegetable oils, industrial producers speed up the process by using a filtering media like diatomaceous earth in conjunction with various refining techniques.[154,157]

Oil refining removes undesirable impurities from oils and consists of multiple stages that vary by type. In the degumming stage, phosphatide "gums" and entrained oil and meal particles are removed via water (for palm, palm kernel, or olive) or acid process (for canola, sunflower, and other seed oils). Water or acid (usually phosphoric, citric, or malic) is added, allowing the gums to agglomerate where they can then be separated.[158] This necessitates neutralization, in which aqueous alkali are added to remove remaining free acids. Many oils are then bleached by heating to 180-190C mixed with bleaching earth, comprised of various types of clay, which absorb remaining impurities and leave the oils with lighter colors, neutral flavors, and higher oxidative stability.[159]

Modification: Following filtration and refining, producers modify many oils to create textures suitable for various food products (such as margarine spreads) or to improve oxidative stability and shelf-life. The main processes available to alter physical and chemical properties are fractionation, hydrogenation, and interesterification.

In fractionation, producers separate the stearin (solid) and olein (liquid) portions of oil. These can then be added products based on desired textural characteristics. In dry fractionation, producers separate stearin and olein by controlled cooling, a natural process easily seen in coconut oil. The olein portion may then be separated from the stearin through filtration or centrifugation. Solvent fractionation achieves a similar end through the addition of hexane or acetone, though this is expensive and less commonly employed.[160]

Hydrogenation refers to the process by which producers introduce hydrogen gas to oil. Hydrogenation converts double carbon bonds into single carbon bonds, transforming unsaturated FA or their glycerides into saturated (and solid) FA compounds. In most oils, hydrogenation selectively reduces ALA content while retaining a proportion of fats from LA.[15] Greater or full hydrogenation leads to more solid products. Light or "brush" hydrogenation is often performed with oils high in LA, such as soybean or rapeseed, reducing PUFA, ALA in particular, and extending shelf life without significantly altering the physical properties of the oil.[153]

In partial hydrogenation, all PUFAs are reduced and replaced with 18:1 trans-FA. The result is a semi-solid fat with a higher melting point and oxidative stability that can be used as a component of a spread or added to various products - most often ultra-processed foods. Small amounts are also added to products like peanut butter to stabilize and prevent separation. During complete hydrogenation, all unsaturated fats are converted into their saturated analogs, producing "hardstock" rich in stearic acid, with low levels of TFA.

Interesterification is an alternative to hydrogenation in which FA are shifted between triglyceride molecules, altering physical properties of the oil. Through the processes of acidolysis, alcoholysis, glycerolysis, or transesterification, tricyglycerol compositions (and thus texture) are changed while preserving nutritional composition.[161] Depending on the functionality desired, the interesterified fat may have improved spreadability characteristics or an altered melting point. For example, interesterified soft oils like canola or soy can be blended with a hardstock oil (usually palm or some fully hydrogenated oil), reducing the need for hydrogenation and eliminating trans fatty acids from the final product.[153]

In 2015, the United States Food and Drug Administration required all food manufacturers to remove partially hydrogenated oils from products no later than 2018. As a result, interesterified oils will likely increase in market share.[162] A dearth of research interesterified oils on health suggests caution is warranted. In one small trial, partially-hydrogenated and interesterified palm oil were compared to unmodified palm oil; after 4 weeks of supplementation, patients consuming the modified oils showed significantly elevated LDL/HDL ratios and fasting blood glucose.[163] Further research is needed before interesterification becomes accepted practice.

Dietary and Nutritional Considerations of Oil Processing

In the early 1900s, the agribusiness sector promoted solvent extraction because it was highly profitable – “the new and better way,” as it was presented to the American Oil Chemists’ Society in May of 1930 .[164] The ability to extract oil from crops grown primarily for non-food uses is the reason cottonseed, grapeseed, and rice oils are available.[164] The process subsequently made cheaper oil extraction from crops otherwise consumed whole, e.g. soybean. LA content varies across plant species but is generally found in higher amounts in crops with smaller seeds. Notably, these are the oil crops that require more extensive processing to be edible. Comparisons between cooking fats most often use SFA content to differentiate fat and oil types. The Dietary Guidelines for Americans, for example, orders common fats and oils by their SFA levels and do not differentiate between PUFA types.

In contrast, Figure 9 illustrates how the degree of processing required to make an oil suitable for consumption correlates with its *n*-6 content. Oil types are drawn from the Dietary Guidelines for Americans and re-sorted so that they descend from lowest to highest *n*-6 content. In general, oils move from lowest required processing levels (i.e. low heat render for tallow or pressing for olive oil) to higher processing (hexane solvents and interesterification or hydrogenation in cottonseed).

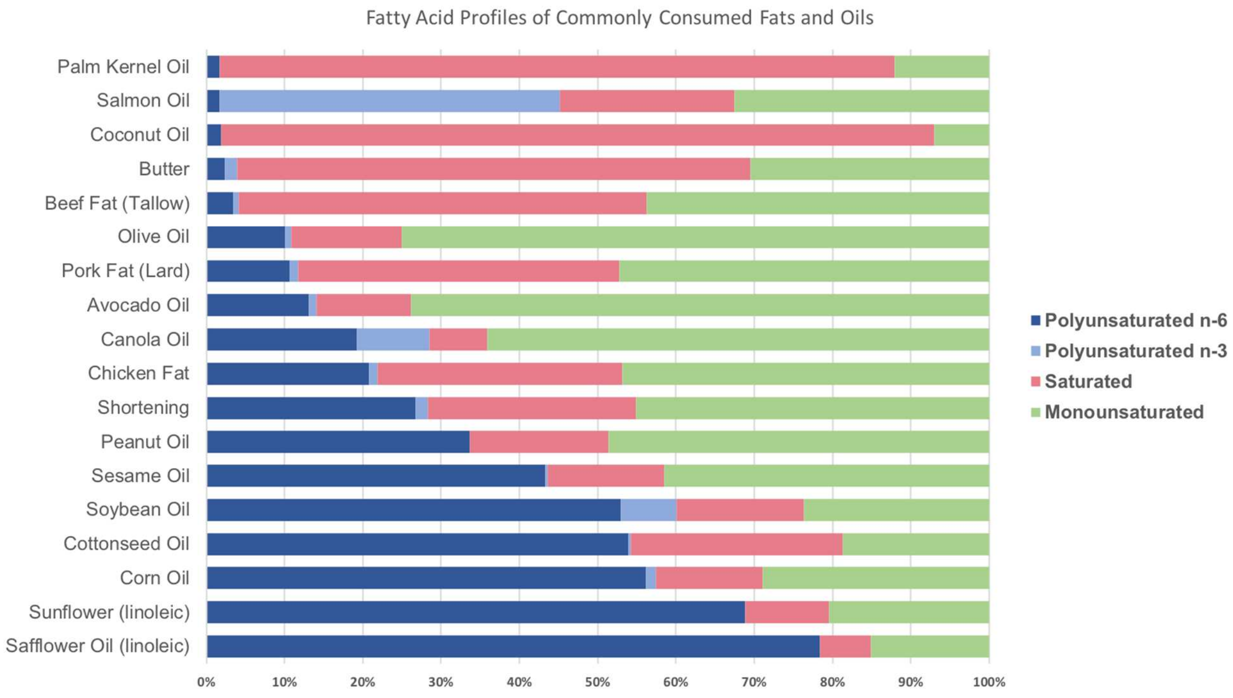

Figure 9: Fatty Acid Profiles of Most Commonly Consumed Vegetable Oils, Adapted from National Dietary Guidelines for Americans 2015-2020

Processing facilitates the consumption of concentrated fat from plants otherwise consumed whole: 100g of boiled soybeans contains 2.66g of *n*-6 and 0.35g of *n*-3, while 100 g of soybean oil contains more than

50g of *n*-6 and 7g of *n-3* FA. Under the recommendation to minimize LA to less than 2% of energy, one tablespoon of soybean oil exceeds limits by over 100% on a standard 2000 kcal diet.[165]

Higher processing also impacts the nutritional value of oil. Refining to obtain neutral flavors and colors decreases the content of nutritionally beneficial compounds. Olive oil is rich in chlorophyll. Chlorophyll is responsible for olive oil's green hue and grassy taste. It also confers a range of health benefits.[166] Red palm oil, still locally produced throughout Africa, is rich in beta-carotene.[152] Supplementation with palm oil can improve maternal and infant serum retinol concentrations and increase concentrations in breast milk.[167,168] The aqueous earth added to oils in the bleaching process binds to and removes these nutrients.[169]

Oil Processing and Food Preparation

Patricia Crotty splits nutrition science into the "post-swallowing" domain (biology, physiology, and biochemistry) and the "pre-swallowing" domain (behavior, culture, and society.[170] Dietary guidelines are based on the post-swallowing domain, while the pre-swallowing domain is comparatively ignored. It may be of particular importance when considering the range of byproducts generated through high heating of cooking oil.

Conjugated lipid hydroperoxydienes (CHPDs) form when LA is heated above 180°C – lower than standard frying temperatures.[171] CHPDs degrade to various secondary products. Most notable of these are aldehydes, some of which are probable carcinogens, while others with endogenously produced aldehydes generated during oxidative stress.[27,172] Much of the cooking oil used by restaurants and street vendors show oxidative products well beyond accepted toxicological ranges.[28,29] In residential contexts, daily cooking with canola oil is shown to produce dangerous levels of volatile organic compounds like formaldehyde.[173] Less processed oils with higher SFA and/or lower LA content are less susceptible to these deleterious effects.[174]

The role of novel and genetically modified crops

An important exception to our framework is genetically modified (GM) or selectively bred crops. Mutant cultivars of crops (particularly soy, canola, peanut, and sunflower) can be selected for higher oleic acid (OA; *n*-9) content. GM varieties of these oils are usually made by targeting the FAD2 gene, which encodes an *n*-6 desaturase that converts OA to LA.[175] However, because the structure of the non-seed plant organs is also impacted through modification, many yields of GM oilseeds have been lower than conventional varieties - although the difference is rapidly decreasing. High-oleic varieties of canola, sunflower, and soybean oil are now widely available in Western markets. Their primary usage is in ultra-processed foods and in deep-frying, where increased stability is needed.[175,176]

Some of these modified oils have positive impacts on health biomarkers. A small trial of high-oleic soybean oil resulted in more favorable cholesterol profiles when compared to traditional soybean oil.[177] A 2015 systematic review found that replacing oils high in *n*-6 PUFA with equivalent amounts of high-oleic oils caused favorable effects on plasma lipid risk factors and overall CHD risk.[178] More research is needed to evaluate the impact of high-oleic crops, both on human health and environmental sustainability.

Essential Fatty Acids, The Environment, and Ecological Perspectives on the Global FA Supply

The nutrition community now recognizes the importance of sustainable food systems research,[179,180] culminating, most notably, in the 2019 EAT-Lancet Commission on Food, Planet, and Health.[181] In applying an ecological perspective to the role of FA, we seek to expand this conversation to include ecosystem functioning and environmental sustainability. We review research, which suggests that FA limitations within ecosystems have cascading effects on animal and human health and apply this to the global food system. In particular, we contrast marine and lacustrine produced fats, animal-source fats, and oilcrops grown within diversified agroecological systems with industrially produced monoculture oilcrops.

Ecological stoichiometry refers to the balance of chemical elements in ecological interactions.[182] The study of nitrogen (N) and phosphorous (P) in agricultural systems is perhaps the best-known example: N and P are the dominant rate-limiting nutrients within ecosystems. Human perturbation of N and P cycles through the use of fertilizers often causes widespread redistribution of nutrients across ecosystems, and long-term impacts on ecosystem dynamics as a result of this are poorly understood.[183] Emerging evidence suggests that EFA may play a similar role in food webs.

Twining et al. have described how the balance of EPA and DHA operates as a limiting factor in ecosystem stability.[184] All vertebrates and most invertebrate groups require DHA for proper tissue functioning; like humans, animal species are unable to produce or synthesize *n*-3 fatty acids endogenously.[108,184] However, highly-unsaturated FA like EPA and DHA are scarce. Their limitation within ecosystems can lead to decreased growth and secondary production across species, similar to the limiting role N and P can play in crop production.

Inadequate dietary EFA and DHA within a food web may lead to improper neurological and hormonal functioning across animal taxa, catalyzing behavioral changes whose effects can cascade across the ecosystem.[184] For example, EFA quality in the diets of tree swallow chicks is more important than food quantity for their growth. In a controlled experiment, chicks grew faster on a lower-caloric diet high in EPA and DHA than on a higher-caloric diet deficient in EPA and DHA. Tree swallows' primary source of EPA and DHA are aquatic insects, suggesting that a loss of the aquatic habitats in which these insects live has played a pivotal role in population decline over time.[185] EPA and DHA limitation may be widespread among all terrestrial animals that evolved with access to aquatic food systems.[186] The full ecological consequence of these losses is not yet understood.

As global food production increases to meet population growth, many marine food-producing ecosystems have been eliminated or pushed beyond their natural carrying capacity.[179] Human population growth has exceeded gains in marine fish landings for nearly 30 years. Catches increased steadily between 1950 and 1990 after which they plateaued at roughly 80 million metric tons globally.[187] Today, over 30% of all marine stocks are overexploited or depleted.[187] Aquaculture offers one way to produce marine foods without taxing ocean-based stocks. However, production is likely to experience the same limitations of EPA and DHA availability if alternative forms of their production are not found.

Alternatives to Seafood-derived EPA and DHA

The majority of EPA and DHA consumed by humans is from lacustrine or marine sources. The high amounts of these FA in marine-based food reflects an intricate food web. Algae is the primary trophic producer of EPA and DHA. Insects and small fish feed on algae, through which EPA and DHA bio-accumulate across the marine food web. Fish species commonly consumed in modern diets, such as salmonids, evolved consuming smaller fish rich in DHA. Like humans, salmonids do not carry mechanisms to convert plant-based EPA and DHA at high enough rates to thrive, requiring the feeding of fish meal and oil to ensure proper fish growth.[188]

Today, aquaculture uses 68% and 88% of the world supply of fishmeal and fish oil, respectively, and demand is estimated to outweigh production soon.[189] Roughly 20% of global fish capture is used in aquaculture. Aquaculture is thus unlikely to offer a viable alternative to supplying human populations with EPA and DHA without greater production of non-marine sources. One untapped source of EPA and DHA may be in freshwater aquaculture applications of not commonly consumed aquatic species. Aquatic amphipods, for example, feed on algae and phytoplankton but are not widely harvested for human consumption.[190] A freshwater pond ~10,000m^2 could supply several tons of EPA and DHA in amphipods. These species are amenable to aquaculture applications, but this remains an understudied area, overshadowed by direct production through algae.

Freshwater algae production is relatively restrictive, as algae require narrow growth conditions in factors such as carbonate, pH, light intensity, and temperature.[190] Indoor applications are more expensive than pond applications due to equipment and labor requirements.[191] In addition, the FA content produced varies markedly by algal species.[184] Current production of algae is predominantly in the form of spirulina, the species most amenable to production. Global production has not been systematically reviewed since 2008, when production numbered 68,000 tons, mostly in China.[187]

Algae is one of the main sources of DHA in infant formula, but has yet to reach wider adoption in other products.[192] The role of algal oil on risk factors for cardiovascular disease (or other conditions) requires further research, but some literature suggests they have a beneficial impact. In a meta-analysis of 11 studies conducted between 1996-2011, algal oil supplementation decreased triglycerides and increase both LDL- and HDL-cholesterol.[193] Of the six studies that measured LDL particle size, five reported an increase and one reported no change, suggesting that algal supplementation may be beneficial despite the increase in LDL-cholesterol.

Still, large questions remain regarding the effectiveness of introducing algal oil directly into the food supply. Consumer acceptance of either the pure oil or oil mixed into food is low.[188] However, algal production can play an important role in ecosystem management, and combined with modified plant-based EPA and DHA sources could serve as a dietary source.[192]

Oilcrops, Animal Husbandry, and Agricultural Systems

The long-term consequences of the 20th-century shift toward industrial agriculture are only beginning to be understood. Consensus on the benefits of diversified agroecological systems as an alternative to industrial agriculture systems continues to grow.[194] Such systems are now recognized to maximize biodiversity, strengthen long-term soil fertility, and support livelihoods. However, because diversified systems produce diverse outputs, their nutritional, ecological, and social impact are difficult to assess.[194,195]

Olive oil, for example, is traditionally harvested from olive groves located in inclined areas and low fertility soils, requiring limited water or resources and increasing biodiversity.[196] Only in the past two decades have producers adopted intensive and more ecologically damaging monocultural set-ups. These systems are largely a result of agricultural subsidies, which were in turn influenced by an intense lobbying push by the industry.[197] Other oilcrops which existed in diets prior to industrial processing include palm oil and coconut oils, both of which play an important role within smallholder agricultural systems.[152,198] As production shifts to intensive monocultural systems, however, negative consequences are seen. In Malaysia, for example, palm oil production has led to the loss of over 1.0 million ha of forest.[199] This has led to a decrease in the diversity of national food production, offset only through increased imports of more diverse foods.[49]

Although livestock are a smaller source of EFA in the current global food system, they offer another critical perspective on the interconnections between animal environments, human nutrition, and global agriculture. Wild game or pasture-raised animals have more desirable fatty acid profiles compared to farmed species, in large part due to difference in diet.[12] Pastured-raised steer, for instance, despite having higher percentages of SFA, have lower percentages of intramuscular fat and lower *n*-6:*n*-3 ratios than conventionally raised cattle, which are largely fed on corn or soybeans.[200] Wild salmon similarly have lower total fat levels and lower *n*-6:*n*-3 ratios.[201]

Animal husbandry almost impacts livestock FA content. Large-scale, industrial meat producers have responded to economic pressure for inexpensive meat by selective breeding and restricting animal exercise, altering fat distribution in animals. Chicken meat has trended both towards higher amounts of fat and higher *n*-6:*n*-3 FA ratios over time. Total fat content has increased from less than 4g/100 g in the late 19th century to over 23g/100g today, with modern ratios *n*-6:*n*-3 FA as high as 9:1.[202] Cereal-based diets and the loss of mitochondria-rich muscle stemming from lack of exercise have reduced DHA specifically, from over 1% of total FA to 0.12-0.21%.[202]

Conclusion

This study quantified, for the first time, changes in the global supply of FA over the past six decades. We refute the hypothesis that the *n*-6:*n*-3 FA ratio has increased in the recent modern era, though our analysis cannot shed light on trends prior to 1961. However, we do show that the global supply of FA has grown larger and less diverse at the same time**.** The intensive focus on minimizing SFA in diets throughout the second half of the 20th century represents a case of problem closure: as soon as the etiology of CVD was considered "solved," alternative nutrition factors and solutions to the rising heart disease in America were no longer considered.[56] As a result, vegetable oils occupy an increasingly prominent role in global in diets and production trends suggest their consumption will continue to increase.

The individual nutrient-centered model remains the dominant framework in nutrition science. Recognizing the interrelations between dietary patterns, foods, and nutrients offer a major step forward in improving dietary guidelines,[203]; however, such an approach is still limited in its ability to describe only what associations already exist within modern food systems – rather than what may be optimal for human health.

In small or moderate amounts, vegetable oils play an essential role in health promotion around the world, mainly through increasing the availability of EFA in LMICs. However, their growth is balanced by multiple trade-offs, including substantial and possibly detrimental increases in the global supply of LA and decreased attention on supplying adequate amounts of EPA and DHA. Policies to better align the global supply of FA are likely only to be effective if enacted upstream from consumers and will require incentives for agribusiness corporations and food manufacturers to supply different foods.[85] Such incentives are likely only to be provided by national and international trade and agricultural policies.[85] To support this, future research in the vegetable oils market might utilize consumption-oriented food supply chain analysis to identify effective intervention points in the global supply of FA.[204] Life-cycle assessment and system dynamics offer unique methodologies to better understand the ecological impact of vegetable oil production and consumption.[205,206]

It is unlikely that nutrition science will arrive at definitive conclusions on the roles of various FA in human health soon. In the absence of such uncertainty, new frameworks can help both to bridge the gap between empirical evidence and dietary guidelines. We have proposed a new framework for assessing cooking fats based on the degree of processing. This perspective is complemented by an evolutionary framework, which we suggest indicates both that high consumption of *n*-6 may be more harmful than demonstrated in the epidemiological literature and that consumption of high amounts of isolated fats of any kind is problematic. In expanding our review and analysis to ecological and systems perspectives, we suggest that aligning food systems to support optimal FA consumption is essential not just for human but animal and environmental health. The prominence of vegetable oils in the food systems today, arising mainly from a narrowly characterized health problem of excess SFA in the diets, suggests the need to develop new frameworks in nutrition that catalyze food system realignment. Evolutionary and processing frameworks highlight the importance of drawing distinctions between vegetable oil types and within processing levels, while ecological perspectives suggest that such changes may be equally crucial for the ecosystem as human health.

Chapter 3: Measuring the Associations Between Ultra-Processed Food and Sugar-Sweetened Beverage Sales and National Nutrient Supplies

Abstract

Background: Staple cereals, sugar, and vegetable oils now comprise over three-quarters of the global calorie supply. An increasingly large percentage of these foods provide input for ultra-processed foods (UPF) and sugar-sweetened beverages (SSB), which are associated with obesity and adverse health outcomes. This study sought to quantify the relationship between UPF, SSB, and national nutrient supply.

Methods: Ninety-six foods encompassing primary commodities and processed commodities (i.e., vegetable oils) from the Food and Agriculture Organization's Food Balance Sheets (FBS) were matched to food items in the United States Department of Agriculture Food Composition Database to calculate national energy and nutrient supplies. Total UPF and SSB sales were calculated for 80 countries using data from Euromonitor International. Multi-level longitudinal models were used to analyze the associations between UPF, SSB, and availability of calories, carbohydrates, sugar, total fat, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), omega-6 fatty acids (FA), omega-3 FA, the omega-6:omega-3 FA ratio, and percentage of calories from non-staple crops (as a proxy for dietary diversity).

Results: Globally, average daily supplies of calories, fat, carbohydrates, and sugar increased by 26%, 61%, 17%, and 30%, respectively. Increases in fatty acids were most substantial in *omega-6* (87%) and *omega-3* (107%), and smaller in MUFA (70.5%) and SFA (42.4%). Globally, a one SD increase in yearly UPF sales (52kg/person) predicted daily per capita increases in the supply of calories (123 kcal), carbohydrates (13g), sugar (4.7g), total fat (7.3g), MUFA (2.6g), and SFA (2.6g). There was no significant association between UPF sales and omega-FA. A one SD increase in yearly SSB sales (40.1 liters/person) predicted increases in the supply of calories (69.4 kcal), carbohydrates (6.8g), and sugar (8.8g).

Conclusion: Sales of UPF and SSB have identifiable impacts on national nutrient supplies and, by implication, population dietary patterns. Results are consistent with individual-level analyses indicating UPF and SSB consumption are positively associated with consumption of calories, sugars, and fats. While transnational corporations seek to frame diet-related non-communicable diseases (DR-NCDs) as issues of individual responsibility, our analysis suggests more robust regulatory measures may be needed to limit the impact of industrial food manufacturers on the global food system.

Introduction

Over the past five decades, national nutrient supplies have increased in calories, protein, and fat, with a growing proportion of those nutrients provided by highly energy-dense foods: animal products, vegetable oils, and sugars.[48] National diets have grown increasingly homogenous, veering towards a global standard food supply. The crop commodities with the highest relative changes in production since 1961 are soybean, sunflower, palm, and rapeseed (canola).[48] Growth has been highest in the global south: between 1980 and 2013, the availability of vegetable oils in developing countries increased by 213%, compared to just 84% in developed countries.[207] This growth has caused marked changes in the amounts and types of fats consumed globally, particularly in high-income countries. In the United States, for example, estimated per capita consumption of soybean oil increased more than 1000-fold between 1909 to 1999.[8] The increase in demand for ultra-processed foods and drinks is one possible driver of this homogeneity, but how UPF sales have influenced dietary supply diversity is not yet understood. What is known is that UPF and SSB sales are growing across nearly all regions.

UPF are products made from processed substances extracted or refined from whole foods.[99,208] These include plant-based oils, hydrogenated oils or fats, flours or starches, sugar variants, and remnants of animal foods, with no or small amounts of whole foods incorporated.[31] In many high-income countries, UPF provide greater than 50% of calories consumed.[32] Consumption is rapidly growing across low- and middle-income countries (LMICs).[33] High UPF consumption is associated with higher rates of all-cause mortality,[209,210] some types of cancer,[211] adverse lipid profiles[40], increased risk of obesity[32,41–43,51], and a range of other diet-related non-communicable diseases (DR-NCDs).[44,212]

SSBs are beverages that have sugars added to increase palatability. The vast majority of SSBs sold are soda (or carbonates) with a small percentage comprised of sweetened coffee or tea, energy drinks, and artificial juices. In many countries, they are the largest source of added sugars in the diet.[213,214] High intake of SSBs is consistently associated with an increased risk of type 2 diabetes mellitus, coronary heart disease, hypertension, and overweight and obesity.[45,46] SSB consumption appears to displace healthier foods in the diet: heavy drinkers eat fewer nutrients and across less diverse food groups.[215] Global consumption is estimated to be over 4 oz a day,[38] while the average American consumes over 200 SSB calories a day.[216] In children and adolescents in high-income countries, SSBs constitute between 10-20% of total calories consumed.[217]

The theory of dietary dependency posits that a country's integration into the global economy, particularly the opening of markets to trade and foreign investment, makes a country dependent upon imports from and investments by multinational processed food firms.[218] As these firms grow more entrenched and powerful within national food systems, small scale farmers either collapse or integrate into the supply chain for commodity crops, providing the inputs for processed foods. As these commodity crops have grown in production and become surplus, their price has decreased. This glut of cheap raw materials, in concert with the development of advanced food processing techniques, ushered in a global food environment now dominated by UPF and SSB.[31] How, exactly, the rise in UPF and SSB influences a country nutrient supply has not yet been studied.

This paper explores the relationship between UPF and SSB sales and national nutrient supply. It addresses three central questions: 1) How do national sales of UPF and SSB shape dietary supplies of total energy, carbohydrates, and sugar? 2) What is the association between UPF sales and national level dietary supplies of fatty-acids and the omega-6:omega-3 fatty acid ratio? 3) Is there an association between sales of ultra-processed foods and national food supply dietary diversity as measured by the share of calories supplied by non-staple foods?

In tackling the issue of diet-related NCDs, the majority of population nutrition research has focused on how to change the behavior of individuals[77] or 'nudge' food environments.[80] Growing consensus suggests upstream approaches have a far greater chance of effectively shifting population dietary patterns toward limited UPF and SSB.[56,81–86] A better understanding of how UPF and SSB have altered nutrient supply at the national level helps to bridge food-based, holistic approaches[54] with the nutrient-level paradigm upon which the majority of nutrition-research is built.[127] In doing so, it makes a stronger case for leveraging national level policy and programming to re-shape food systems for human health.

Methods and Data Sources

Nutrient Database Composition: Data on food group availability was obtained from the Food Balance Sheets (FBS) of the Food and Agriculture Organization (FAO) of the United Nations. FBS provide a comprehensive picture of the pattern of a country's food supply for each year between 1961 and 2013. FBS include 96 primary commodities and several processed commodities (i.e., vegetable oils) available for human consumption. For each food commodity, FBS calculates available supply by adding domestic production and imports and subtracting for quantities exported, fed to livestock, used for seed, processed for non-food uses, and lost during storage and transportation. Each commodity is then divided by the total population of the country to obtain per capita data. Full details of FBS construction are available from the FAO.[129]

We calculated data on the nutrient composition FBS food items by matching them to foods cataloged in the United States Department of Agriculture's (USDA) FoodData Central database.[91] If FBS use an aggregated category where FoodData Central provide disaggregated data (e.g., FBS include "beef" while USDA lists more than ten different beef cuts), we calculated an average of parts. For categories in which FBS record an aggregate category (e.g. "oilcrops – other," which includes linseed, castor oil, and hempseed oil, among others) but FAO production data records the disaggregated food items, we weighted the nutrient profile to match. If a food item was not available in the USDA FoodData Central, we obtained data from the New Zealand Food Composition Database.[92]

Finally, because FBS numbers represent raw, unprocessed food items and nutrient data are generally available for only the edible portion of a food item, we used refuse factors from USDA FoodData Central to calculate edible portions of available foods. The per capita available of every nutrient i in year t and country c can be expressed as:

$$N_{itc} = \sum_{f=1}^{96} N_{fitc}$$

Where f is the FBS food item, t ranges from 1961 to 2013. FBS data was available for 118 countries and territories, included in Appendix A.

The percentage of calories from non-staple crops was used as a proxy for dietary diversity at the national level. This variable was calculated by adding total calories from wheat, rice, maize, sugar, and all vegetable oils and dividing by total available calories.

We compare calculated nutrient supplies with those from the Global Nutrient Database (GND).[219] Although the methodology in calculating nutrient supplies was similar, the GND uses FAO Supply and Utilization Accounts (SUA), which are the disaggregated data source (containing 394 food and agricultural commodities, vs. 96 in FBS) by which FBS are calculated.

Ultra-Processed Food Sales: Euromonitor International is a global market research company that collects sales data on ultra-processed food trends from government statistics, trade associations and industry bodies, trade journals, business press, and other public filings. Euromonitor's Packaged Food database tracks total retail sales of pre-packaged foods, sub-divided into dairy products, oils and fats, baked goods, and pre-packaged meals. Data on total packaged food sales is available for 99 countries between 2005 and 2018.

Because EuroMonitor aggregates ultra-processed foods with processed or minimally processed foods, we excluded any categories with both UPF and minimally processed combined (i.e., sweetened yogurt drinks and dairy). The following categories were used to calculate the final variable for UPF: meal replacements, sauces, dressings, and condiments; sweet spreads; chocolate confectionery; sugar confectionery; savory snacks (such as chips/crisps); sweet biscuits, snack bars, and fruit snacks; and baked goods (which includes ultra-processed and industrial bread, pastries, dessert mixes, frozen baked goods, and cakes). For SSBs, the following categories were included in the variable calculation: soda (soft drinks), carbonates (similar to sodas but marketed as alternatives), energy drinks, sports drinks, and sugar/fruit concentrates.

Covariates

Income: The nutrition transition occurs as country income grows, with the food supply increasing in total calories and proportions of animal products, vegetable oils, and sugars.[4,213,220] UPF and SSB sales are highest in high-income countries, but growing across all levels of development.[221] Data on national income (per capita GDP, calculated in $1000s) were obtained from the World Bank.[222]

Regions: Despite increasing homogenization in the global food supply,[48,83] there remain significant disparities in crop dominance, macronutrient distributions,[12] and micronutrient supplies between regions.[223] UPF and SSB impact will likely vary between regions.[224] We used World Bank regional designations of East Asia and Pacific, Europe and Central Asia, Latin America and the Caribbean, Middle East and North Africa, North America, South Asia, and Sub-Saharan Africa.

Urbanization: Urbanization and migration to cities are shown to increase private investment in the food sector[83,225] and to drive food system transformation.[226] In particular, demand for meat, dairy products, vegetable oils, sugars, and alcohol appears to increase with urbanization.[227,228] There are also more nuanced effects within regions. In Asia, for example, where rice comprises a large percentage of the food supply, urbanization is associated with decreasing demand for and consumption of rice and increasing demand for wheat.[229] Data on urbanization (as a percentage of a country's total population) was collected from United Nations World Urbanization Prospects for the years 2005 to 2015.[230]

Statistical Analysis

Longitudinal multi-level analyses were used to estimate the effects of UPF and SSBs on calorie and nutrient levels. Models were built and analyzed using the lme4[93] package in RStudio (1.2.1335) using a "bottom-up strategy."[94] In the first step, an unconditional growth model was fit with year as the only level-1 predictor, and with the country as the level-2 unit. In the second model, all covariates were included. To assess improvement in the model with the addition of UPF or SSB as predictors, we added each variable separately to the basic covariate model. Improvement in model fit was assessed in two ways. A likelihood ratio test, measured as χ^2, was used to compare the addition of predictor variables to model fit. If the addition of UPF or SSB significantly improved model fit, interactions were explored and tested until a final model was reached. Marginal and conditional R-squared were calculated (following the approach outlined in Nakagawa, 2012[95]) to assess further the impact of increasing covariates in the models. *P*-values for individual variables are presented using the Kenward-Roger approximation for degrees of freedom,[96] which produces acceptable Type 1 error rates even at small sample sizes.[97]

Outcomes

Calories: As the basic unit of food energy, calories were once the predominant focus in nutrition economics and agricultural research, with a substantial amount of attention paid to increasing crop yields and ensuring calorie sufficiency across the globe.[231,232] While calorie insecurity at the national level is now exceedingly rare (there is a global calorie surplus), insufficient energy and food insecurity remains a major driver of undernutrition.[233,234] Greater academic and policy focus now falls on calorie overconsumption, as in the case of menu labeling to decrease calorie-dense orders.[235] While an increasing food supply is the main driver of the obesity epidemic, research shows that calories alone cannot explain the growing prevalence of overweight and obesity.[52,236]

Carbohydrates: Carbohydrates are the majority source of calories across the globe. Estimates of carbohydrate consumption among hunter-gatherers is ~40% of energy, although healthy populations are found among wide macronutrient ratios.[12,60] Excess consumption, particularly of refined carbohydrates, is associated with an increased risk of obesity and type two diabetes.[237,238] More critical is likely the type of carbohydrate, with diets high in glycemic load associated with worse health outcomes.[239]

Fat: Dietary fat has historically engendered substantial controversy.[240] Fat comprises roughly 60% of the human brain and is an essential component of cell membranes throughout the body.[240] Dietary fat must be adequate to meet requirements for EFAs and fat-soluble vitamins, at least 15% of total energy for adults,[241] while the Acceptable Macronutrient Distribution Range (AMDR) is 20-35%.[130]

Saturated Fat: Saturated fats are commonly thought to be associated with increased cardiovascular disease risk, although this is widely (and increasingly) debated.[6,57,98,203] Some analyses show that participants who consume high levels of UPF also consume higher levels of saturated fats.[209] Significant sources include animal-source foods as well as "tropical" oils, notably palm and coconut.

Monounsaturated Fat: Widely regarded as a "healthy fat" due to its prominence in the "Mediterranean" diet, monounsaturated fats (MUFA) are found in high amounts in olive oil and rapeseed oil, nuts, and some animal-source foods such as beef. Most studies show null or decreased cardiovascular risk with MUFA consumption,[242–244] although other studies have regarded the MUFA literature to be lacking sufficient evidence to evaluate causal relationships according to Bradford Hill criteria.[245]

Polyunsaturated Fats: Found predominantly in vegetable oils and to a smaller extent in animal-source foods (particularly poultry), PUFA are generally liquid at room temperature. PUFA include the "essential" fatty acids - alpha-linolenic acid (ALA, 18:3 *omega-3*) and linoleic acid (LA, 18:2 *omega-6*) – which the body either cannot synthesize or cannot synthesize in sufficient amounts to meet physiologic requirements.[137] In some studies, PUFA are not associated with cardiovascular events; in others, they confer a small reduction in risk.[244] Beyond CVD, some evidence suggests high *omega-6* consumption can have negative health impacts. Eicosanoids from *omega-6* are generally inflammatory, while those from *omega-3* are anti-inflammatory.[24] There is evidence that high *omega-6* FA consumption inhibits the anti-inflammatory and inflammation-resolving effect of *omega-3* FA, but the exact roles remain unclear.[246]

Few studies have assessed associations between PUFA consumption and UPF, usually because PUFA are not considered a dietary risk factor in the same way as SFA. However, there is some evidence to suggest that UPF may impact *omega-6* consumption. In the U.S. in 2005-2006, 3 of the top 5 largest food sources of *omega-6* were UPF (grain-based desserts, salad dressings, and potato/corn/other chips).[145]

Omega-6:Omega-3 Ratio: Humans likely evolved in environments in which the ratio between *omega-6* and *omega-3* was 1:1.[11] Today, ratios in "Western" diets range between 6 and 20:1.[15]Higher ratios are hypothesized to contribute to obesity,[18] cancer,[19,20] and CVD.[247,248] There is also some evidence to suggest that lower ratios are associated with higher dietary quality, at least in children.[249]

Dietary Diversity: As a proxy for dietary diversity, we use the percentage of available calories in the country food supply from all foods other than wheat, rice, maize, tubers, or sugar. Similar measures are provided by the FAO and used in an analysis by Remans et al.[49] on the association between food supply diversity and malnutrition outcomes We modified this variable to include sugar given that across the data-set, mean percentage of country calorie availability from sugars was 10%. A high share of UPF in individuals' diets is associated with high consumption of free sugars, total, saturated, and monounsaturated fat, and low consumption of protein, dietary fiber, and vitamins and minerals,[250] while SSB are the largest source of added sugars in most diets.[145] At the national level, diversity of national food supplies is negatively correlated with national prevalence of stunting, wasting, and underweight in children but not associated with overweight.[49] Other studies show that UPF consumption predicts lower dietary quality[221,251], but there is no research on how high UPF consumption influences dietary diversity, either at individual or country-levels.

Results

UPF: Between 2005 and 2018, there was little change in UPF sales or the distribution of sales by categories. Yearly capita sales increased slightly, from 87.4 kg to 87.9 kg. Baked goods comprised substantially more than half of all sales but decreased from a mean value of 54.2 kg/person/year in 2005 to 51.5 kg/person/year in 2018.

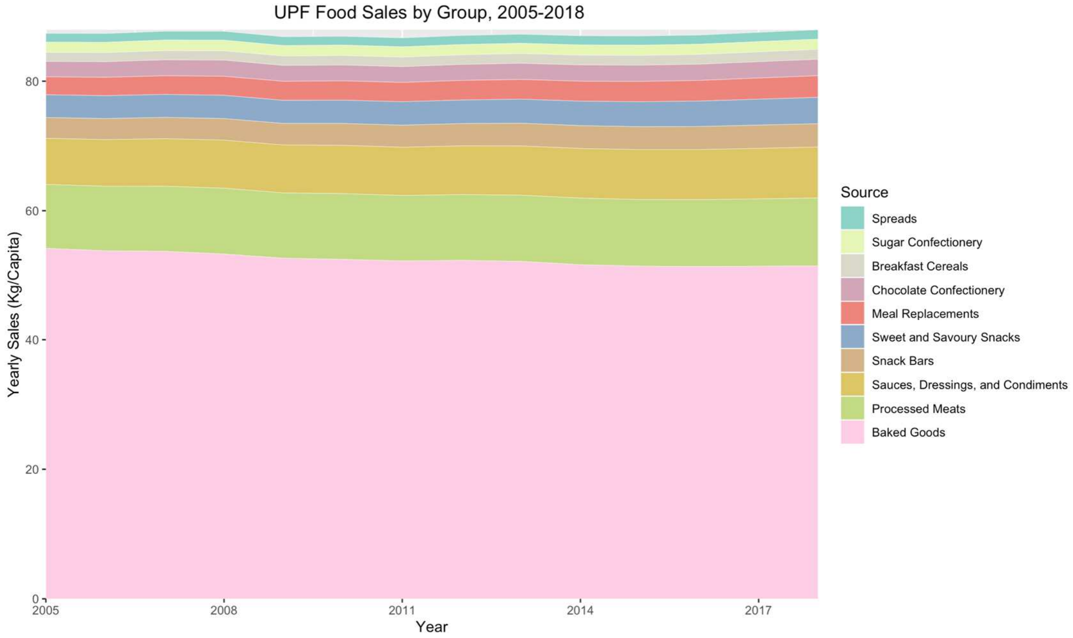

Figure 10: UPF Sales by Group, 2005-2018

Yearly mean per capita sales of SSB decreased slightly, from 60.3 liters in 2005 to 59.2 liters in 2018, largely due to declining sales in North America (155.5 liters in 2005 vs. 120.5 liters in 2018). Carbonates (soda) comprised the large majority of SSB (56.1 liters per person in 2018).

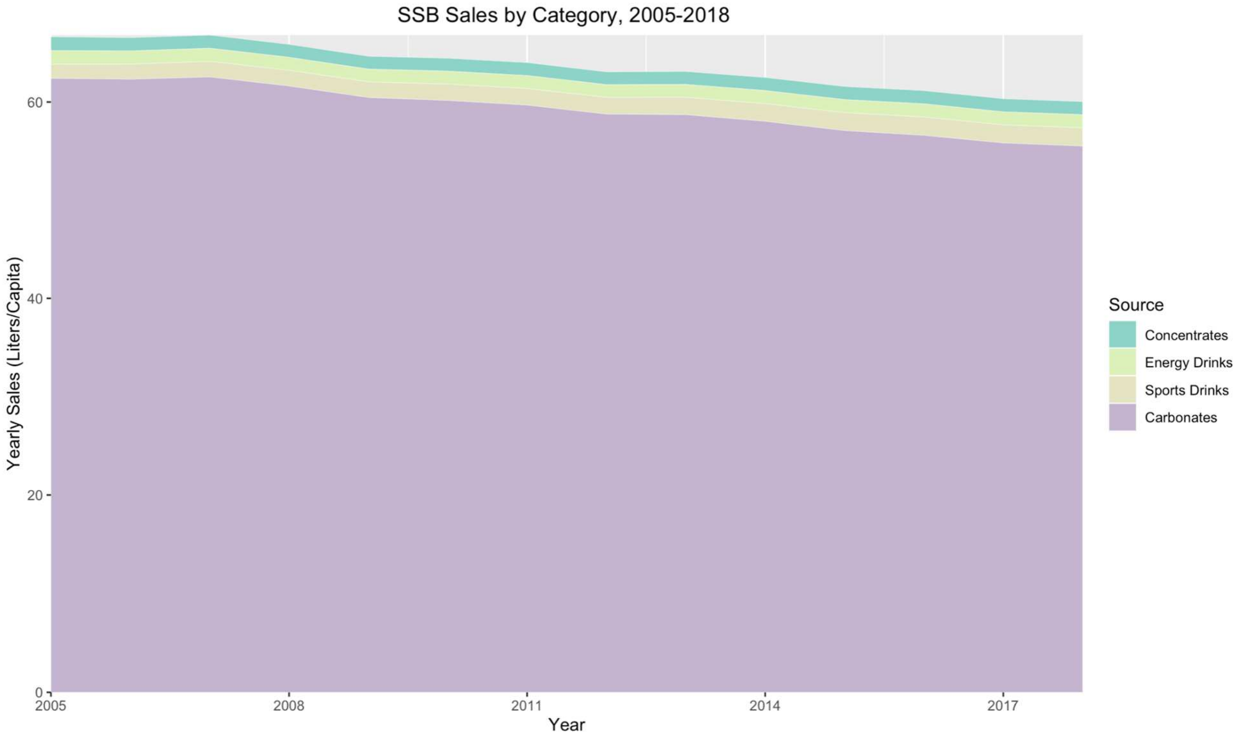

Figure 11: SSB Sales by Category, 2005-2018

Estimates of nutrients and comparisons to other literature:

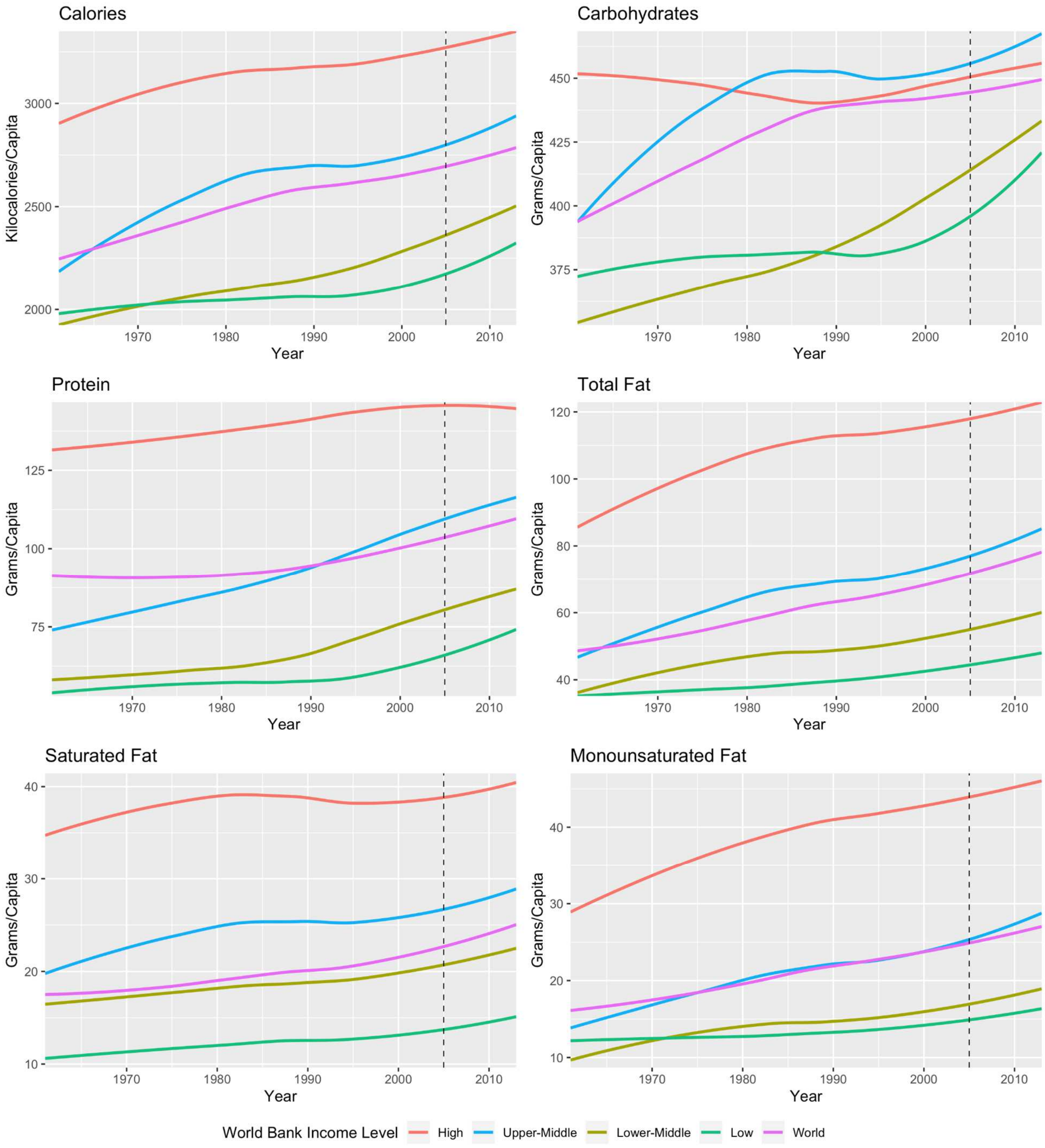

Figure 12: Changes in Selected Mean National Nutrient Availability by World Bank Income Classification, 1961-2013

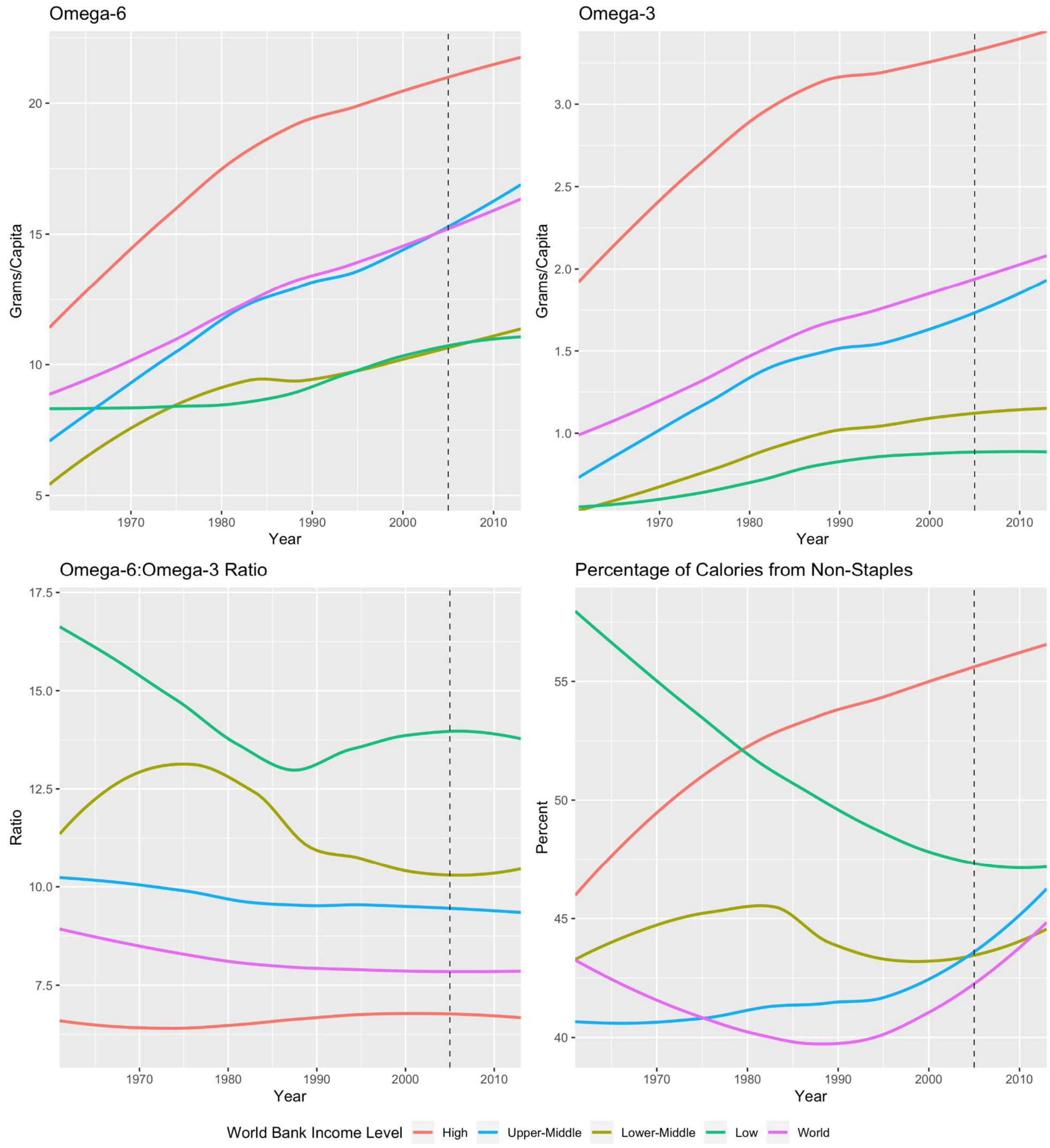

Figure 13: Changes in Selected Mean National Nutrient Availability by World Bank Income Classification, 1961-2013

Calories: The GND estimates that global energy availability increased from 2380 kcal per person per day to 2710 kcal per person per day between 1980 and 2013.[219] Our equivalent estimates were 2481 in 1980 to 2783 in 2013, higher by less than 5%.

Carbohydrates: Globally, cereals are the largest source of energy.[252] By some estimates, they comprise over 2/3 of all calories. According to the GND, carbohydrate supply rose from 430 g per person per day to 473 g per person per day in 2013.[219] Our estimates were similar, at 424 g in 1980 and 452 g in 2013 – differences of 1.4% and 4.4% respectively.

Fat: The GND estimated total fat availability at 72 g per person per day in 2013, up from 54 g in 1980.[219] Our estimates diverged by 5%: 57 g in 1980 and 76 g in 2013.

Omega-6 Fatty Acids: Micha et al. estimated global omega-*6* PUFA consumption in 2010 at 5.9% of total energy or roughly 13.1 g per person per day.[113] Our estimate is substantially lower than the 6.1 g per person per day total PUFA in 2013 (non-differentiated) estimated in the GND.[219] Our estimates were higher than either but much closer in line to Micha et al., at 13.7 g per person per day in 1980 and 18.4 g in 2013.

Omega-3 Fatty Acids: Micha et al. estimated global plant-based omega-*3* consumption at 1.371 g per person per day,[95] markedly lower than the GND estimates, which in 2013 were ~0.18 g per. By comparison, we estimated daily per capita availability to be 1.47 g in 1980 and 2.03 g in 2013. We explore possible reasons for discrepancies are in the limitations.

Results

Calories: Final models are presented in Table 3.1. Between 2005 and 2013 in the countries included in the model, average per capita calorie availability increased from 2977 to 3057, or roughly 10 kcal (SD=0.8) every year. The addition of UPF and SSB both separately and combined significantly improved model fit according to likelihood ratio tests, with the inclusion of both (Model 3) decreasing AIC by 50 points, $\chi^2=53.56$, $p<.001$. There was a significant positive association between both UPF and SSB sales and calorie availability. For every 1kg/capita/year increase in UPF sales, energy availability increased 2.7 kcal, or 166.4 kcal for every SD increase in UPF (53.68kg/p/y in 2005). The effect size of SSBs was slightly smaller, where every 1liter increase in SSBs predicted a 1.73kcal increase, or 71.6 kcal for every SD increase in SSB sales (41.4 liters/p/y in 2005).

Various interactions were tested. The largest improvement in model fit (reduction in AIC from 9301 in Model 3 to 9225 in Model 4) was found in the interaction between year and region, which indicated steeper slopes in the increasing calorie supply in MENA, Sub-Saharan Africa, and Latin-America. There was a decreasing calorie supply in North America. While UPF and SSB had a minimal impact on marginal R-squared value, their estimates nonetheless explain substantial variation within the global calorie supply. A country 1 SD above the median in both UPF and SSB would have an estimated ~230 calories greater energy supply (Model 3).

Carbohydrates: Final models are presented in Table 3.2. Between 2005 and 2013 in the countries included in the model, average per capita carbohydrate availability increased ~0.8g/day, from 459.3 at baseline. The addition of UPF and SSB both separately and combined significantly improved model fit according to likelihood ratio tests ($\chi2=14.42$, $p<.001$, Model 3 compared to model 2.) The joint effect of UPF and SSB is presented in Model 3.

Similar to calories, there was a significant positive association between both UPF and SSB availability and carbohydrate availability. In the full model (Model 3) for every 1kg/capita increase in UPF sales, carbohydrate availability increased 0.25g/capita, or, for every SD increase in UPF, carbohydrate availability increased 17.17g/capita. For SSBs, every 1-liter increase predicted a 0.17g increase in carbohydrate availability, or ~7 g for every SD increase.

The interaction model (Model 4) indicates that the association between UPF and carbohydrates diminishes over time. Over the nine-year period, an increase of 10kg UPF per capita would decrease from 2.3 g in 2005 to 0.7 g in 2013. No effect was found for an interaction between year and SSBs, and SSBs were not significant when the interaction was included.

Sugar: Full models are presented in Table 3.3. Both UPF and SSB, independently and combined (Model 3), improved model fit over the demographic model alone. The magnitude of SSB sales was larger than UPF, with every 1-liter increase predicting a 0.22g increase in daily sugar availability, compared to a 0.09g increase for UPF.

A significant interaction was found between SSB sales and region. This interaction reflects opposing trends between regions, in which SSB sales and the supply of sugar is decreasing in some areas - such as Europe - but increasing in South Asia. The trend is reflected in Figure 2, which shows that increasing SSBs sales are predicted to have a larger relative impact on sugar supply in Sub-Saharan Africa and South Asia, and to a lesser extent, in North America and Middle East & North Africa. While the standard error was high due to smaller sample size in South Asia and Sub-Saharan Africa, these trends illustrate an identifiable impact of SSBs on the sugar supply in these regions.

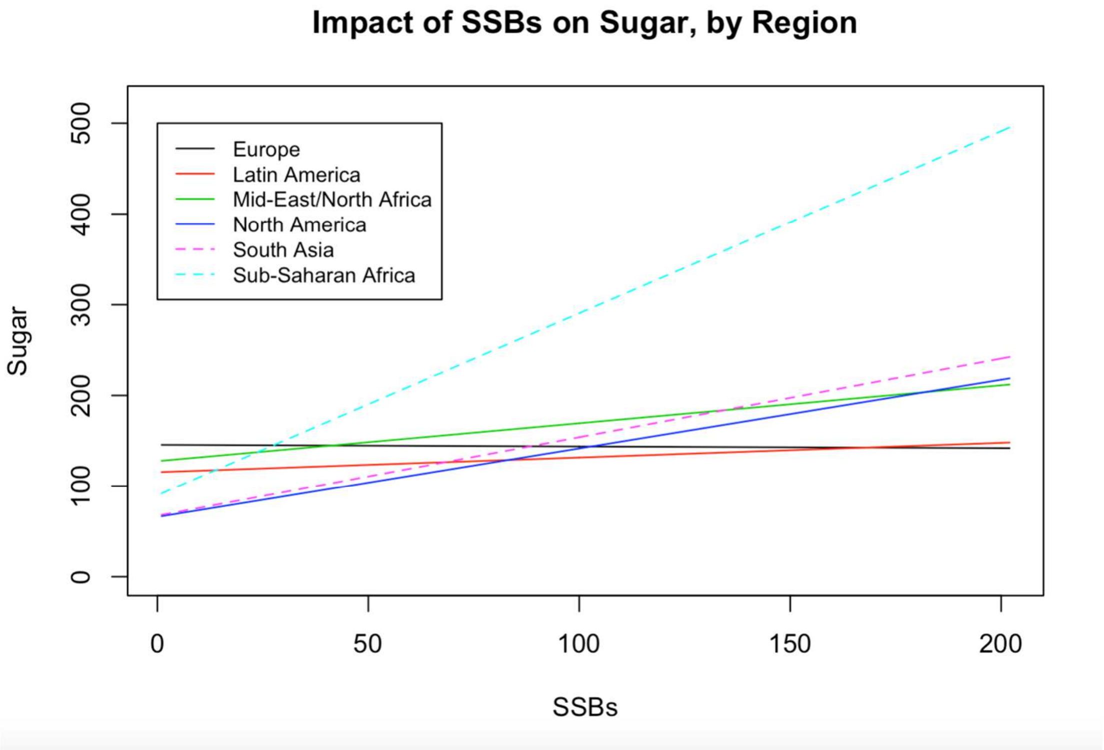

Figure 14: Estimated Differential Impact of SSB Sales on National Availability of Sugar (g/person/day)

Fat: Full Models are presented in Table 3.4. Average total fat availability across the study sample was 90.7 g per person per day in 2005, with availability increasing yearly by 0.63 g (Table 4, Model 1). Compared to the demographic model (Model 2), the inclusion of UPF (Model 3) improved model fit, χ^2=17.92, *p*<.001. Every 1 kg increase in UPF sales was associated with a 0.14 g increase in daily fat availability, or roughly 7.5 g for every 1 SD increase in UPF.

When taking into account a significant interaction between year and GDP (Model 4), the impact of UPF decreased to a 0.09 g increase in total fat availability with every 1 kg increase UPF.

Omega-6: Full models are presented in Table 3.5. Average estimated daily per capita *omega-6* availability in the study sample was 17.53g in 2005, increasing 0.09 each year. There was no significant association between UPF sales when comparing Model 3 to the demographic model (Model 2), χ^2=2.04, *p*=0.15. While there was a significant interaction between year and region, reduction in AIC was minimal (from 3005 to 3001) and is not presented.

Omega-3: Full models are presented in Table 3.6. Average estimated daily per capita *omega-3* availability in the study sample was 2.276, increasing marginally, but significantly, 0.009 g per year. Similar to the *omega-6* model, there was no significant association between UPF sales and *omega-3* availability, χ^2=1.90, *p*=0.16. There were significant associations between urbanization and GDP. At a SD of 20.0 for urbanization and 19.4 for GDP ($1000s), 1 SD increases predicted an increase in daily per capita *omega-3* availability of 0.43 g and 0.13 g.

Omega-6:Omega-3 Ratio The average estimated *omega-6*:*omega-3* FA ratio in the study sample was 9.08 in 2005 (Table 3.7, Model 1). Although in the unconditional growth model, estimates showed the FA ratio increasing roughly 0.004 g each year, the standard error was high (0.011), and time was not significant. The demographic model marginally and significantly improved on the unconditional growth model (χ^2=16.218, *p*=.039), but AIC showed almost no improvement (2431.9 to 2431.7). There was no significant improvement with the inclusion of UPF (χ^2=0.0016, *p*=0.96), and AIC estimates showed poorer fit due to the inclusion of additional predictors. Marginal r-squared was also very low compared to other outcomes: 0.125. In all other models, R-squared reached between 0.5 and 0.8.

Monounsaturated Fat Average estimated availability of MUFA was 32.59 g per person per day in 2005, increasing 0.3 g each year (Table 3.8, Model 1). Inclusion of UPF (Model 3) significantly improved model fit compared to the demographic model (Model 2), χ^2=11.704, *p*<.001. Every 1kg increase in UPF sales predicted a 0.54 g increase in MUFA, or an increase of 2.9 g for every SD increase in UPF sales. Like the total fat model, a significant interaction was found between year and GDP, showing negative trends in countries with GDP per capita above $50,000, but positive trends in those below (Figure 4).

Saturated Fat: In the unconditional growth model, average SFA availability was 29.7 in 2005, increasing 0.17 g each year (Table 3.9, Model 1). The addition of UPF (Model 3) significantly improved model fit over the demographic model (Model 2), χ^2=16.60, *p*<.001. There was a significant association between UPF and SFA, where every 1kg increase in UPF sales predicted a 0.054 increase in SFA, or a

2.9-gram daily per capita availability increase for every SD increase in UPF. Like total fat and MUFA, there was a significant interaction (Model 4) between year and GDP, reflecting a decreasing SFA supply in high-income countries and an increasing supply in lower-income countries. UPF remained significant in the interaction model (p=0.018), although its estimated impact was reduced from 0.05 to 0.03 g for every 1 kg increase.

Percentage of Calories from Non-Staples: Across the study sample, the average percentage of calories from non-staple crops was 45.3%, increasing 0.19% on average each year between 2005 and 2013 (Table 3.10, Model 1). UPF and SSB both independently and combined significantly improved model fit over the demographic model (Model 3 vs. Model 2, χ^2=15.58, p<0.001). A 1 SD increase in UPF predicted a 1.6% increase in the percentage of calories from non-staple crops, while the equivalent increase in SSB predicted a 0.8% increase. There was also a significant interaction between SSB and region (Model 4). This likely captures divergent SSB sales trends across regions. Most notably, the estimates indicate that SSB sales are positively associated with percentage of the food supply from non-staple crops South Asia but negatively associated with the metric in Sub-Saharan Africa and MENA.

Discussion

Our results indicate that global growth in UPF and SSB has had a small but identifiable impact on national nutrient supplies. Globally, a one SD increase in yearly UPF sales predicted daily per capita increases in a country's supply of calories (123 kcal), carbohydrates (13g), sugar (4.7g), total fat (7.3g), MUFA (2.6g), and SFA (2.6g). A one SD increase in yearly SSB sales (40.1 liters/person) predicted increases in the supply of calories (69.4 kcal), carbohydrates (6.8g), and sugar (8.8g). There was no association between UPF and omega-6 FA, omega-3 FA, or the *omega-6:omega-3* FA ratio. To our knowledge, this is the first study to show that the supply of UPF and SSB (measured by proxy through sales) is associated with changes in national nutrient supply.

One possible explanation for these patterns is that transnational food and beverage corporations shape global and local food systems through their influence across the supply chain, shifting availability, price, desirability, and ultimate consumption of other foods.[218] The theory of dietary dependency suggests that corporations have substantial enough influence to shape national agricultural systems or imports to provide greater materials for food processing. Our findings that carbohydrates, fats, and sugars are higher in countries with higher UPF and SSB sales is consistent with this finding. We also show that in some regions – MENA, Sub-Saharan Africa, and Latin America and Caribbean – there is an inverse relationship between SSB sales and country supply of foods from non-staple crops. In other words, while some regions experience increased dietary diversity with growth in the processed foods industry others may a see a trade-off, in which production or importation of staple crops used in UPF or SSB, displaces more diverse food groups. Further research might examine this pattern in granularity, identifying which, if any, food groups are more or less likely to be displaced.

Our findings are similar to studies which have identified how UPF and SSB consumption alters individual dietary patterns. Two studies in Brazil showed that higher UPF consumption is associated with higher calories, total fat, saturated fat, and free sugars,[250,253] Another analysis of French adults found that the highest quartile UPF and SSB consumption group had higher intakes of energy (145.7 kcal/d) and added sugar (17.1g/day). In Canada, adults in the highest quintile of consumption consumed more carbohydrates, substantially more free sugars (15.2% of total energy vs. 6.3% of total energy between highest and lowest quintile), and higher proportions of energy intake from total fats and saturated fat.[254]

Both UPF and SSBs predicted increases in total available sugar. Availability is already extremely high in the countries surveyed: equivalent to 560 calories per person per day globally. Growing consensus calls for taxation of SSBs as a way to decrease the availability of SSBs at the individual level.[255–257] Less attention has been paid to the supply side and expanding availability to sugar in the first place. The divergent growth in UPF and SSB sales in Sub-Saharan Africa and South Asia, coupled with the associations between the sugar supply, suggests a need for supply-side oriented policies. India and China, for example, are already two of the top five largest SSB markets.[258] While it is likely that the impact of SSBs will level off after a period of time, our models suggest their influence may have a larger effect on untapped markets – particularly South Asia and Sub-Saharan Africa – in the future.

Recommended intake levels for saturated fat are less than 10% of total energy.[130,259] In 2005, daily global mean SFA availability equated to 267 calories, or 9.0% of the total energy supply. However, saturated fats were greater than 10% of total energy in 27 out of the 89 countries sampled, all but 5 of which were high-income. While models suggest SFA availability is decreasing in high-income countries, UPF sales are predicted to increase SFA availability by .031 g per kg of yearly UPF sales (Model 4). At the highest ends of UPF sales, this equates to up to 6.2 g per person per day additional SFA, for example, in Mexico, and 4.8 g per person per day in the United States.

This analysis shows that the omega-6:omega-3 FA ratio has remained stagnant or even decreased over time. At current rates of growth, at least in the study sample, the ratio is likely to increase, though marginally, with omega-6 increasing at 0.09 g per year, compared to just 0.01 annual estimated increase in omega-3. Contrary to our hypothesis, the models showed no significant association between UPF and the availability of any omega FAs in the countries for which data was available. Indeed, none of the covariates included in the demographic model significantly improved model fit for the omega FA ratio. There are several interpretations for this finding. First, although it is well established that UPF have altered FA intake in high-income countries, the impact on global diets and nutrients consumed may be too small to be measurable. Second UPF are higher in high-income countries where dietary diversity and omega-3 are also high. Finally, our analysis has shown that omega-6 and *omega-3* growth were highest between 1961 and 1990, with growth rates leveling off since then. A longer timeline of UPF data would shed light on this question.

Our finding that food diversity increases in concert with UPF and SSB sales is best explained by the relationship between UPF and SSB sales and country income. Remans et al. have shown that the diversity of national food supplies is positively associated with a country's level of development.[49] In this sense, economic growth brings a double-edged sword to country food supply. Supermarkets, for example, are shown both to diversify dietary availability but also to reduce the ability of marginalized populations in particular to purchase higher-quality foods, encouraging instead the consumption of UPF.[220] This is well documented in Kenya, where proximity to supermarkets is associated with decreased rates of child undernutrition due to increased dietary diversity, but increased risks of adult obesity.[260,261] Further research could explore in more nuance the reasons that dietary diversity increases with SSB sales in South Asia but decreases with SSB sales in MENA and Sub-Saharan Africa. One analysis has shown that Malaysia's dietary diversity, which was once obtained through indigenous production, is now totally dependent on imports because so much land has been converted to palm oil production.[262] It is possible that other countries with the regions have followed a similar pattern, either due to local sugar production or preferential importation of sugars over other foods.

As global diets grow more homogenous, the need to effect solutions on a global scale has become more evident.[263] Although it is estimated that the global food supply is sufficient to meet average nutrient demands for the aggregate global population, severe disparities exist between regions and countries.[264] Historically, state policies have incentivized the production of staple crops, oilseeds, and sugar.[265] The increased productivity of cereals and oilseeds provided inexpensive feed for livestock and raw ingredients for UPF, arguably increasing the risk for obesity and other diet-related NCDs. Shaping food systems to deliver improved nutrition requires sound policies, regulations, and investments across the global supply chain.[266] Given the prominence of UPF and SSB in the global food landscape, this study sought to understand what, if any, identifiable impacts UPF have had on national nutrient supplies.

There are major limitations to our analysis. In using national-level data, we were not able to identify relationships UPF/SSB sales and individual or household diets. Although national food environments ultimately influence individual dietary patterns, these are highly variable within countries and likely to be different between regions, socioeconomic status, and gender.[234,267] Nevertheless, smaller scale studies show a trickle-down effect from local environment to individual diets. There are clear associations between UPF and SSB availability and the amounts of energy, saturated fat, and sugar in supermarkets.[268] The literature on food deserts similarly illustrates that when UPF come dominate market environments, dietary patterns grow more energy-dense and rich in fats and sugar.[269] Further research might endeavor to understand how closely coupled are the positive and negative aspects of a homogenizing food supply and what policies may better support diversifying diets while limiting UPF spread.

As with any observational analysis, we cannot identify causality in the association between the growth of UPF and SSBs with national dietary supplies. We cannot rule out endogeneity between UPF and SSB sales and our outcomes of interest. More pointedly, FAO FBS from which we calculated country nutrient supply are known to have several limitations. FBS encompass the vast majority of food produced in a country but do not capture foods not included in primary commodities - notably indigenous crops.[129] FBS are based only on estimates drawn from multiple sources and their accuracy may vary between countries. The Global Nutrient Database compared estimates from FAO supply and utilization accounts (on which FBS are based) and three national dietary surveys, finding the out-of-sample correlation between predicted and observed intake for greater than 0.8.[219] We used averages for the most commonly caught and consumed fish in our calculations, but because omega-3 FA content varies widely between fish species and rearing methods, the confidence interval should be regarded as wide. In addition, we cannot account for the wide variety of oil crop cultivars with FA content that varies, sometimes substantially, from the amounts listed in the USDA Database.[177,178]

Despite these limitations, our results provide important preliminary evidence that national nutrient supplies are influenced by UPF and SSB sales. We offer corroboration of the theory of dietary dependency,[218] showing that national nutrient supplies are, in part, a function of corporate influence. More pointedly, the outsize impact of UPF and SSB sales on the nutrient supplies (particularly free sugars) in South Asia and Sub-Saharan Africa suggests that without mitigation, low and middle-income countries are likely to see “Westernization” of the national food supply far faster than was achieved in high-income countries over the past half century.[218] Our findings help to illustrate the importance of independent monitoring sales and consumption of UPF and SSB globally. Further studies are needed to understand how best to limit corporate influence across all food systems; low-income contexts in particular offer an opportunity to avert penetration by industrial food manufacturers before they are entrenched.

Table 3.1: Association between UPF and SSB Sales and National Supply of Calories

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF/SSB**			**Model 4 Interactions**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	2976.65	61.23	<0.001	1994.43	125.77	<0.001	2061.96	127.03	<0.001	2217.55	128.96	<0.001
Year	10.02	0.84	<0.001	5.15	1.09	<0.001	6.57	1.10	<0.001	14.31	2.47	<0.001
Europe				590.75	100.27	<0.001	410.02	106.92	<0.001	505.90	109.02	<0.001
Latin Amer./Carib				-302.79	114.35	0.009	-411.62	118.01	0.001	-317.98	120.13	0.002
Mid. East/N. Africa				344.74	122.66	<0.001	277.83	125.88	0.030	343.26	128.46	0.010
North America				843.54	223.73	0.010	535.04	231.76	0.023	748.96	236.91	0.069
South Asia				102.88	122.66	0.528	107.76	165.40	0.516	23.55	167.89	0.501
Sub-Saharan Africa				-225.36	162.54	0.091	-203.61	134.91	0.135	-252.44	137.17	<0.001
Urbanization %				12.02	1.61	<0.001	8.44	1.67	<0.001	5.35	1.71	0.002
GDP ($1000s)				0.91	0.70	0.196	-0.18	0.70	0.795	0.47	0.70	0.501
UPF Sales (kg/p/y)							2.37	0.53	<0.001	2.39	0.52	0.010
SSB Sales (L/c/y)							1.73	0.40	<0.001	1.12	0.40	<0.001

Year * Europe										-14.06	2.58	<0.001
Year * Latin Amer./Carib										-2.33	2.94	0.429
Year * Mid. East/N. Africa										-0.89	3.06	0.772
Year * North America										-24.30	5.72	<0.001
Year * South Asia										-4.48	3.98	0.261
Year * Sub-Saharan Africa										-1.83	3.32	0.581
Random Effects												
σ^2	3758.70			3701.88			3429.34			3154.55		
τ_{00}	335977.35 $_{\text{country}}$			81382.66 $_{\text{country}}$			84615.01 $_{\text{country}}$			86878.41 $_{\text{country}}$		
ICC	0.99			0.96			0.96			0.96		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.002 / 0.989			0.747 / 0.989			0.749 / 0.990			0.732 / 0.991		
AIC	9552.0			9351.6			9301.5			9226.0		

Table 3.2: Association between UPF and SSB Sales and National Supply of Carbohydrates

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF/SSB**			**Model 4 Interactions**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	459.29	7.89	<0.001	374.91	24.89	<0.001	379.08	25.47	<0.001	397.26	25.30	<0.001
Year	0.78	0.16	<0.001	0.62	0.21	0.003	0.74	0.33	0.001	2.12	26.95	<0.001
Europe				44.14	20.08	0.030	24.81	21.57	0.253	33.91	21.34	0.115
Latin Amer./Carib				-47.68	22.88	0.040	-58.88	23.84	0.015	-45.99	23.63	0.479
Mid. East/N. Africa				109.89	24.54	0.031	102.07	25.44	<0.001	113.79	25.19	<0.001
North America				30.16	44.80	0.502	-2.46	46.82	0.958	12.12	46.28	0.794
South Asia				45.02	32.49	0.169	47.15	33.42	0.162	34.17	33.04	0.030
Sub-Saharan Africa				-8.30	26.53	0.754	-4.95	27.28	0.857	-12.15	26.94	0.653
Urbanization %				1.01	0.313	0.001	0.69	0.33	0.038	0.30	0.33	0.366
GDP ($1000s)				-0.29	0.32	0.028	-0.39	0.14	0.030	-0.10	0.14	0.142
UPF Sales (kg/p/y)							0.25	0.10	0.017	0.23	0.10	0.024
SSB Sales (L/c/y)							0.17	0.08	0.029	0.11	0.08	0.14
Year * UPF Sales (kg/p/y)										-0.02	0.00	<0.001
Random Effects												

σ^2	134.27	131.73	128.53	123.36
τ_{00}	5550.60 $_{country}$	3268.38 $_{country}$	3466.85 $_{country}$	3377.43 $_{country}$
ICC	0.98	0.96	0.96	0.96
N	90 $_{country}$	90 $_{country}$	90 $_{country}$	90 $_{country}$
Observations	809	809	809	809
Marginal R^2 / Conditional R^2	0.001 / 0.976	0.442 / 0.978	0.437 / 0.980	0.429 / 0.980
AIC	6794.5	6696.1	6691.4	6670.5

Table 3.3: Association between UPF and SSB Sales and National Supply of Sugar

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF/SSB**			**Model 4 Interactions**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	139.11	5.43	<0.001	36.56	14.32	0.012	42.24	13.72	0.002	31.83	13.82	0.022
Year	0.09	0.09	0.317	-0.42	0.12	0.001	-0.35	0.122	0.005	-0.38	0.13	0.003
Europe				47.22	11.51	<0.001	37.15	11.48	0.002	80.45	13.83	<0.001
Latin Amer./Carib				24.61	13.12	0.064	12.72	12.65	0.317	50.26	18.81	0.190
Mid. East/N. Africa				40.81	14.07	0.005	38.35	13.48	0.006	62.44	0.06	0.001
North America				74.45	25.68	0.005	48.50	24.83	0.054	0.77	1.32	<0.001
South Asia				14.53	18.64	0.437	14.25	17.72	0.423	24.77	0.08	0.190
Sub-Saharan Africa				-10.24	15.18	0.601	-10.00	14.44	0.490	2.15	38.46	0.891

Urbanization %				1.14	0.18	<0.001	0.88	0.18	<0.001	0.57	0.19	0.003
GDP ($1000s)				0.16	0.07	0.042	0.10	0.07	0.203	0.24	0.07	0.003
UPF Sales (kg/p/y)							0.09	0.06	0.132	0.08	0.06	0.179
SSB Sales (L/c/y)							0.22	0.04	<0.001	1.13	0.21	<0.001
South Asia * SSB Sales (L/c/y)										0.88	1.32	0.507
Europe * SSB Sales (L/c/y)										-1.15	0.23	<0.001
Sub-Saharan Africa * SSB Sales (L/c/y)										-0.26	0.31	0.409
Latin Amer./Carib * SSB Sales (L/c/y)										-0.97	0.22	<0.001
Mid. East/N. Africa * SSB Sales (L/c/y)										-0.71	0.23	0.002
North America * SSB Sales (L/c/y)										-0.37	0.29	<0.001
Random Effects												
σ^2	45.49			44.70			43.29			41.22		
τ_{00}	2631.71_{country}			1073.66_{country}			966.87_{country}			931.20_{country}		
ICC	0.98			0.96			0.96			0.96		
N	90_{country}			90_{country}			90_{country}			90_{country}		
Observations	809			809			809			809		

Marginal R^2 / Conditional R^2	0.000 / 0.983	0.587 / 0.984	0.621 / 0.984	0.653 / 0.985
AIC	5950.9	5830.0	5808.7	5782.9

Table 3.4: Association between UPF Sales and National Supply of Total Fat

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF**			**Model 4 Interactions**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	90.70	4.21	<0.001	36.23	9.10	<0.001	37.13	8.98	<0.001	43.09	8.96	<0.001
Year	0.63	0.05	<0.001	0.30	0.07	<0.001	0.36	0.07	0.010	0.59	0.06	<0.001
Europe				38.38	7.62	<0.001	29.84	7.77	<0.001	32.90	7.75	<0.001
Latin Amer./Carib				-4.89	8.67	0.574	-6.25	8.55	0.467	-2.48	8.53	0.772
Mid. East/N. Africa				2.84	9.29	0.760	-1.32	9.21	0.886	2.90	9.19	0.753
North America				74.60	16.98	<0.001	65.53	16.87	<0.001	68.06	16.80	<0.001
South Asia				-7.14	12.27	0.562	-5.97	12.09	0.623	-9.56	12.05	0.429
Sub-Saharan Africa				-14.43	10.02	0.154	-12.41	9.89	0.213	-14.36	9.85	0.148
Urbanization %				0.61	0.11	<0.001	0.51	0.11	<0.001	0.38	0.11	0.001
GDP ($1000s)				0.16	0.14	<0.001	0.11	0.04	0.010	0.33	0.06	<0.001
UPF Sales (kg/p/y)							0.14	0.03	<0.001	0.09	0.08	0.006

Year * GDP ($1000s)										-0.02	0.003	<0.001
Random Effects												
σ^2	13.11			13.33			13.07			12.51		
τ_{00}	1587.78 $_{\text{country}}$			472.72 $_{\text{country}}$			459.00 $_{\text{country}}$			455.08 $_{\text{country}}$		
ICC	0.99			0.97			0.97			0.97		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.002 / 0.992			0.666 / 0.991			0.679 / 0.991			0.676 / 0.991		
AIC	5012.670			4895.366			4884.757			4863.215		

Table 3.5: Association between UPF Sales and National Supply of Omega-6 Fatty Acids

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	17.535	0.815	<0.001	5.029	2.167	0.022	5.196	2.159	0.017
Year	0.087	0.016	<0.001	0.017	0.020	0.392	0.024	0.021	0.254
Europe				5.109	1.689	0.033	4.290	1.780	0.018
Latin Amer./Carib				1.335	1.929	0.491	1.217	1.919	0.527
Mid. East/N. Africa				5.379	2.069	0.011	4.994	2.075	0.018

North America				21.828	3.771	<0.001	20.981	3.797	<0.001
South Asia				-1.550	2.746	0.573	-1.482	2.730	0.588
Sub-Saharan Africa				-0.658	2.230	0.769	-0.490	2.220	0.826
Urbanization %				0.143	0.028	<0.001	0.131	0.030	<0.001
GDP ($1000s)				0.028	0.013	0.035	0.023	0.030	0.089
UPF Sales (kg/p/y)							0.013	0.010	0.157
Random Effects									
σ^2	1.35			1.35			1.35		
τ_{00}	59.24 $_{\text{country}}$			23.00 $_{\text{country}}$			22.71 $_{\text{country}}$		
ICC	0.98			0.94			0.94		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.001 / 0.978			0.594 / 0.977			0.599 / 0.977		
AIC	3088.4			3005.7			3013.2		

Table 3.6: Association between UPF Sales and National Supply of Omega-3 Fatty Acids

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	2.276	0.148	<0.001	0.660	0.399	0.100	0.688	0.398	0.085

Year	0.009	0.003	0.002	-0.004	0.004	0.334	-0.003	0.003	0.510
Europe				0.590	0.309	0.059	0.440	0.326	0.180
Latin Amer./Carib				-0.241	0.353	0.497	-0.262	0.350	0.456
Mid. East/N. Africa				-0.163	0.378	0.667	-0.234	0.379	0.539
North America				3.771	0.689	<0.001	3.615	0.693	<0.001
South Asia				-0.301	0.502	0.550	-0.287	0.499	0.566
Sub-Saharan Africa				-0.618	0.407	0.133	-0.586	0.405	0.151
Urbanization %				0.022	0.005	<0.001	0.019	0.006	0.001
GDP ($1000s)				0.008	0.002	0.001	0.007	0.002	0.005
UPF Sales (kg/p/y)							0.002	0.004	0.185
Random Effects									
σ^2	0.05			0.05			0.05		
τ_{00}	1.95_{country}			0.77_{country}			0.75_{country}		
ICC	0.98			0.94			0.94		
N	90_{country}			90_{country}			90_{country}		

Observations	809	809	809
Marginal R^2 / Conditional R^2	0.000 / 0.975	0.559 / 0.973	0.566 / 0.973
AIC	404.1	362.9	373.9

Table 3.7: Association between UPF Sales and National Omega-6:Omega-3 Fatty Acid Ratio

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	9.08	0.38	<0.001	8.97	1.51	<0.001	8.97	1.52	<0.001
Year	0.00	0.01	0.742	0.02	0.01	0.166	0.02	0.01	0.177
Europe				0.71	1.18	0.548	0.70	1.25	0.575
Latin Amer./Carib				0.61	1.34	0.653	0.61	1.35	0.654
Mid. East/N. Africa				2.64	1.44	0.071	2.64	1.46	0.074
North America				-1.25	2.63	0.636	-1.25	2.67	0.639
South Asia				-0.63	1.91	0.744	-0.62	1.92	0.746
Sub-Saharan Africa				3.19	1.55	0.044	3.19	1.56	0.044
Urbanization %				-0.01	0.02	0.606	-0.01	0.02	0.622
GDP ($1000s)				-0.02	0.01	0.046	-0.02	0.01	0.054
UPF Sales (kg/p/y)							0.00	0.01	0.991

Random Effects			
σ^2	0.66	0.67	0.67
τ_{00}	12.86_{country}	11.17_{country}	11.21_{country}
ICC	0.95	0.94	0.94
N	90_{country}	90_{country}	90_{country}
Observations	809	809	809
Marginal R^2 / Conditional R^2	0.000 / 0.951	0.125 / 0.951	0.124 / 0.951
AIC	2439.217	2438.735	2448.888

Table 3.8: Association between UPF Sales and National Supply of Monounsaturated Fat

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF**			**Model 4 Interactions**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	32.58	1.80	<0.001	13.69	4.27	0.002	13.99	4.20	0.001	16.60	4.23	<0.001
Year	0.31	0.02	<0.001	0.19	0.03	<0.001	0.22	0.03	<0.001	0.32	0.03	<0.001
Europe				17.49	3.51	<0.001	14.11	3.59	<0.001	15.43	3.62	<0.001
Latin Amer./Carib				-2.75	4.00	0.494	-3.30	3.93	0.404	-1.65	3.97	0.679
Mid. East/N. Africa				0.94	4.29	0.828	-0.73	4.24	0.864	1.11	4.28	0.795
North America				28.53	7.83	0.001	24.92	7.76	0.002	26.02	7.82	0.001
South Asia				-6.48	5.67	0.256	-5.99	5.57	0.285	-7.56	5.61	0.181

Sub-Saharan Africa				-5.88	4.62	0.208	-5.06	4.55	0.269	-5.91	4.58	0.200
Urbanization %				0.19	0.05	<0.001	0.15	0.05	<0.001	0.09	0.05	0.080
GDP ($1000s)				0.07	0.02	<0.001	0.06	0.02	0.010	0.15	0.02	<0.001
UPF Sales (kg/p/y)							0.05	0.03	<0.001	0.03	0.04	0.038
Year * GDP ($1000s)										-0.01	0.00	<0.001
Random Effects												
σ^2	3.24			3.29			3.26			3.14		
τ_{00}	291.73 country			100.34 country			96.68 country			98.09 country		
ICC	0.99			0.97			0.97			0.97		
N	90 country			90 country			90 country			90 country		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.002 / 0.989			0.621 / 0.988			0.636 / 0.988			0.628 / 0.988		
AIC	3857.2			3765.6			3762.7			3749.9		

Table 3.9: Association between UPF Sales and National Supply of Saturated Fat

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF**			**Model 4 Interactions**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	29.68	1.44	<0.001	10.71	3.63	0.004	11.26	3.63	0.002	13.85	3.54	<0.001

Year	0.17	0.02	<0.001	0.06	3.97	0.043	0.08	0.02	0.004	0.19	0.03	<0.001
Europe				11.43	3.02	<0.001	8.10	3.14	0.011	9.52	3.05	0.002
Latin Amer./Carib				-2.77	3.43	0.422	-3.27	3.45	0.346	-1.50	3.35	0.656
Mid. East/N. Africa				-4.21	3.68	0.256	-5.80	3.72	0.122	-3.84	3.61	0.290
North America				15.20	6.73	0.026	11.72	6.81	0.089	12.79	6.59	0.056
South Asia				3.45	4.86	0.479	3.80	4.88	0.438	2.23	4.73	0.638
Sub-Saharan Africa				-5.11	3.96	0.202	-4.39	3.99	0.275	-5.22	3.86	0.180
Urbanization %				0.24	0.04	<0.001	0.19	0.05	<0.001	0.14	0.04	0.002
GDP ($1000s)				0.05	0.02	0.008	0.03	0.01	0.115	0.14	0.01	<0.001
UPF Sales (kg/p/y)							0.05	0.03	<0.001	0.03	0.01	0.018
Year * GDP ($1000s)										-0.01	0.00	<0.001
Random Effects												
σ^2	2.19			2.22			2.17			2.05		
τ_{00}	184.59 country			74.09 country			74.79 country			70.00 country		
ICC	0.99			0.97			0.97			0.97		
N	90 country			90 country			90 country			90 country		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.001 / 0.988			0.556 / 0.987			0.564 / 0.988			0.570 / 0.988		
AIC	3537.7			3457.9			3450.1			3415.7		

Table 3.10: Association between UPF Sales and Percentage of Calories from Non-Staple Crops

	Model 1 Unconditional Linear Growth			**Model 2 Demographic**			**Model 3 UPF/SSB**			**Model 4 Interactions**		
Predictors	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*	*Estimates*	*SE*	*p*
(Intercept)	45.32	1.27	<0.001	27.79	3.32	<0.001	28.36	3.29	<0.001	27.41	3.36	<0.001
Year	0.19	0.02	<0.001	0.08	0.02	<0.001	0.10	0.025	<0.001	0.11	0.05	0.008
Europe				10.40	2.81	0.001	8.16	2.87	0.005	6.60	3.33	0.049
Latin Amer./Carib				4.68	3.20	0.147	3.42	3.19	0.287	5.56	4.71	0.161
Mid. East/N. Africa				-4.54	3.43	0.189	-5.43	3.41	0.115	-0.18	3.87	0.126
North America				17.93	6.27	0.005	14.21	6.27	0.026	17.25	8.65	0.498
South Asia				-6.96	4.52	0.127	-6.77	4.47	0.134	-6.64	4.70	0.161
Sub-Saharan Africa				8.05	3.69	0.032	8.41	3.66	0.024	10.96	3.93	0.006
Urbanization %				0.19	0.04	<0.001	0.15	0.04	<0.001	0.14	0.05	0.001
GDP ($1000s)				0.06	0.02	<0.001	0.05	0.02	<0.001	0.05	0.02	0.002
UPF Sales (kg/p/y)							0.03	0.01	0.014	0.03	0.01	0.012
SSB Sales (L/c/y)							0.02	0.009	0.028	0.07	0.05	0.126
North America * SSB Sales (L/c/y)										-0.06	0.06	0.003

South Asia * SSB Sales (L/c/y)										0.18	0.25	0.498
Europe * SSB Sales (L/c/y)										0.002	0.05	0.964
Sub-Saharan Africa * SSB Sales (L/c/y)										-0.13	0.07	0.05
Latin Amer./Carib * SSB Sales (L/c/y)										-0.06	0.04	0.22
Mid. East/N. Africa * SSB Sales (L/c/y)										-0.13	0.05	0.008
Random Effects												
σ^2	1.63			1.63			1.60			1.54		
τ_{00}	145.28 $_{\text{country}}$			64.48 $_{\text{country}}$			63.13 $_{\text{country}}$			63.33 $_{\text{country}}$		
ICC	0.99			0.98			0.98			0.98		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.002 / 0.989			0.521 / 0.988			0.535 / 0.989			0.547 / 0.989		
AIC	3303.7			3231.6			3222.0			3200.7		

Chapter 4: Country-Level Sales of Ultra-Processed Foods and Sugar-Sweetened Beverages and Their Associations with Adult and Child and Adolescent BMI, Overweight, and Obesity Prevalence

Abstract

Background: Ultra-processed foods (UPF) and sugar-sweetened beverages (SSB) now comprise over 50% of energy intake in many upper-middle and high-income countries. UPF and SSB sales are growing fastest in less saturated markets in South Asia and Sub-Saharan Africa. In studies of individuals, high intake of UPF and SSB is associated with an increased prevalence of overweight and obesity, but few studies have examined the association between UPF, SSB, and weight status at the country level.

Objective: The objective of this study was to evaluate global trends in UPF and SSB sales and their associations with adult, child, and adolescent trends in body mass index (BMI), overweight, and obesity. A secondary aim was to characterize associations between UPF and SSB sales and BMI trends among these populations stratified by sex.

Methods: Data on UPF and SSB sales were obtained from EuroMonitor International. BMI, overweight, and obesity data were obtained from the NCD Risk Factor Collaboration. Potential confounders were collected or calculated from the World Bank and the World Health Organization Global Health Observatory. Longitudinal multi-level models were used to estimate the relationship between country-level UPF and SSB sales and BMI trajectories between 2005 and 2016. Associations between UPF and SSB sales and BMI trajectories were adjusted for potential confounders of national calorie supply, the prevalence of insufficient physical inactivity, per capita GDP, percentage of population living in urban areas, and region.

Results: UPF sales grew by 2.7% between 2005 and 2018. Sales were highest in high-income contexts of North America (139.3kg/p/y) and Europe (117.3kg/p/y) but grew most rapidly in South Asia and Sub-Saharan Africa. SSB sales grew 1.9% globally but ranged from -22.4% in North America (120.3 liters/person/year in 2018) to 144.7% in South Asia (7.3 liters/p/year in 2018).

Both UPF and SSB sales were significant and positive predictors of BMI for all adults, and for males and females separately, with 1 SD increases across the sample set associated with a mean increase in BMI between 0.1kg/m^2 and 0.3kg/m^2. UPF and SSB sales were also significantly and positively associated with higher prevalence of overweight for all adults and males separately. There was no association between UPF or SSB sales and adult obesity prevalence.

In children and adolescents age 5-19, SSB sales significantly predicted BMI, overweight prevalence, and obesity prevalence. UPF sales predicted overweight prevalence for all adolescents and for male adolescents. Associations between SSB sales and BMI were of equal magnitude to adults, while a 1 SD increase in SSB predicted a 0.8% and 0.4% increase in overweight and obesity prevalence, respectively.

In general, results were robust when controlling for calories and physical inactivity, providing moderately consistent evidence of the relationship between UPF and SSB sales and weight status trends.

Conclusions: UPF and SSB sales demonstrate a significant and positive impact on country-level BMI trajectories and overweight prevalence, although consistency across model iterations was moderate. Associations were less consistent for obesity prevalence. All associations held controlling for country energy supply and physical activity levels. This analysis indicates that while individual-level approaches to obesity remain important, more considerable research must focus on how to affect change at the national food supply level.

Introduction

Worldwide, overweight and obesity are estimated to cause 4 million deaths each year and account for 4% of both years of life lost (YLLs) and disability-adjusted life-years (DALYs).[89] Globally, cardiovascular disease is the leading cause of death and DALYs related to BMI, accounting for 2.7 million deaths and 66.3 million BMI-related DALYs.[270] Diabetes is the second leading cause of BMI-related death, followed by chronic kidney disease. Risk factors are higher for obese individuals compared to overweight individuals, but a total of 39% of deaths and 37% of DALYs are estimated to occur in individuals with BMIs below 30 kg/m^2.

The nutrition transition,[4] in which countries experience reductions in undernutrition and infectious disease with swift increases in non-communicable diseases (NCDs) is now occurring on some level in every country. Diet-related NCDs were once regarded as the product of "Westernization" in high-income countries. However, rapid increases in body size and associated health effects are now widely documented across contexts urban and rural, wealthy and poor.[213] NCDs account for nearly 75% of the global disease burden, with a majority traced to dietary risk factors coincident with overweight and obesity.[271]

A pillar of change in global diets is the growth of UPF. UPF are products made from processed substances extracted or refined from whole foods – vegetable oils and fats (many of them hydrogenated), flours and starches, variants of sugar, and some remnants of animal foods – with little or no whole foods included.[31] The best researched and most widely used classification system for levels of food processing is the NOVA framework, first developed by Monteiro in 2011[208] and now widely adopted within the nutrition community. The NOVA classification system defines industrial processing as distinct from artisanal or domestic processing and preparation. It divides foods into four categories: unprocessed or minimally processed, processed culinary ingredients (e.g., flours and oils), processed foods (e.g. cheeses and breads), and ultra-processed foods (e.g. soft drinks, packaged snacks, and prepared dishes).

In many high-income countries, UPF make up 50% or more of all calories consumed.[35] Studies consistently show intake of UPF to be inversely correlated with dietary quality. Individuals who consume more UPF consume more calories, sugars, saturated fats, and sodium,[36,208,251,272] and less protein, fiber, and vitamins.[221,251] Higher UPF consumption is also associated with higher carbohydrate intake,[221,251] although this is not often a focus of studies given the difficulty in assessing carbohydrate consumption and health outcomes.[244,273]

SSB comprise a smaller but still significant portion of the global diet – close to 5 oz per day, on average, with substantially higher consumption in adults between age 20-39 (8 oz), and in children . [38] Less data are available for children, but in some high-income contexts, children age 2-19 consume more calories from SSB than adults.[39] Evidence on the harmful health impacts of SSB is highly consistent. High intake of SSB is associated with an increased risk of type 2 diabetes mellitus, coronary heart disease, hypertension, and overweight and obesity.[45,46]

The dominant public health rhetoric of the food and beverage industry locates diet-related NCDs as an issue of individual responsibility.[44] Like the alcohol and tobacco industries, food and beverage corporations use sponsored research and media campaigns to shift public and academic focus to individual choice, ignoring the broader context in which these choices occur.[274] In his classic work "Sick Individuals and Sick Populations," Geoffrey Rose illustrated how population changes in the incidence of disease might be missed if research is narrowly focused on individual cases.[275] Although the evidence base of the associations between UPF, SSB, and BMI trajectories is increasingly well-established among individuals, a paradigm shift may be needed to catalyze changes in the global diet effectively. To date country-level, longitudinal analyses are mostly absent in the literature. This study aimed to evaluate the associations between UPF, SSB, and overweight and obesity at the national level. Specifically, it seeks to answer whether after controlling for income, region, country calorie supply, and prevalence of physical inactivity, an association exists between UPF/SSB sales and national BMI, overweight prevalence, and obesity prevalence trajectories. In doing so, this analysis lays the foundation to help reframe the obesity epidemic as a problem of the global food system, requiring new strategies in obesity prevention.

Methods

This study is an ecological analysis that collected data from multiple sources to analyze the associations between UPF and SSB sales and global BMI trajectories for the years 2005 to 2016. Data sources and rationale for inclusion in models are as follows:

BMI, Overweight, and Obesity Data: Data on BMI, Overweight, and Obesity data was obtained for all countries between 1975 and 2016, as published by the NCD-RisC group and available from the WHO Global Health Repository.[276,277] NCD-RisC applied a Bayesian hierarchical model to 1,698 (for adults) and 2,416 (for children and adolescents ages 5-19) population-based data sources to create age-standardized metrics for mean BMI, and prevalence of overweight (>25 kg/m^2) and obesity (>30 kg/m^2).

Ultra-Processed Food Sales: Euromonitor International is a global market research company that collects sales data on ultra-processed food and beverage trends from government statistics, trade associations and industry bodies, trade journals, business press, and other public filings.[34] Euromonitor's Packaged Food database tracks total retail sales of pre-packaged foods, sub-divided into dairy products, oils and fats, baked goods, and pre-packaged meals. Data on total packaged food sales are available between 2005 and 2018. EuroMonitor aggregates some ultra-processed foods with processed foods. To calculate UPF sales, we added the following categories: sauces, dressings, and condiments; sweet spreads; chocolate confectionery; sugar confectionery; savory snacks (such as chips/crisps); sweet biscuits, snack bars, and fruit snacks; and baked goods (which includes ultra-processed and industrial bread, pastries, dessert mixes, frozen baked goods, and cakes). To calculate SSB sales, we totaled carbonates (soda), energy drinks, sports drinks, and concentrates.

We controlled for the following variables, with brief rationales:

Income: UPF and SSBs are highest in high-income countries, but growing across all levels of development.[221] BMI is similarly correlated with national income, although some research suggests that it resembles a U-shaped curve for women.[238] We collected data on national income (per capita GDP, calculated in $1000s) from the World Bank.[222]

Region: There are substantial disparities in overweight and obesity between regions.[276,277] We used World Bank designations of East Asia and Pacific, Europe and Central Asia, Latin America and Caribbean (LAC), Middle East and North Africa (MENA), North America, South Asia, and Sub-Saharan Africa.

Urbanization: Urbanization is consistently cited as a risk factor for obesity,[238,278] although more recent research shows that 55% of the global increase in BMI between 1985 and 2017, and more than 80% in some LMICs, is due to increases in BMI in rural areas.[279] Data on urbanization (as a percentage of a country's total population) was collected from United Nations World Urbanization Prospects for the years 2005 to 2015.[230]

Prevalence of Insufficient Physical Activity: Prevalence of insufficient physical activity is defined as fewer than 150 minutes of moderate physical activity per week. Most evidence suggests that while physical activity is vital for health and functioning (i.e., musculoskeletal health and function, cognitive decline, and depression and anxiety),[280,281] increases in BMI are predominantly the result of excess energy intake rather than insufficient physical activity.[236,282,283] However, some evidence shows that physical activity is inversely related to BMI or that physical activity prevents weight gain.[284,285] At the global level, activity inequality (the distribution of physical activity within a population) is strongly predictive of average BMI in a population.[286]

Kilocalories: We calculated country calorie supply using two sources. We obtained food group availability from Food Balance Sheets (FBS) of the Food and Agriculture Organization (FAO). FBS provide a comprehensive picture of a country's food supply for each year between 1961 and 2013. FBS include 96 food groups (predominantly primary commodities, i.e., wheat, but also some processed commodities like vegetable oils). For each food commodity, FBS calculates available supply by adding domestic production and imports and subtracting for quantities exported, fed to livestock, used for seed, processed for non-food uses, or lost during storage and transportation. [129]

Data on the nutrient composition of the food items contained in the FBS was obtained by matching individual food items in the United States Department of Agriculture's (USDA) FoodData Central database with those in FBS.[91] Where the FBS provide an aggregate category, and the USDA provides nutrient data for specific parts of food (for example, FoodData Central provides nutrient information for more than ten different cuts of beef, but not an aggregate "beef" category), we calculated an average. For categories in which FBS record an aggregate category (i.e., "oilcrops – other," which includes linseed, castor oil, and hempseed oil, among others), we weighted the nutrient profile according to global production values of the individual crops. If a food item was not available in the USDA FoodData Central, nutrient data was obtained via the New Zealand Food Composition Database.[92]

Finally, because FBS numbers represent raw, unprocessed food items and nutrient data are generally available for only the edible portion of a foodstuff, refuse factors were obtained from USDA FoodData Central and used to calculate edible portions of available foods. The per capita available of every nutrient i in year t and country c can be expressed as:

$$N_{itc} = \sum_{f=1}^{96} N_{fitc}$$

Where f is the FBS food item, t ranges from 1961 to 2013.

Statistical Analysis: Longitudinal multi-level analyses were used to estimate the effects of UPF and SSBs on average country BMI and prevalence of overweight and obesity for both adults and children and adolescents less than 19. Models were built and analyzed using the lme4[93] package in RStudio (1.2.1335) using a "bottom-up strategy."[94] In the first step, an unconditional growth model was fit with year as the only level-1 predictor, and with country as the level-2 unit. In the second model, region, GDP, and urbanization were included. To assess improvement in the model with the addition of UPF or SSB as predictors, each variable was added separately to the basic covariates model. Improvement in model fit was assessed in two ways: A likelihood ratio test, measured as χ^2, was used to compare the addition of predictor variables to model fit. If the addition of UPF or SSB significantly improved model fit, interactions were explored and tested. Marginal and conditional R-squared were calculated (following the approach outlined in Nakagawa, 2012[95]) to assess further the impact of increasing covariates in the models. *P*-values for individual variables are presented using the Kenward-Roger approximation for degrees of freedom,[96] which produces acceptable Type 1 error rates even at small sample sizes.[97]

In order to maximize power because availability of calories was only available up to year 2013, and prevalence of insufficient physical activity was only available for 69 countries, we ran three versions of models: 1) The primary model, 2005-2015, with 1001 observations; 2) Calorie-controlled model, 2005-2013, with 809 observations; and 3) Insufficiency Physical Inactivity Prevalence controlled model, 2005-2013, with 621 observations. Because prevalence of insufficient physical activity was only available for one year for a limited number of countries, we ran models only for BMI, overweight prevalence, and obesity prevalence with sexes aggregated. We report full models without interactions to enable comparison (Table 4.3-4.8). All analyses, including interaction models, calorie-controlled models, and physical-activity controlled models are provided in Appendix B.

Results: Descriptive Statistics

UPF Sales and Availability

Globally, average sales of UPF totaled 77.3 kg/person/year –a 2.7% increase since 2005. Sales in 2018 were highest in North America at 136.5 kg/person/year and Europe, at 117.3 kg/person/year. South Asia and Sub-Saharan Africa had the lowest sales in 2018, at 6.9 kg/person/year, and 9.3 kg/person/year, respectively. Across the 90 countries for which sales were available, daily UPF sales were the equivalent of 0.21kg per person – just under ½ pound.

There was a clear gradient in UPF sales across country GDP classifications, where UPF sales in 2018 totaled 112.8 kg/person/year in high-income countries, followed by 78.3 kg/person/year in upper-middle-income countries, 24.1 kg/person/year in lower-middle-income countries, and 5.1 kg/person/year in low-income countries. Across regions, growth was highest in South Asia (81.6%), followed by East Asia and the Pacific (18.6%) and Sub-Saharan Africa (16.3%). Growth was low in Europe (0.2%), Latin-America and Caribbean (2.7%) and Middle East and North Africa (3.1%). Sales declined in North America by 2.0%. Stratified by income, , growth declined 0.7% in high-income countries, while growing 4.5% in upper-middle economies, 20.5% in lower-middle economies, and 8.5% in low-income countries.

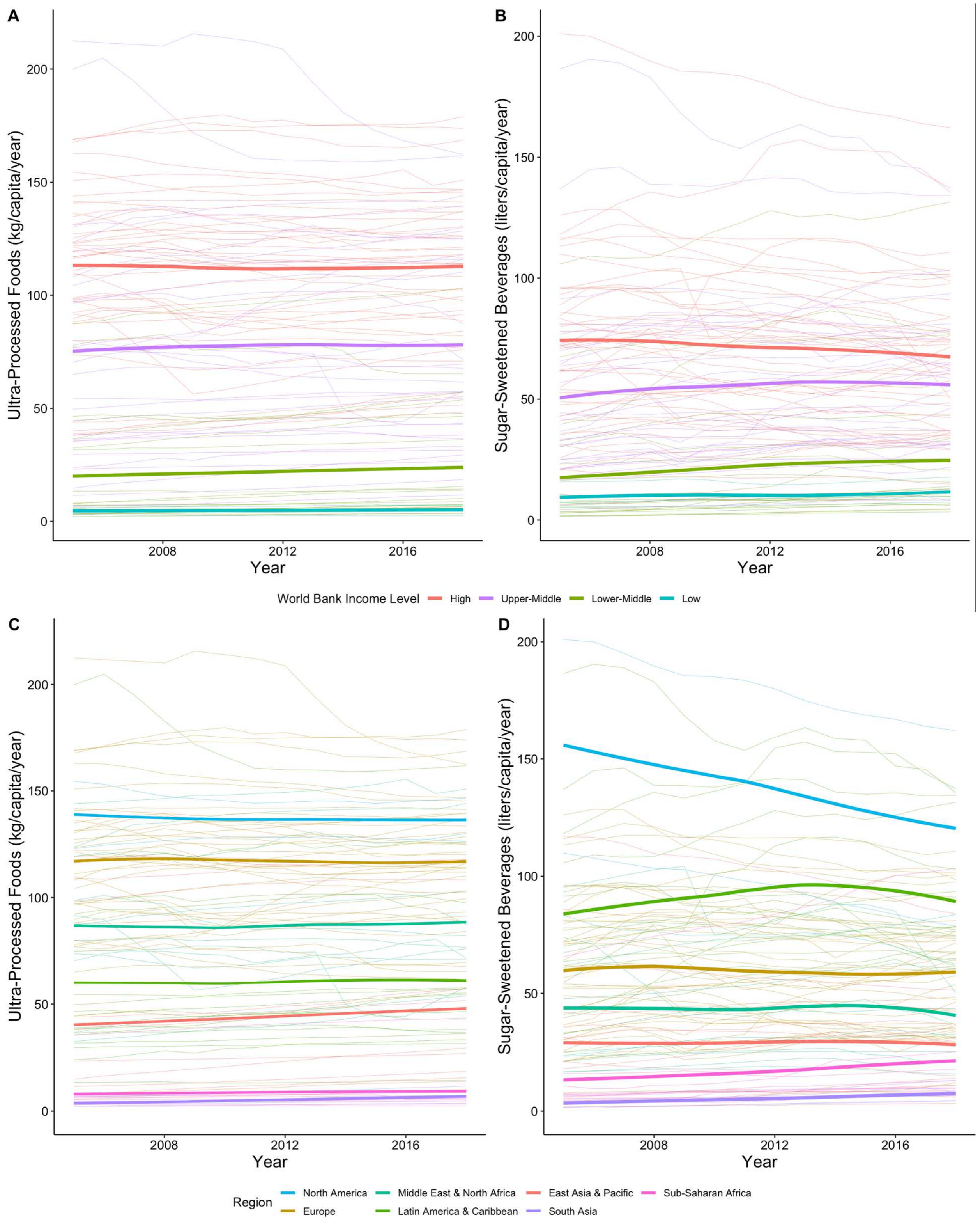

Figure 15: Trends in Ultra-Processed Food and Sugar-Sweetened Beverage Sales, 2005-2018, by Income Classification (A, B) and Region (C, D)

SSB Sales and Availability

Globally, average sales of SSBs increased 2% between 2005 and 2018, from 51.7 to 52.7 liters/person/year - equivalent to 0.14 liters/person/day, or just less than 5 ounces. Sales were highest in North America at 120.3 liters/person/year, although this is a decline of 22.5% from 2005 when sales totaled 155.1 liters/person/year. Latin-America and the Caribbean had the second-highest sales per capita, at 89.8 liters/person/year, followed by Europe (59.6), MENA (40.4), and East Asia and the Pacific (28.3). Growth was mixed. Increases were highest in South Asia, which more than doubled from 3.4 to 7.3 liters/person/year, and in Sub-Saharan Africa, where sales increased nearly 60% from 13.3 to 21.2 liters/person/year. Sales also declined in the Middle East and North Africa (-6.9%) and in East Asia and Pacific (-2.4%). Across income classifications, sales were highest in high-income countries at 67.6 liters/person/year, followed by upper-middle-income countries, at 56.3 liters/person/year. Growth was highest in lower-middle-income countries, where sales grew over 40%, from 17.7 to 24.9 liters/person/year.

Table 4.1: Trends in Ultra-Processed Food and Sugar-Sweetened Beverage Sales, 2005-2018

	Ultra-Processed Food Sales (kg/p/year)			**Sugar-Sweetened Beverage Sales (liters/p/year)**		
Region	2005	2018	Growth (%)	2005	2018	Growth (%)
East Asia And Pacific	40.3	47.8	*18.6*	29	28.3	*-2.4*
Europe	117.1	117.3	*0.2*	59.1	59.6	*0.8*
Latin America and Caribbean	59.5	61.1	*2.7*	83.2	89.8	*7.9*
Middle East and North Africa	86	88.7	*3.1*	43.4	40.4	*-6.9*
North America	139.3	136.5	*-2.0*	155.1	120.3	*-22.4*
South Asia	3.8	6.9	*81.6*	3.4	7.3	*114.7*
Sub-Saharan Africa	8	9.3	*16.3*	13.3	21.2	*59.4*
Income						
High	113.6	112.8	*-0.7*	73.6	67.6	*-8.2*
Upper-Middle	74.9	78.3	*4.5*	50.1	56.3	*12.4*
Lower-Middle	20	24.1	*20.5*	17.7	24.9	*40.7*
Low	4.7	5.1	*8.5*	9.5	11.6	*22.1*
Global	**75.3**	**77.3**	***2.7***	**51.7**	**52.7**	***1.9***

BMI

Full details of trends in BMI, overweight, and obesity prevalence from which study data are derived are available from NCD-RisC.[276,277] This section reports on trends by income and region for the period 2005-2016, for which UPF and SSB sales data are available.

Mean BMI across the 90 countries included was 25.0 kg/m^2, increasing 3.3% to 25.8 in 2016. Mean BMI was highest in 2016 in North America at 29.9 kg/m^2, followed by Middle East and North Africa (27.7 kg/m^2) and Latin-America and Caribbean (27.1 kg/m^2). Lowest mean BMI was in South Asia, at 22.5 kg/m^2 and in Sub-Saharan Africa (23.5 kg/m^2). The most substantial growth over the study period was in Middle East and North Africa, where mean BMI increased by 4.5%. Only in East Asia and Pacific did average BMI decrease due to a decrease in BMI among women in high-income Asia-Pacific countries which has yet to be fully explored.[276]

Stratified by income classification, growth in BMI was higher in upper-middle income countries, where average BMI grew 3.5%, from 25.7 to 26.6 kg/m^2, achieving parity for the first time with BMI in high-income countries, which grew 1.9%. There was no increase in average BMI in low-income countries.

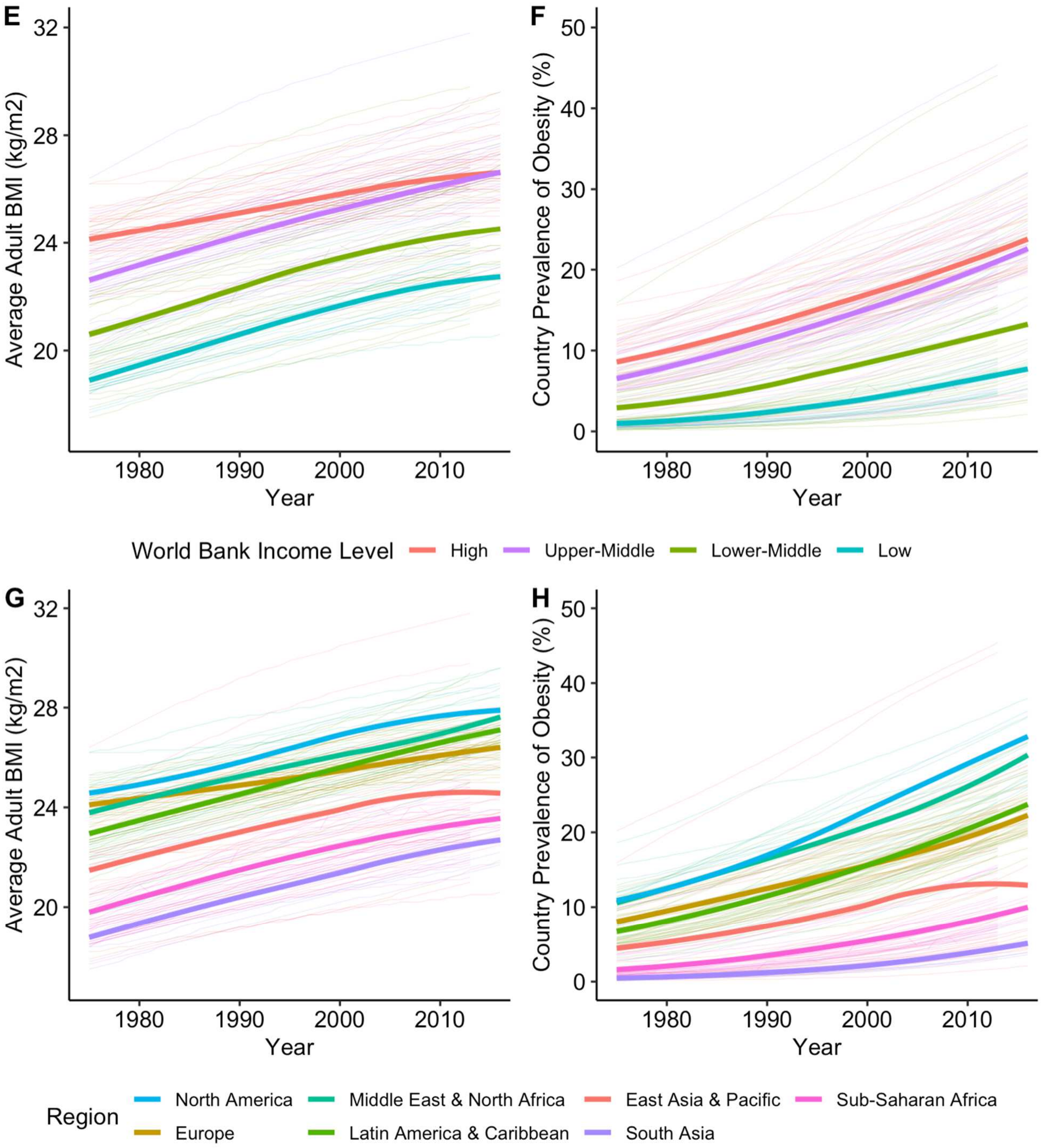

Figure 16: Trends in Adult BMI and National Prevalence of Obesity, 1975-2016, by Country Income Classification (E, F) and Region (G, H)

Overweight

Globally, the average prevalence of overweight increased from 42.4% in 2005 to nearly half of all individuals – 48.9% - in 2016. Over 65% of the population was overweight in North America (66%) and MENA (65.6%), and over 55% in Latin-America and Caribbean (59.1%) and Europe (57.6%). Only in South Asia was prevalence lower than 30%, at 22.6% of the population. South Asia and Sub-Saharan Africa also had the highest growth rates, at 35.3% and 25.6%, respectively. Increases were the most rapid in lower-middle-income countries, where prevalence increased by 18.2%, from 31.9% to 37.7%. Changes were nearly as high in upper-middle income countries, which grew 17.1% to 55.6%, just behind high-income countries, where prevalence was 58.9%.

Obesity

Globally, the average prevalence of obesity across the study sample was 15.2% in 2005, which increased by nearly a third to 19.9% in 2016. Compared to overweight, obesity is increasing much more rapidly. Across regions, it ranged from 32.8% in North America to 5.0% in South Asia. Increases were highest in South Asia, where prevalence increased by 72%, from 2.9% to 5.0%.

Prevalence is nearly equal in high (23.9%) and upper-middle income countries (22.6%), while growth was highest in lower-middle-income countries, where prevalence increased over 1/3, from 9.8% to 13.1%.

Table 4.2: Trends in Adult BMI, Obesity, and Overweight, 2005-2016

	BMI			Obesity Prevalence (% of population)			Overweight Prevalence (% of population)		
Region	**2005**	**2016**	***% Δ***	**2005**	**2016**	***% Δ***	**2005**	**2016**	***% Δ***
East Asia And Pacific	24.3	24.2	*-0.4*	12	11	*-8.3*	36	35.6	-1.1
Europe	25.8	26.4	*2.3*	17.3	22.3	*28.9*	51.6	57.6	11.6
Latin American and Caribbean	26.1	27.1	*3.8*	17.9	23.8	*33.0*	49.7	59.1	18.9
Middle East and North Africa	26.5	27.7	*4.5*	23.2	30.7	*32.3*	57.6	65.6	13.9
North America	27.4	27.9	*1.8*	26.2	32.8	*25.2*	60.2	66	9.6
South Asia	21.9	22.5	*2.7*	2.9	5	*72.4*	16.7	22.6	35.3
Sub-Saharan Africa	22.9	23.5	*2.6*	6.6	10.3	*56.1*	24.2	30.4	25.6
Income									
High	26.1	26.6	*1.9*	18.9	23.9	*26.5*	52.7	58.9	11.8
Upper-Middle	25.7	26.6	*3.5*	17.2	22.6	*31.4*	47.5	55.6	17.1
Lower-Middle	24.5	25.7	*4.9*	9.8	13.1	*33.7*	31.9	37.7	18.2
Low	22.1	22.1	*0.0*	5.1	6.1	*19.6*	22.1	23.7	7.2
Global	**25.0**	**25.8**	***3.3***	**15.2**	**19.9**	***31.4***	**42.4**	**48.9**	**15.4**

Results: Modeling

BMI

Adults (Table 4.3)

Average adult BMI in the 91 countries included in the sample was 25.1, estimated to increase 0.07 points each year. Average male adult BMI was 25.0, slightly lower than average female adult BMI at 25.3. For all adults, adult males, and adult females, both UPF and SSB sales significantly predicted increases in average BMI (Table 4.3). Using mean UPF sales of 76.3 kg/person/year, the estimated increase in average BMI ranged from 0.22 kg/m^2 for all adults, 0.15 kg/m^2 in men, and 0.38 kg/m^2 in women. For SSB sales, at a mean of 53.3 liters/person/year, the estimated increase in average BMI ranged from 0.27 kg/m^2 for all adults, 0.32 kg/m^2 in men, and 0.27 kg/m^2 in women. Controlling for all economic and demographic covariates, at the highest level of UPF sales (215.6 kg/person/year in Turkey in 2009), average adult BMI would be predicted to be 0.65 kg/m^2 higher than a country with no UPF sales. Similarly, at the highest levels of SSB sales (201 liters/person/year in the United States in 2005), average adult BMI would be predicted to be 1.0 kg/m^2 higher than a country without SSB sales.

For all adults and adult males, the association between UPF sales and average BMI remained significant when controlling for calories but not physical activity (Table 4.9.C, Table 4.10.C). For adult females the association remained significant across the three models. SSB sales remained significant for all models.

Children and Adolescents Less than 19 Years (Table 4.4)

Average child and adolescent BMI was 19.1 kg/m^2 in 2005, projected to increase 0.025 points each year. Average BMI in 2005 was slightly higher for males (19.0 kg/m^2) than females (19.3 kg/m^2). For children and adolescents less than 19 years, SSB sales, but not UPF sales, significantly predicted BMI trajectories. At mean SSB sales, the estimated increase in average BMI for all adolescents under 19 was 0.27 kg/m^2, 0.16 kg/m^2 in males under 19 years, and 0.21 kg/m^2 in females under 19 years (Table 4.4). We also controlled for prevalence of physical inactivity for children and adolescents less than 19 years combined; physical inactivity was not a significant predictor and the positive association between SSB sales and child, and adolescent BMI remained (4.12.C).

These associations remained significant controlling for country calorie supply in most models; for child and adolescent males, SSB sales dropped from significance when a significant interaction between year and region was included (Table 4.13.B).

Overweight

Adults (Table 4.5): For all adults and adult males, both UPF and SSB sales significantly predicted increases in country prevalence of overweight. For adult females, SSB sales but not UPF sales predicted increases in overweight prevalence. Using mean sales, UPF predicted an increase in overweight prevalence of 1.1% for all adults, 0.5% for adult males, and 1.7% for adult women. Using mean sales, SSB predicted an increase in overweight prevalence of 0.4% for all adults and 0.9% for adult males. Together, mean sales of UPF and SSB predicted overweight prevalence increases of 1.5% for all adults, 0.9% for adult males, and 1.7% for adult women.

When calories were included as a covariate (Table 4.21.B), UPF sales but not SSB sales remained a significant predictor of adult overweight prevalence. Both variables were significant in the truncated dataset including physical activity.

Children and Adolescents Less than 19 Years (Table 4.6): For children and adolescents less than 19 years, UPF sales predicted increases in overweight prevalence for the general population of adolescents and for adolescent males. SSB sales predicted increases in overweight for all adolescents, and for male and female adolescents separately. Using mean sales, UPF predicted increases in overweight prevalence of 0.9% for all adolescents and 1.2% for males less than 19; SSB sales predicted increases in overweight prevalence of 1.1% for all children and adolescents less than 19, 1.4% for males less than 19, and 1.0% for females less than 19.

Associations were robust controlling for country energy supply and for prevalence of insufficient physical activity. However, in several interaction models, UPF and SSB did not have a significant relationship with overweight prevalence.

Obesity

Adults (Table 4.7): Neither UPF nor SSB sales were significantly associated with obesity in all adults. In adult males, SSB was significantly but negatively associated with SSB, with a 1 SD increase in SSB sales predicting a decrease of 0.5% in obesity prevalence. This association held when controlling for country energy supply (Table 4.16.B). For adult females, 1 SD increase in UPF sales significantly predicted a 0.4% increase in obesity prevalence. This association was robust controlling for calories (Table 4.17.B)

Children and Adolescents (Table 4.8): In children and adolescents less than 19 years, SSB sales but not UPF sales significantly predicted increases in obesity prevalence. Using mean sales, SSB predicted increases in obesity prevalence of 0.6% for all children and adolescents less than 19 years, 0.4% in males less than 19, and 0.6% in females less than 19. These associations held in interaction models and in models controlling for country calorie supply and prevalence of insufficient physical activity.

Table 4.3: Associations Between Ultra-Processed Food and Sugar-Sweetened Beverage Sales and Adult BMI

	All Adults			**Adult Males**			**Adult Females**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	22.145	0.358	<0.001	22.692	0.352	<0.001	21.584	0.455	<0.001
Year	0.067	0.003	<0.001	0.075	0.003	0.047	0.061	0.004	<0.001
Europe	1.880	0.354	<0.001	2.444	0.346	<0.001	1.301	0.450	0.005
LAC	2.135	0.399	<0.001	1.845	0.389	<0.001	2.389	0.506	<0.001
MENA	3.036	0.426	<0.001	2.692	0.416	<0.001	3.495	0.540	<0.001
North America	2.801	0.783	0.001	3.437	0.765	<0.001	2.234	0.994	0.027
South Asia	-0.963	0.554	0.086	-1.557	0.542	0.005	-0.390	0.704	0.581
Sub-Saharan Africa	-0.089	0.445	0.842	-1.092	0.448	0.017	0.897	0.566	0.117
Urban Pop. %	0.017	0.001	0.027	0.007	0.001	0.406	0.026	0.002	0.001
GDP ($1000s)	-0.003	0.001	<0.001	-0.001	0.001	<0.001	-0.005	0.001	<0.001
UPF (kg/year)	0.003	0.002	<0.001	0.002	0.002	<0.001	0.005	0.002	<0.001
SSB (liters/year)	0.005	0.001	<0.001	0.006	0.001	0.033	0.005	0.001	<0.001
Random Effects									
σ^2	0.01			0.01			0.02		
τ_{00}	1.02 $_{\text{country}}$			0.97 $_{\text{country}}$			1.64 $_{\text{country}}$		
ICC	0.99			0.99			0.99		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		

Observations	1001	1001	1001
Marginal R^2 / Conditional R^2	0.721 / 0.997	0.752 / 0.998	0.628 / 0.995
AIC	-826.041	-964.616	-330.764

Table 4.4: Associations Between Sugar-Sweetened Beverage Sales and Child and Adolescent BMI

	All			**Male**			**Female**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	17.219	0.259	<0.001	17.017	0.292	<0.001	17.546	0.256	<0.001
Year	0.015	0.279	0.010	0.025	0.308	0.001	0.007	0.282	0.172
Europe	0.396	0.002	<0.001	0.499	0.002	<0.001	0.319	0.002	<0.001
LAC	0.509	0.001	0.534	0.240	0.002	0.432	0.812	0.001	0.975
MENA	0.692	0.219	0.074	0.629	0.241	0.041	0.800	0.221	0.152
North America	0.987	0.251	0.046	0.834	0.278	0.390	1.191	0.253	0.002
South Asia	-1.049	0.266	0.011	-1.183	0.294	0.035	-0.980	0.269	0.004
Sub-Saharan Africa	-0.739	0.491	0.047	-1.112	0.543	0.128	-0.388	0.495	0.018
Urban Pop. %	0.023	0.003	<0.001	0.025	0.004	<0.001	0.020	0.003	<0.001
GDP ($1000s)	0.001	0.001	<0.001	0.001	0.001	<0.001	-0.000	0.001	<0.001
SSB (liters/year)	0.005	0.000	<0.001	0.006	0.000	<0.001	0.004	0.000	<0.001
Random Effects									
σ^2	0.02			0.03			0.02		

τ_{00}	0.39_{country}	0.47_{country}	1.64_{country}
ICC	0.96	0.95	0.99
N	91_{country}	91_{country}	91_{country}
Observations	1001	1001	1001
Marginal R^2 / Conditional R^2	0.728 / 0.988	0.735 / 0.986	0.628 / 0.995
AIC	-625.000	-247.627	-330.764

Table 4.5: Associations Between Ultra-Processed Food and Sugar-Sweetened Beverage Sales and Adult Overweight Prevalence

	All			**Male**			**Female**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	11.840	1.738	<0.001	13.117	1.958	<0.001	10.505	2.092	<0.001
Year	0.455	0.011	<0.001	0.522	0.014	<0.001	0.387	0.005	<0.001
Europe	19.387	1.878	<0.001	24.337	2.074	<0.001	14.410	2.220	<0.001
LAC	18.982	2.123	<0.001	16.675	2.342	<0.001	21.171	2.504	<0.001
MENA	24.722	2.265	<0.001	22.575	2.499	<0.001	27.436	2.675	<0.001
North America	23.025	4.169	<0.001	28.168	4.600	<0.001	17.849	4.921	<0.001
South Asia	-2.918	2.935	0.323	-6.502	3.242	0.048	0.667	3.470	0.848
Sub-Saharan Africa	0.834	2.370	0.726	-7.874	2.616	0.003	9.238	2.800	0.001
Urban Pop. %	0.287	0.004	0.032	0.260	0.005	0.621	0.312	0.014	<0.001
GDP ($1000s)	-0.008	0.002	<0.001	0.002	0.003	<0.001	-0.018	0.003	<0.001

UPF (kg/year)	0.014	0.005	<0.001	0.007	0.007	<0.001	0.022	0.007	<0.001
SSB (liters/year)	0.008	0.003	<0.001	0.017	0.003	0.051	/	/	/
Random Effects									
σ^2	0.11			0.19			0.22		
τ_{00}	29.18 $_{\text{country}}$			35.43 $_{\text{country}}$			40.61 $_{\text{country}}$		
ICC	1.00			0.99			0.99		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001		
Marginal R^2 / Conditional R^2	0.878 / 1.000			0.889 / 0.999			0.812 / 0.999		
AIC	1428.566			1928.642			2035.144		

Table 4.6: Associations Between Ultra-Processed Food and Sugar-Sweetened Beverage Sales and Youth Overweight Prevalence

	All			**Male**			**Female**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	2.298	1.727	0.184	3.619	1.931	0.062	0.803	1.693	0.636
Year	0.450	0.020	<0.001	0.519	0.024	<0.001	0.377	0.018	<0.001
Europe	1.373	1.557	0.380	1.005	1.689	0.553	1.780	1.595	0.267
LAC	3.660	1.739	0.038	0.785	1.880	0.677	6.616	1.788	<0.001
MENA	6.640	1.856	0.001	4.921	2.005	0.016	8.436	1.910	<0.001

North America	9.969	3.416	0.004	8.901	3.692	0.018	11.073	3.514	0.002
South Asia	-3.896	2.431	0.112	-5.039	2.630	0.058	-2.652	2.494	0.290
Sub-Saharan Africa	-4.731	1.940	0.017	-10.08	2.094	<0.001	0.788	1.998	0.694
Urban Pop. %	0.221	0.008	<0.001	0.219	0.010	0.001	0.226	0.007	<0.001
GDP ($1000s)	-0.036	0.004	<0.001	-0.033	0.006	<0.001	-0.041	0.004	<0.001
UPF (kg/year)	0.012	0.011	<0.001	0.016	0.014	<0.001	0.007	0.010	<0.001
SSB (liters/year)	0.021	0.006	0.038	0.026	0.007	0.021	0.018	0.005	<0.001
σ^2	0.61			0.96			0.42		
τ_{00}	18.86_{country}			21.79_{country}			20.21_{country}		
ICC	0.97			0.96			0.98		
N	91_{country}			91_{country}			91_{country}		
Observations	1001			1001			1001		
Marginal R^2 / Conditional R^2	0.763 / 0.993			0.774 / 0.990			0.726 / 0.994		
AIC	2052.9			3321.8			2566.9		

Table 4.7: Associations Between Ultra-Processed Food and Sugar-Sweetened Beverage Sales and Adult Obesity Prevalence

	All			**Male**			**Female**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	1.236	1.464	0.400	3.979	1.548	0.011	-2.234	1.735	0.200
Year	0.375	0.005	0.002	0.415	1.867	0.085	0.331	0.005	<0.001
Europe	10.020	1.440	<0.001	10.715	0.008	<0.001	8.579	1.767	<0.001
LAC	10.780	1.620	<0.001	8.827	0.006	<0.001	12.501	1.987	<0.001
MENA	16.650	1.730	<0.001	13.144	1.468	<0.001	20.998	2.126	<0.001
North America	17.943	3.183	<0.001	20.168	1.672	<0.001	15.207	3.908	<0.001
South Asia	-2.010	2.254	0.375	-4.461	1.780	<0.001	0.959	2.764	0.729
Sub-Saharan Africa	1.328	1.810	0.465	-3.256	3.278	<0.001	6.085	2.225	0.008
Urban Pop. %	0.096	0.014	<0.001	0.027	0.016	0.084	0.171	0.015	<0.001
GDP ($1000s)	0.016	0.004	0.005	0.030	0.003	0.003	0.003	0.005	0.588
UPF (kg/year)	0.000	0.003	0.943	/	/	/	0.008	0.003	0.019
SSB (liters/year)	-0.003	0.003	0.320	-0.009	0.003	0.002	/	/	/
Random Effects									
σ^2	0.23			0.23			0.23		
τ_{00}	68.45 $_{\text{country}}$			16.60 $_{\text{country}}$			16.75 $_{\text{country}}$		
ICC	1.00			0.99			0.99		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		

Observations	1001	1001	1001
Marginal R^2 / Conditional R^2	0.025 / 0.997	0.756 / 0.997	0.754 / 0.997
AIC	2135.589	1987.717	2010.121

Table 4.8: Associations Between Ultra-Processed Food and Sugar-Sweetened Beverage Sales and Child and Adolescent Obesity Prevalence

	All			**Male**			**Female**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	-0.764	0.964	0.428	0.238	1.087	0.827	-1.881	0.939	0.047
Year	0.250	0.006	<0.001	0.291	1.163	<0.001	0.205	0.005	<0.001
Europe	-0.831	0.007	<0.001	-0.931	0.008	<0.001	-0.771	0.829	<0.001
LAC	0.839	0.945	0.377	-0.028	0.658	0.540	1.724	0.949	0.002
MENA	3.882	0.824	0.316	3.138	0.910	0.309	4.635	1.008	<0.001
North America	6.011	1.848	0.001	5.956	1.047	0.979	5.981	1.859	0.073
South Asia	-1.320	1.002	<0.001	-2.143	1.108	0.006	-0.421	1.329	0.751
Sub-Saharan Africa	-2.670	1.051	0.012	-4.677	2.045	0.005	-0.554	1.057	0.602
Urban Pop. %	0.098	0.012	<0.001	0.100	0.013	<0.001	0.096	0.010	<0.001
GDP ($1000s)	-0.009	0.004	0.074	-0.004	0.003	<0.001	-0.013	0.004	<0.001
SSB (liters/year)	0.011	0.002	<0.001	0.012	0.006	<0.001	0.010	0.002	<0.001
Random Effects									

σ^2	0.23	0.33	0.18
τ_{00}	5.52 $_{\text{country}}$	6.72 $_{\text{country}}$	5.63 $_{\text{country}}$
ICC	0.96	0.95	0.97
N	91 $_{\text{country}}$	91 $_{\text{country}}$	91 $_{\text{country}}$
Observations	1001	1001	1001
Marginal R^2 / Conditional R^2	0.700 / 0.988	0.697 / 0.986	0.667 / 0.990
AIC	1883.2	2248.6	1647.2

Discussion

In this multi-level analysis which uniquely combined longitudinal data on country-level food and drink sales, BMI and weight status, energy supply, and economic and demographic covariates, increases in UPF and SSB sales consistently predicted increases in adult and adolescent BMI across age and sex groups, as well as overweight and obesity prevalence in some groups. At mean sales volume of UPF, predicted increases in BMI ranged from 0.15 kg/m^2 in adult to 0.38 kg/m^2 in women. At mean sales volume of SSB, predicted increases in BMI ranged from 0.27 kg/m^2 in women and 0.32 kg/m^2 in men. For children and adolescents less than 19 years, SSB significantly predicted increases in BMI, obesity prevalence, and overweight prevalence, although the associations were not always robust for various iterations of the model.

Our estimates are relatively consistent with the only other global analysis of BMI and UPF. Vandevijvere et al.[51] using similar data (years 2002-2014 and different covariates) estimated that every SD in volume sales of UPF increased BMI by 0.316 kg/m^2 for men, but did not find a significant association for women (the relationship was negative, with one SD predicting a 0.004 decrease in mean population BMI). In contrast, this analysis found significant associations for both men and women, with one SD increases associated with a 0.11 kg/m^2 increase in mean BMI for men and a 0.27 kg/m^2 increase for women. That analysis did not account for interactions between time and either GDP, which our analyses showed improved model fit but, in some models, resulted in non-significance of UPF or SSB sales.

Despite some inconsistency in the relationships we identified, our broad findings are corroborated by individual-level analyses. In one prospective study among non-overweight/obese university graduates, participants in the highest quartile of UPF consumption were at higher risk of developing overweight or obesity (adjusted HR: 1.26) than those in the lowest quartile.[287] In another ecological analysis, Monteiro et al. found that each percentage point increase in household availability of UPF resulted in a 0.25% percentage point increase in obesity prevalence across 19 European countries.[32] In Kenya, a lower-middle-income country, a 1% increase in the share of calories from UPF (mean 8.07 +/- 8.12) was associated with a 0.11 kg/m2 increase in BMI.[288]

Predicted increases were similar in magnitude among children and adolescents less than 19 years. SSB sales had more consistent positive associations with overweight and obesity prevalence than UPF sales. These associations held across models controlling for country energy supply and prevalence of physical inactivity. This analysis adds to a growing body of evidence illustrating how the rapidly expanding role of UPF and SSB consumption has a demonstrable impact on weight status at the population level.

There are several possible explanations for why SSB sales more consistently predicted weight status trajectories than UPF sales in children and adolescents. First, individuals under 19 may consume more SSB than adults. Global analyses have shown that SSB consumption is highest in younger populations.[38] In the US, for instance, children aged 2-19 consumed, on average, 155 kcal/day from SSBs, compared to 151 kcal/day in adults; when energy needs are factored in, these numbers will represent an even higher proportion of total calories.[39] SSB may also be more obesogenic than UPF. High fructose exposure during early development can affect lifelong neuroendocrine function, appetite control, and overall metabolism.[289] One study in Australia showed SSB consumption, but not UPF consumption, increased risk of obesity in children 4-12.[290] However, studies contradict these explanations, finding, for instance, inconsistent relationships between SSB and obesity in children and adolescents in Australia,[291] or substantially higher UPF (24.5% of total energy) consumption than SSB (5.3% of total energy) in Mexico.[292] Because global data is lacking, future studies may endeavor to delineate better the respective roles of UPF and SSB in this population.

In general, urbanization was a significant and positive predictor of all three outcomes. Simple correlation between urbanization and BMI was r=0.71, p<.001. This is somewhat at odds with recent research that found higher growth rates of overweight and obesity in rural areas.[212,293] The pattern may reflect the disparate impacts that urbanization has on obesity across development contexts. In the United States, for instance, urbanization is associated with a lower prevalence of obesity.[294] This may not be the case in less developed contexts: urbanization is associated with increased risk of obesity in, for example, Nigeria.[295] Popkin[212] notes programs and policies designed for rural areas are a global gap in overweight and obesity initiatives, yet our analysis indicates that urbanization still plays a substantial role in BMI trends.

Strengths and Limitations

Throughout the first two decades of the 21st century, the dominant framing of the obesity crisis was as a matter of individual responsibility. This paradigm precludes population strategies for mitigation.[296] Even in research that highlights environmental context as a driver of obesity –for example, in food deserts[220,297] or in schools[298–300] – proposed solutions are likely to be implemented only a community level.[301] This study begins building the evidence base that high weight status and its associated morbidities are a predictable outcome of market economies and the global rise in ultra-processed food and drink industries. Further strengths of this study are the disaggregation of outcomes by sex and by age, multiple controls that suggest UPF and SSB have an identifiable impact on BMI trajectories independent of country calorie supply and physical activity levels, and the use of multi-level models, which is well-suited to clustered data and allows more reliable generalization to a broader population.

The study is limited by using UPF and SSB volume sales, rather than the dietary share of energy from these foods. While sex-disaggregated data were available for several of the covariates, UPF and SSB sales are only available per capita, preventing more nuanced analyses of differences in consumption between groups. Although improvement in model fit with the inclusion of UPF and SSB sales was small (increases in marginal R^2 were usually 0.01), validation with energy and physical inactivity covariates strengthens confidence in the effects seen, these data were limited. A wider longitudinal dataset would strengthen the analysis. We also cannot rule out residual confounding. Finally, as with any ecological analysis, it cannot strictly determine causality or rule out other possible confounders.

Conclusion

Between 2005 and 2016, country UPF and SSB sales were positively associated with BMI across age and sex brackets, as well as overweight and obesity prevalence across some age and sex brackets. SSB sales were more consistently associated with weight status, particularly in children and adolescents less than 19 years. BMI is now rising fastest in upper-middle and lower-middle-income countries. While UPF sales in high-income economies appear to be plateauing and SSB sales declining, sales continue to grow in upper-middle and lower-middle-income countries – particularly throughout Latin America and the Caribbean, where SSB sales, if current trends continue, will overtake North America. Our analysis indicates the need to address the links between UPF, SSB, and BMI trends which are well established in high-income contexts, while also illustrating the possibility of minimizing their impact in regions where such foods are not so entrenched in the food system. Focusing on SSB consumption in children seems particularly compelling, given the consistency of associations between sales and weight status.

Chapter 5: Conclusion

It is a bitter irony that in an era in which undernutrition continues to decrease and famines have been all but eradicated, the global burden of disease caused by overweight and obesity continues to inch higher. Such trends would suggest that decreases on one end of the malnutrition spectrum are balanced by increases on the other. The rising prevalence in overweight and obesity has been called a pandemic.[213,301] Yet unlike the COVID-19 pandemic which at this moment continues to spread in the US but has, in other countries, been contained, there is no evidence of a national success story in halting the spread of overweight, obesity, and diet-related NCDs.[89,276]

Worldwide, the proportion of overweight adults increased between 1980 and 2013 from 28.8% to 36.9% in men, and from 29.8% to 38.0% in women.[89] Just under one-quarter of children and adolescents in developed countries were overweight in 2013, while in developing countries overweight increased roughly 50% between 1980 to 2013 to 12.9% of boys and 13.4% of girls.[89] Sub-optimal diet is now estimated to be responsible for more deaths – 11 million per year - than any other risks globally, including tobacco smoking.[302] Although dietary risk factors vary widely between countries, it is also clear that many national food supplies are veering towards a "global standard diet" characterized by heightened interdependence between countries are a very limited number of crops: wheat, rice, maize, and sugar; soybean, sunflower, palm , and rape and mustard oils.[48]

It remains unclear what percentage of these crops become the inputs for ultra-processed foods and sugar-sweetened beverages, but data on their spread shows both their dominance in high- and upper-middle-income contexts and their rapid growth in lower-middle and low-income areas. In 2013, among all countries for which data is available, average daily per capita availability of all UPF 0.21 kg, ranging from .01 kg to 0.53 kg per day. Estimates using panel surveys put UPF consumption as high as 58% of calories in the US (and 89% of added sugars),[303] 30% in Brazil,[304] and 18% in France.[305]

To date, the wealth of nutrition research related to UPF and SSB has been focused on individual-level associations. Country-level analyses represent a substantial gap in the literature – and perhaps a gap of growing importance, given that interconnection in the global food system suggests the need to tackle malnutrition at the global food supply first.[48,81] Several studies have used FBS to estimate country nutrient diversity, but these have not been tied to data on food products like UPF.[48,49] In short, we have a working knowledge of what foods are grown and produced globally, but there are few resources that track what those foods become as they move from farm to factory to fork.

There is also a dearth of studies which apply the country-level lens to health outcomes. One study has analyzed the association between UPF and SSB sales and BMI at the national level, which found an association between UPF sales and male BMI trajectories, but not female trajectories.[51] Another study in Latin America showed that between 2000 and 2009, every 20 kg increase in UPF sales was associated with an increase of 0.28 kg/m^2 in age -standardized BMI scores.[42] To date, there are no global analyses of the associations between UPF, SSB, and child and adolescent BMI trends. Nor are there analyses which have controlled for country supply of calories – a factor which has shown to be the predominant predictor in obesity rates.[52]

This dissertation aimed to fill this gap by assessing the relationship between ultra-processed foods, country nutrient supplies, and national trends in BMI, overweight, and obesity, through the following specific aims.

Aim 1: To investigate, through an evolutionary framework, the historical trends of the rapid increase in vegetable oils in the 20th century and their impact on national supply levels of fatty acids

Aim One sought to quantify and compare global and national supplies of FA and to integrate more holistic theories into the space of nutrition research. That analysis found that globally, the supply of calories and fat from vegetable oils has risen sharply – a 198% increase in the global calorie supply, from 3.7% to 8.7%. Per capita availability of all fatty acids has increased, *n-6* and *n-3* have grown the fastest – more than doubling between 1961 and 2013, compared to an increase of 42% in saturated fat and 71% in monounsaturated fat. Contrary to our hypothesis, the *n-6*:*n-3* FA ratio has decreased by 7.7% since 1961. Disagreement over or lack of guidelines for FA consumption ratios make broad conclusions difficult, but at a global average ratio of 9.6:1, the *n-6*:*n-3* FA ratio is almost ten times hypothesized evolutionary consumption patterns. Roughly half of all countries fall into adequate AMDR for *n*-6 and *n*-3, but few countries meet adequate average amounts for *n*-3.

The study concluded with a synthesis of emerging (and sometimes competing) frameworks in nutrition science. Applying both an evolutionary (and related food processing framework) questions the healthfulness of any isolated fat or oil, but particularly illustrates the possible negative impacts of substantial increases in *n*-6 FA availability. Further still, preliminary ecological evidence suggests that disrupting environmental FA supplies can have cascading negative consequences across ecosystems.

Aim 2: To analyze the association between ultra-processed food sales, sugar-sweetened beverage sales, and national nutrient supplies

Aim Two analyzed the association between ultra-processed food sales and country-level nutrient supplies. High sales of UPF have similar impacts on national nutrient supplies as high UPF consumption has on individual diets: higher in calories, carbohydrates, sugars, total fats, and saturated fat. Globally, a one SD increase in yearly UPF sales (52 kg/p/y) predicted daily per capita increases in the supply of calories (123 kcal), carbohydrates (13g), sugar (4.7g), total fat (7.3g), MUFA (2.6g), and SFA (2.6g). There was no significant relationship between UPF sales and omega-FA. High sales of SSB also have similar impacts on national nutrient supplies as high consumption has on individual diets: higher in calories, carbohydrates, and sugars. A one SD increase in yearly SSB sales (40.1 liters/person) predicted increases in the supply of calories (69.4 kcal), carbohydrates (6.8g), and sugar (8.8g).

Regions demonstrated substantial disparities, with a leveling off of SSB sales, carbohydrates, and sugar supply in North America and Europe, compared to stark increases in South Asia and Sub-Saharan Africa.

Aim 3: To assess the associations between ultra-processed food sales, sugar-sweetened beverage sales, and obesity at the national level

Aim Three assessed the association between UPF and SSB sales and national trends in mean BMI and prevalence of overweight and obesity, both in the general population and sex-disaggregated, for adults and children and adolescents less than 19 years. At the national level, UPF and SSB sales had consistent and positive associations with BMI across age and sex groups. 1 SD increases across the sample set associated with a mean increase in BMI between 0.1kg/m^2 and 0.3kg/m^2

Sales also predicted obesity and overweight in some groups. SSBs in particular were positive and significant predictors of all three measures of weight status in children and adolescents, both in the general population and disaggregated by sex. Associations between SSB sales and BMI were of equal magnitude to adults but were larger than adults for overweight. A 1 SD increase in SSB sales predicted a 0.8% and 0.4% increase in overweight and obesity prevalence, respectively.

There was little evidence of reductions in UPF and SSB sales or rising rates of overweight and obesity, save declining SSB sales in North America. Growth in UPF/SSB sales in other regions is forecasted to increase, which is likely to contribute to a higher global prevalence of overweight and obesity.

A long-term objective of this study is to lay the foundation of an evidence base in favor of more robust regulation of the UPF and SSB industries – in much the same way that governments regulated tobacco and alcohol sales. Comparing the health impact of these foods to tobacco and health outcomes suggests this would not be excessive. An estimated 9% of diabetes cases in the United States are attributable solely to sugar-sweetened beverages.[306] Up to 5.5% of deaths from CVD in Brazil could be averted if UPF were reduced by 25% and replaced with unprocessed or minimally processed foods; in a more optimistic scenario, CVD could be reduced by 32.0% if UPF were reduced by 75%.[307] Estimated attributable fractions for smoking on cancer mortality are around 20% in men and 6% in women.[308]

As research on the negative health impacts of UPF and SSB consumption increases, the dearth of evidence on how to prevent their consumption grows ever more glaring. This conclusion begins with a review of policy and programming implications of this study. Policy research linking globalization, ultra-processed foods, and health outcomes is limited,[309] overarching themes are as follows:

- The design and implementation of policies affecting food prices should emphasize the need to increase accessibility to and affordability of more nutritious foods
- At the same time, it may be necessary to decrease the accessibility to and affordability of UPF and SSB through some regulatory measures
- While there is some evidence to suggest that community and individual level programming can produce modest effects on obesity prevention, their impact is likely to be minimal and ineffective for population changes in BMI
- Any policy which directly targets UPF or SSB must anticipate resistance from the food and beverage industry
- National level policies may be more politically viable; marketing and labeling are two areas that may have the highest success of implementation with possible moderate impacts on consumption – particularly among children and adolescents

Rapid changes in food environments associated with trade liberalization, economic growth, and rapid urbanization have driven worldwide increases in obesity and related NCDs.[310] Although the dominant change in food environments has been an increase in available calories,[52] a substantial portion of surplus grain and oil calories trickles down to UPF and SSB consumption. Obesity is now a global problem, necessitating global solutions to the food supply. Policymakers across institutional areas and levels must also make it a priority. We organize policy options and implications from macro to microlevel, beginning with global, multi-lateral, and bi-lateral options.

Policy Options

Global

Prioritizing Obesity: The WHO Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013-2020[311] places obesity and type 2 diabetes targets at a 0% increase. This goal alone speaks to the lack of concrete evidence on how to address the global rise in obesity, given that there is little to no evidence for what works to reduce or even limit increases in prevalence.

Strengthening accountability systems and prioritizing obesity prevention is a first but necessary step in reducing global obesity.[312]

In addition to obesity targets, setting clear targets for reductions in UPF and SSB sales is an important first step in strengthening the obesity accountability systems. Our research adds to the growing body of evidence implicating UPF and – more consistently - SSB in overweight and obesity. Moreover, as a country-level analysis it strengthens the rationale for reducing UPF and SSB sales at the national level. Macro-level surveillance of vegetable oils, UPF, and SSB done by an independent entity (EuroMonitor, the only global source for UPF and SSB sales, is a market research firm) represents a first step to prioritizing their reduction globally. Tobacco regulation offers one model to follow.[44] When the associations between lung cancer and tobacco usage became clear, it was monitoring and regulation of the tobacco industry – not lung cancer targets – that helped to reduce smoking rates.

Agricultural Policy

Our analysis is one of the first to calculate national nutrient supplies from FBS and provides a longer time span than others available.[219] One important finding is that, although on average the global food supply has expanded in the percentage of calories from non-staple crops, growth has been very low – an increase of just 6% between 1961 and 2013, from 35.6% to 41.5% of calories. While the absolute amount of calories from almost all food groups has risen, given what is known about food and nutrient distribution within a country's population, it is quite likely that dietary diversity remains unequally distributed between individuals within a country.[264,313] We also showed that vegetable oils have increased more than any other food group and identified some of the chief causes – namely more efficient food processing techniques and corporate structures incentivized on maximizing production and profit.[84,116,132,314]

Indeed, the global agricultural system is oriented around crop yields and calorie production – not nutrient density or dietary diversification. Agricultural policies enacted through the 1960s and 1970s– chiefly subsidies and tariffs – helped to dramatically reduce famine and calorie insufficiency in resourcepoor areas, particularly Sub-Saharan Africa and South Asia. However, this came at the cost of dietary diversity in some areas, as more productive industrial farming systems replaced integrated farming systems.[135] The continuation of policies designed to eliminate hunger now incentivize production of grains, sugar, and oils over more diverse and nutrient-dense foods.[83,315,316] As demand for products of surplus drops, a way for suppliers and corporations to maximize profits from pre-existing supply chains it to turn these foods into ultra-processed products.[195] Re-aligning the global agricultural system is akin to steering a large boat at sea – though slow and heavy, small changes may have substantial impacts over the proceeding years.

One possible but understudied solution is the adoption of "crop neutral" agricultural policies, which allow farmers to respond to consumer demand rather than biases toward staple grains.[317] Such policies would include removing corn, wheat, soybean, and sunflower subsidies in high-income countries.[318] Development programs sponsored by high-income countries are also biased towards staple crop production through LMICs, which may have the impact of lowering relative prices of staples (and by extension UPF) while increasing relative prices of other foods. USAID's Feed the Future initiative, the most extensive agricultural development program in the world, could less heavily emphasize staple grains, thereby encouraging greater dietary diversity in LMICs.[317]

LMICs face particular challenges due to substantial pressure from high-income countries for exploitative trade agreements. The North American Free Trade Agreement (NAFTA) and Central American Free Trade Agreement (CAFTA) reduced tariffs and facilitated favorable investment environments for transnational corporations – mainly based in the United States and Europe. In Mexico, NAFTA had the impact of increasing the availability of animal products, animal feed grains, and ultra-processed foods.[86] Since 1994 (NAFTA's passage), corn exports from the US to Mexico quadrupled, and soybean exports tripled.[319] American products, which comprise 98% of imported packaged foods in the country, flooded the Mexican market throughout the 1990s and are widely regarded as key to the still-growing Mexican obesity epidemic.[319]

National

National-level interventions are likely to be, in the short term, more politically feasible to enact. Possible options include food-based dietary guidelines, reassessment of agricultural subsidies, bans on UPF and SSB advertising, and taxes (either on primary producers or consumers).

Food-Based Dietary Guidelines: Food-based dietary guidelines (FBDG) have gained traction in recent years, beginning with the 2014 push in Brazil.[149] FBDGs promote dietary patterns as a whole, in contrast to nutrient-based guidelines (e.g. limit saturated fat to 10% of calories or less). In theory, FBDGs can influence the food environment by informing policy and shifting consumer attitudes.[320] A substantial body of evidence shows that industry rely on nutrient-based guidelines to advertise nutrient claims on food (e.g. low sodium), while consumers rate packaged products with these claims as more healthy.[321] FBDGs are least common in LMICs.[320] Our research showed UPF and SSB along with overweight and obesity increasing fastest in these regions. Although FBDGs are unlikely to make an immediate impact upon the food environment, widespread adoption may help to re-orient consumer and research perspectives towards foods over nutrients. This in turn may have the trickle-down effect of decreasing acceptance of UPF.[149]

Subsidies: Subsidies are pre-defined sums of money provided by a government (or other public bodies) to agricultural producers to ensure the price of a food commodity stays low or competitive. The United States, for example, currently subsidizes corn, soybeans, wheat, rice, sorghum, dairy, and livestock – the last two themselves enabled by subsidies for feed grains.[318] Similar policies are in place in most developed countries with high agricultural output.[84] Although subsidies differ across countries, nearly all provide price supports for staple grains, oil crops, and meats. Subsidies have far-reaching food system impacts. In the US, 56% of total calorie intake comes from subsidized food commodities.[322]

Because subsidies distort the actual cost of food, they make it less likely that consumers will choose healthier food combinations. In countries where subsidies underwrite food surplus, excess supplies can lead to an increase in the relative price of more nutritious foods, leading to an even wider gap between actual diets and healthiest diets.[323] Reassessment of subsidies is theorized to have direct impacts on health outcomes. There is a linear and positive relationship between the share of the diet from subsidized crops and obesity and other measures cardiometabolic health.[322] Subsidizing fruit and vegetable production is estimated to decrease obesity in the US by 10%.[318]

The trickle-down effect from subsidies to UPF and SSB manufacture and consumption is difficult to estimate. However, many have suggested that subsidy support combined with technological innovation in food manufacture led to the inexpensiveness of and subsequent proliferation of UPF in the global market.[197,324] In North America, large farms, the majority of which engage in monoculture of staple crops, receive close to half of federal subsidies, compared to small farms that receive just 14%.[318] Disproportionately allocated subsidies in the United States have forced hundreds of small, biodiverse farms out of business,[318] allowing vertically-integrated agricultural conglomerates to develop a larger market share.[116] Some have suggested entirely phasing out market support for agricultural producers as a means to realign food prices with production costs and by extension combat obesity.[325]

Advertising: Advertising of ultra-processed products to children is very effective. In a meta-analysis of 17 studies, children exposed to unhealthy dietary marketing increased dietary intake by 30.4 kcal during or shortly after exposure and had a higher risk of selecting the advertised foods or beverages.[326] A total ban on advertisements in America is estimated to reduce the number of overweight children by up 18%.[327] Advertisements are also widespread. In 2009, expenditures targeted to youth totaled $1.8 billion in the United States alone, with 72% devoted to breakfast cereals, fast foods, and SSBs. In Argentina, the average child watches 61 ads for UPF per week.[328] In New Zealand, that number reaches 27 advertisements per day if food packaging and billboards are included.[329]

Despite widespread consensus that that advertising is harmful to children's health, there have been few efforts to curtail its reach. A 1980 ban on advertising fast food in Quebec resulted in significantly fewer purchases among households, but overlap in media weakened the impact.[330] Bans would have to be enacted at the national level to avoid market overlap.[330] There is almost no research on advertising to adults – an avenue for further research. Given that our research has indicated a highly consistent association between SSB sales and all measures of weight status in individuals less than 19 years, banning advertising to children offers a fast and effective way to minimize obesity growth in children and adolescents.

Taxes: The basic premise and justification for enacting taxes to reduce excess UPF and SSB consumption is that UPF and SSB prices do not reflect their actual cost, which is the cost of production *plus* the external costs of treating NCDs associated with consumption. UPF and SSB taxes have faced considerable opposition from both industry and from the public.[255,331] The argument against taxation rests on a perennially American ideal: free choice. This argument begins to break down with clearer evidence showing that individual choice is ultimately a product of the market environment. Our analysis is one of the first to show that higher sales of UPF and SSB within countries are associated with higher BMI for most groups. For example, UPF and SSB sales in the United States totaled 146.7 kg/p/y and 162.2 l/p/y respectively. Taken together, these predict an average adult BMI 1.2 kg/m^2 higher than a country with no sales – a fact that begins to build a stronger argument for widespread taxation. The two most well-researched approaches are taxes at the producer level (taxes on primary products) and taxes at the consumer-level (i.e., a soda tax leveled in stores).

Countries with high producer prices and border protection also have relatively lower levels of obesity (e.g., Japan, Korea, Norway, or Sweden).[332] Proponents of taxing primary producers point toward this association in support of placing more protections on trade. Other case studies illustrate the converse: that greater market liberalization results in rapid increases in the proportion of the food supply from staple products and UPF – as in the case of Mexico following the signing of the North American Free

Trade Agreement (NAFTA).[319] To date, mainly because of the lack of political will to implement such measures, taxes at the producer level have been little explored.

Taxes that fall on consumers are more politically feasible and better researched. SSBs, in particular, have seen the most considerable amount of research and experimentation, likely a result of the fact that the downsides of SSB taxes – disproportionate burden on lower-income consumers, or consumers with higher-calorie needs – are reduced. Although modeling has shown some efficacy on health outcomes (a 20% tax on SSBs would reduce obesity in the UK by 1.3%, for example)[333] other evidence suggests they generate revenue but do not have significant impacts on consumption behavior. A 34% tax increase in SSBs in Philadelphia decreased demand in the taxed area by 46%.[334] However, "cross-shopping" to stores outside of Philadelphia off-set more than half of the reduction in sales in the city, reducing the net decrease in sales of SSBs to 22%. The authors of that study suggest increasing the geographic area of the SSB tax to avoid such cross-shopping. A French tax on SSBs had similarly small effects. At €0.0716 per liter, the tax decreased consumption by just 0.5 liters per year.[335] Only in Mexico is there evidence of widespread taxation success, where a 1 peso (~ $.05) per liter tax in Mexico reduced the purchase of SSBs by roughly 7.5% between 2014 and 2015.

The case for taxation against SSBs may be more convincing than any other foods given that they provide no added nutritive value of any kind beyond energy.[46] SSB taxes may have a further benefit of forcing transnational companies to reformulate products. The UK's graduate levy on sweetened beverages, for example, has already resulted in soda manufacturers reducing the sugar content of their products.[336]

There are fewer case studies of taxes on UPF taxation. In 2014, Mexico instituted an 8% tax on foods deemed "nonessential," defined as having an energy density ≥ 275kcal/100 g, including salty snacks, chips, cakes, pastries, and frozen desserts. Mean volume purchases of taxed foods declined by 5.1%, with no changes in the purchase of untaxed foods.[337] Reduction in purchases was even higher among low-income households, but high-income households showed no change. Hungary instituted a similar tax in 2011 on pre-packaged foods high in sugar (>25 g/100 g for sweets, or >40 g/100 g for sweets without cocoa) and salt (>1 g/100 g), resulting in a 3.4% reduction in purchases of taxed foods and a 1.1% increase in non-taxed foods.[338]

Not all taxes are equal, and any proposed taxes must anticipate corporate resistance. In 2011, Denmark introduced the world's first tax on saturated fat.[339] Just 15 months later, the country abolished the tax. While the form of the tax received criticism for poor design, it also faced intensive lobbying from industry representatives who used lawsuits and actively cast doubt on scientific evidence around saturated fat – tactics learned from the alcohol and tobacco industries.[44] Similar strategies have already been used to question the validity of sugar or SSB taxes. Industry-funded research consistently finds smaller effect sizes between SSBs, obesity, and health outcomes than independently funded research,[340] while companies such as Coca-Cola actively fund physical activity research to counter negative publicity.[88]

Whatever form, the priority for taxes must be to reverse the obesogenic nature of food environments. Governments have abdicated responsibility for addressing obesity and placed it upon individuals and community based organizations. However, Mexico's moderate success illustrates both the feasibility and success of taxation efforts.[90] Taxation may be particularly well suited to environments in which UPF are not yet widespread, where resistance both public and private is likely to be lower.[341]

Consensus is that current food labeling has only small impacts on consumer purchasing decisions.[342–344] Front of package claims may be particularly misleading to consumers since few claims can be verified.[345,346] Food labeling laws can, however, create incentives for food manufacturers and restaurant chains to change their products.[120] In general, since nutrient claims and package labeling are more prominent on packaged and ultra-processed foods, food labeling is likely only to make small impacts on UPF/SSB sales and consumption.

Community

Bans in Schools: Although children who have access to SSBs in school environments are likely to be high consumers,[347] most research shows that banning or reducing the availability of SSB in schools does not result in decreases in SSB consumption.[348] Indeed, children and adolescents seem to respond to restricted access in schools by increasing SSB consumption in other environments.[349]

Physical Activity: Physical activity, though necessary for health, cannot be recommended as an effective population-wide intervention for obesity. Although beneficial for other health[280,281] changes in diet are likely to be more effective in obesity prevention.[236,282,283] Ultimately the goal is more likely to succeed if greater focus in on shifting food environments – not physical activity within them.

Academia

A "low-hanging fruit" would be for academic publications to reject all publications with industry sponsors. Transnational food corporations now undermine diet-related NCD prevention and control.[44] Borrowing from the playbook written by Big Tobacco, food and beverage manufacturers use a dual-pronged strategy to shift focus away from individual regulation through 1) the of use various forms of sponsorship to frame the ever-growing epidemics in diet-related NCDs as problems of individual choice and 2) the funding of research into the role of various compounds in health and disease.

Mars, Inc., for instance, has sponsored tens of studies on the roles of cocoa flavanols on health - for example, arterial function and blood pressure, concluding these flavanols have the potential to maintain cardiovascular health even in low-risk subjects.[350] Coca-Cola sponsored the Fifth International Congress on Physical Activity in Public Health, held in Rio de Janeiro in 2014.[88] In both the United States and now China, the company actively funds scientists who emphasize the link between obesity and physical activity rather than diet.[351] In one analysis of intervention studies sponsored by food-related industries, the proportion with unfavorable conclusions was 0% for all industry funding vs. 37% for non-industry funding.[352] Despite calls to ban industry-funded research reaching as high as Lancet[44] or JAMA[353], industry-funded articles persist.

Limitations and Future Research

As a country-level secondary analysis, this study is limited in its ability to determine a causal relationship between UPF sales, country nutrient supplies, and BMI trends. Model diagnostics suggest caution in the interpretation of results. We used AIC, likelihood ratio tests, and *p*-values as the main criteria in assessing model fit. However, even at high levels of significance according to likelihood ratio tests, marginal-R^2 improvements were small. While estimated coefficients were relatively equal between interaction and non-interaction models, there were some large changes which indicated exogeneity is likely to exist. We have provided numerical calculations of changes in BMI or weight status with increases or decreases in UPF and SSB sales, but the more important criteria are the consistency of relationships across age groups and models.

Moreover, there are well known limitations to FAO FBS – the main focus of Aims 1 and 2. For many food groups, FAO estimates overestimate individual intakes – e.g. a 270% overestimation for whole grains.[354] It is also expected that estimates are less accurate in countries with less developed agricultural infrastructure and inconsistent national agricultural surveys. The most glaring gap in FBS is that they do not provide information on individual consumption or distribution of food among a population. This is a particular limitation of Aim 1, which focused on the availability of FA, and particularly the omega-6:omega-3 FA ratio. Although we assessed overall availability of the omega fatty acids, it is more than likely that consumption is variably distributed throughout the population. The limitation is less applicable to While it is quite likely that the estimated impact of our models varies widely across countries, our goal was to assess the association between UPF and SSB sales and availability. Further research may find ways to tie availability to actual consumption – national dietary surveys are an obvious place to start – but our analysis strengthens the case for national level regulation.

Aim 3 also faces several major limitations. Although stratified weight status data is available for gender and age, all of our models use aggregate country-level sales. We are thus tying the same national sales to dis-aggregated data. In addition, sales data cannot provide information on true consumption patterns. While we adjusted for important confounders, it is impossible to rule out residual confounding. UPF and SSB sales follow economic development and may also associate with a range of factors not captured in our models (i.e. infrastructure, labor patterns, or economic inequality).

Our analyses suggest multiple areas for future research. We did not stratify analyses based on income or region, although these were covariates in all models. Given the disparate trajectories in UPF and SSB growth between income classifications, a more complete analysis might seek to understand whether the associations hold across economic contexts. A further area of exploration is the role of trade. Large trade agreements – or changes within nearby trading partners – can have consequential impacts on food supplies (e.g. Mexico and NAFTA). Understanding the relative impact of these agreements on nutrient supplies and population weight trajectories will provide an important public health perspective for those working in the policy environment to consider.

To better understand the effects of UPF and SSB on nutrient supply and weight status will require more significant changes in population nutrition research. We elaborate upon recommendations in epidemiology, intervention, and policy research.

Epidemiology

In the past several years, attention to UPF has increased dramatically within epidemiological analyses. NOVA classification has now been used in publications as prominent as *The Lancet*,[355] but the a majority of research remains focused exclusively on nutrients or the relationship between UPF and nutrient intake. This is unlikely to change in the immediate future; nutrient-approaches are the dominant framework upon which scientists have been trained and the evidence-base (particularly dietary guidelines) is built. However, more widespread use of the NOVA classification or improvements upon it can help to bridge nutrient-based approaches with food-based approaches. In addition to being perhaps more relevant in research, this approach is also likely to be more effective in altering consumer behavior.[127]

Given that nutrition is built upon understanding detailed metabolic pathways between nutrients and physical function, "technological indices" provide a promising avenue to more accurately quantifying degree of processing.[150] Using machine-learning, Fardet et al. found that NOVA classifications aligned with specific physicochemical properties of foods, including compression and shear measurements to represent texture, water activity, glycemic index, and shelf life.[150] Minimally processed foods were less hyperglycemic, more satiating, had higher water activity, shorter shelf life, lower maximum stress, and higher energy at break than UPF. Together, these results suggest that, contrary to some opposition from industry-sponsored critiques,[356] it is possible to define a quantitative index to characterize the degree of processing.

Our research also sets a precedent for continuing to explore associations between UPF and SSB and other health outcomes. While we have analyzed overweight and obesity, possible directions include using similar datasets to understand the relationship with type 2 diabetes, cardiovascular disease, and even cancer. While these analyses should only serve as a complement to more rigorous and accurate individual-level associations, a growing concert of national level studies may help to move policy forward faster.

Interventions

Hall's 28-day in-patient trial of ultra-processed diets compared to minimally processed diets offered the first clinical proof that ad-libitum food intake and weight gain is a direct result of processing levels.[357] This research should be expanded to better delineate the impact of UPF on physiological outcomes: different study lengths, varying gradations of processing, and a physical activity component are all aspects that will help elucidate the metabolic effects of food processing.

Hall has also proposed more substantial investment in domiciled feeding facilities.[358] Well-designed research centers can increase the rigor of nutrition science and elucidate more granular mechanisms by which diet affects human physiology. More rigorously controlled trials would provide validation of hypotheses still debated (e.g., saturated fat) and lead to both new discoveries and in the link between diet and physiology and greater trust of nutritional advice.[358]

Policy

Establish specific reduction targets for UPF and SSB consumption: In order for any accountability framework to be put in place, there must be clear and quantified targets.[359] The WHO global obesity target is to halt the rise in obesity by 2025.[311] Recommended policy actions fall into the same trap as the Dietary Guidelines for Americans in focusing on nutrients, rather than foods. Although fruits and vegetables are mentioned by name, policy measures are advised only to "reduce the content of free sugars and fat in food and beverages." Given the growing consensus on the need to limit UPF and SSB consumption across the globe, establishing direct targets and perhaps just as importantly, naming ultra-processed products directly, represents a first step in minimizing the health consequences of these foods.

Conduct research in efficacy, effectiveness, and feasibility of UPF oriented policy: Efficacy refers to the beneficial effects of a program or policy under optimal conditions. To date, efficacy studies have formed the bulk of policy research on UPF and SSB, e.g. modeling studies for taxes.[255] Less common are effectiveness studies, which refer to the success of a program under 'real-world' condition, largely because so few policies have been enacted.[360] Although substantial consensus exists for regulation UPF and SSB sales,[44] feasibility studies that assess how regulation might actually take place are nearly absent from the literature. Future studies might use successful SSB taxes – particularly in Mexico – as case studies to learn from.[90,335]

Incorporate Food Processing into National Dietary Guidelines: In 2014, Brazil was the first country to introduce levels of food processing (using the NOVA classification) in the National Dietary Guidelines.[144] Canada and several other countries have recently followed suit.[251] The development process for the United States Dietary Guidelines for Americans 2020-2025 are underway. The US guidelines have been critiqued for failure to better incorporate food patterns and specifically to name ultra-processed foods.[58] Given that NOVA classifications have gained more widespread acceptance in the literature, incorporation into the US guidelines will both help set an international precedent and support greater UPF research in the future.

Conclusion

Over the past few decades, globalization and an expanding food industry have re-shaped the food environment to be ever more obesogenic. At the same time that most measures of undernutrition show improvement, mean global BMI has increased to the cusp of overweight, and by 2025 obesity will affect one in five people across the globe.[276] Food environments are increasingly dominated by surplus, while the prominence of ultra-processed foods and beverages has dramatically re-shaped national nutrient supplies. These two facts are linked and point towards the importance of realigning the global agricultural system with human health, rather than corporate profit.

Nutrition science and public policy must adapt to this changing food landscape in concert. This study has traced how dietary guidelines based on premature conclusions have had effects that cascaded through the global food supply. The global prominence of vegetable oils has as yet understood impacts on health, but they have provided, in conjunction with inexpensive staple grains and sugars, the primary input materials needed for the ultra-processed food industry. The rise in ultra-processed foods is due, in part, to the food industry's ability to print nutrient claims on packages and market industrial products as healthy. This, in turn, has had an identifiable imprint on the global nutrient supply – higher in calories, carbohydrates, sugar, and fats.

Trade liberalization and open markets represent a double-edged sword, providing dietary diversity but at the same time, making unprocessed dietary patterns less appealing by making ultra-processed products so attractive. This study has indicated, however, that the products of industry have measurable impacts on population weight trajectories even at the country level – suggesting the inevitably of future growth in obesity if measures are not enacted to limit their availability, appeal, and affordability.

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Appendix A: EuroMonitor Country Coverage

Algeria

Angola

Argentina

Australia

Austria

Azerbaijan

Bangladesh

Belarus

Belgium

Bolivia

Bosnia-Herzegovina

Brazil

Bulgaria

Cambodia

Cameroon

Canada

Chile

China

Colombia

Costa Rica

Cuba

Czech Republic
Denmark
Dominican Republic
Ecuador
Egypt
El Salvador
Estonia
Ethiopia
Finland
France
Georgia
Germany
Ghana
Greece
Guatemala
Honduras
Hong Kong
Hungary
India
Indonesia
Iran
Iraq
Ireland
Israel
Italy
Japan

Jordan

Kazakhstan

Kenya

Kuwait

Laos

Latvia

Lebanon

Lithuania

Macedonia

Malaysia

Mexico

Morocco

Myanmar

Netherlands

New Zealand

Nigeria

Norway

Oman

Pakistan

Panama

Paraguay

Peru

Philippines

Poland

Portugal

Romania

Russia

Saudi Arabia

Serbia

Singapore

Slovakia

Slovenia

South Africa

South Korea

Spain

Sri Lanka

Sweden

Switzerland

Taiwan

Tanzania

Thailand

Tunisia

Turkey

Ukraine

United Arab Emirates

United Kingdom

Uruguay

USA

Uzbekistan

Venezuela

Vietnam

Appendix B: Aim 3 Full Models

Table 4.9.A: Adult BMI, Both Sexes

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	25.140	0.202	<0.001	22.064	0.369	<0.001	22.145	0.358	<0.001	22.786	0.369	<0.001
Year	0.072	0.001	<0.001	0.065	0.459	0.759	0.067	0.003	<0.001	0.085	0.003	0.088
Europe				2.199	0.002	<0.001	1.880	0.354	<0.001	2.116	0.377	<0.001
LAC				2.426	0.001	0.278	2.135	0.399	<0.001	2.593	0.426	<0.001
MENA				3.147	0.361	<0.001	3.036	0.426	<0.001	3.339	0.454	<0.001
North America				3.490	0.410	<0.001	2.801	0.783	0.001	3.382	0.835	<0.001
South Asia				-1.000	0.438	<0.001	-0.963	0.554	0.086	-1.372	0.589	0.022
Sub-Saharan Africa				-0.141	0.804	<0.001	-0.089	0.445	0.842	-0.305	0.475	0.521
Urban Pop. %				0.023	0.571	0.083	0.017	0.001	0.027	0.005	0.001	<0.001
GDP ($1000s)				-0.001	0.003	<0.001	-0.003	0.001	<0.001	0.009	0.001	0.057
UPF (kg/year)							0.003	0.002	<0.001	0.002	0.002	<0.001
SSB (liters/year)							0.005	0.001	<0.001	0.001	0.001	0.005
Year * GDP ($1000s)										-0.001	0.000	<0.001
Random Effects												
σ^2	0.01			0.01			0.01			0.01		
τ_{00}	3.69_{country}			1.08_{country}			1.02_{country}			1.16_{country}		
ICC	1.00			0.99			0.99			0.99		
N	91_{country}			91_{country}			91_{country}			91_{country}		

Observations	1001	1001	1001	1001
Marginal R^2 / Conditional R^2	0.014 / 0.996	0.705 / 0.996	0.721 / 0.997	0.686 / 0.997
AIC	-655.143	-765.692	-826.041	-1031.686

Table 4.9.B: Adult BMI, Both Sexes, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	22.0840	0.3734	<0.001	21.5861	0.3889	<0.001	21.8716	0.3805	<0.001
Year	0.0684	0.0020	0.769	0.0670	0.0020	<0.001	0.0690	0.0020	<0.001
Europe	2.2600	0.4722	<0.001	2.1141	0.3607	<0.001	1.9190	0.3549	<0.001
LAC	2.3719	1.1526	<0.001	2.4413	0.4077	<0.001	2.2023	0.7831	<0.001
MENA	3.1370	0.3610	<0.001	3.0489	0.4361	<0.001	2.9933	0.4258	0.066
North America	3.6246	0.4097	<0.001	3.4117	0.8010	<0.001	2.9783	0.4580	<0.001
South Asia	-1.0558	0.4380	<0.001	-1.0692	0.5687	0.063	-1.0314	0.5543	0.066
Sub-Saharan Africa	-0.1393	0.8039	<0.001	-0.0779	0.4697	0.869	-0.0644	1.1351	0.888
Urban Pop. %	0.0229	0.5719	0.068	0.0203	0.0036	<0.001	0.0168	0.0009	0.001
GDP ($1000s)	-4.8167	0.0011	<0.001	-4.9284	0.0001	<0.001	-6.0214	0.0001	<0.001
Calories				0.0002	0.0020	<0.001	0.0001	0.0000	0.020
SSB (liters/year)							0.0034	0.0009	<0.001
UPF (kg/year)							0.0029	0.0006	0.001
σ^2	0.01			0.01			0.01		
τ_{00}	1.08_{country}			1.07_{country}			1.01_{country}		

ICC	0.99	0.99	0.99
N	90 country	90 country	90 country
Observations	809	809	809
Marginal R^2 / Conditional R^2	0.701 / 0.998	0.705 / 0.998	0.717 / 0.998
AIC	-896.65	-911.89	-959.49

Table 4.9.C: Adult BMI, Physical Inactivity Controlled

	Model 1 (Demographic & Calories)			**Model 2 (Physical Activity)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	21.494	0.421	<0.001	20.702	0.495	<0.001	20.994	0.489	<0.001
Year	0.065	0.001	0.001	0.066	0.002	<0.001	0.068	0.012	<0.001
Europe	2.073	0.375	<0.001	1.999	0.458	<0.001	1.904	0.557	0.061
LAC	2.415	0.460	<0.001	2.133	0.800	<0.001	1.897	0.456	0.683
MENA	3.093	0.460	<0.001	2.756	0.568	0.057	2.768	0.450	<0.001
North America	3.356	0.829	<0.001	3.158	0.489	0.651	2.832	0.787	0.033
South Asia	-1.034	0.590	0.083	-1.096	0.004	<0.001	-1.060	0.565	0.226
Sub-Saharan Africa	0.047	0.504	0.927	0.222	0.000	<0.001	0.197	0.479	<0.001
Urban Pop. %	0.021	0.004	<0.001	0.019	0.001	<0.001	0.017	0.446	<0.001
GDP ($1000s)	-0.004	0.000	<0.001	-0.004	0.001	0.007	-0.005	0.001	<0.001
Calories	0.000	0.002	<0.001	0.0002	0.00006	<0.001	0.000	0.000	<0.001
Physical Inactivity %				0.034	0.012	0.006	0.032	0.018	0.008
SSB (liters/year)							0.004	0.0007	<0.001

UPF (kg/year)							0.001	0.001	0.229
σ^2	0.01			0.01			0.01		
τ_{00}	1.14 $_{country}$			1.05 $_{country}$			1.01 $_{country}$		
ICC	0.99			0.99			0.99		
N	82 $_{country}$			82 $_{country}$			82 $_{country}$		
Observations	634			634			634		
Marginal R^2 / Conditional R^2	0.707 / 0.998			0.737 / 0.998			0.745 / 0.998		
AIC	-567.566			-566.128			-563.927		

Table 4.10.A: Adult Male BMI

	Model 1 (Unconditional Growth)			Model 2 (Demographic)			Model 3 (UPF and SSB)			Model 4 (Interaction)		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	24.961	0.213	<0.001	22.697	0.363	<0.001	22.692	0.352	<0.001	23.353	0.371	<0.001
Year	0.077	0.001	<0.001	0.072	0.001	<0.001	0.075	0.003	0.047	0.088	0.003	0.066
Europe				2.636	0.356	<0.001	2.444	0.346	<0.001	2.581	0.378	<0.001
LAC				2.151	0.405	<0.001	1.845	0.389	<0.001	2.192	0.427	<0.001
MENA				2.788	0.357	<0.001	2.692	0.416	<0.001	2.971	0.455	<0.001
North America				3.928	0.405	<0.001	3.437	0.765	<0.001	3.742	0.838	<0.001
South Asia				-1.612	0.432	<0.001	-1.557	0.542	0.005	-1.946	0.592	0.001
Sub-Saharan Africa				-1.165	0.794	<0.001	-1.092	0.448	0.017	-1.330	0.476	0.006
Urban Pop. %				0.010	0.003	0.002	0.007	0.001	0.406	-0.006	0.001	<0.001
GDP ($1000s)				0.002	0.001	0.083	-0.001	0.001	<0.001	0.009	0.001	<0.001

UPF (kg/year)							0.002	0.002	<0.001	0.001	0.002	<0.001
SSB (liters/year)							0.006	0.001	0.033	0.003	0.001	0.178
Year * GDP ($1000s)										-0.001	0.000	<0.001
Random Effects												
σ^2	0.01			0.01			0.01			0.01		
τ_{00}	4.13 $_{\text{country}}$			1.05 $_{\text{country}}$			0.97 $_{\text{country}}$			1.17 $_{\text{country}}$		
ICC	1.00			0.99			0.99			0.99		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.014 / 0.997			0.740 / 0.997			0.752 / 0.998			0.720 / 0.998		
AIC	-743.520			-831.330			-964.616			-1001.578		

Table 4.10.B: Adult Male BMI, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	22.6073	0.3685	<0.001	22.3078	0.3836	<0.001	22.6314	0.3697	<0.001
Year	0.0735	0.0019	<0.001	0.0727	0.0020	0.954	0.0745	0.0019	<0.001
Europe	2.6611	0.3587	<0.001	2.5738	0.3580	<0.001	2.4326	0.3466	<0.001
LAC	2.1013	0.4070	<0.001	2.1417	0.4047	<0.001	1.8564	0.7650	<0.001
MENA	2.7514	0.4351	<0.001	2.6978	0.4328	<0.001	2.6838	0.4160	0.005
North America	4.0048	0.4070	<0.001	3.8766	0.7950	<0.001	3.4220	0.4475	<0.001
South Asia	-1.5724	0.5678	<0.001	-1.5780	0.5643	0.006	-1.5589	0.5415	0.056

Sub-Saharan Africa	-1.1110	0.4690	<0.001	-1.0731	0.4662	0.024	-1.0860	0.0009	0.017
Urban Pop. %	0.0116	0.0034	0.007	0.0101	0.0035	0.003	0.0064	0.0033	<0.001
GDP ($1000s)	-0.0052	0.001	0.996	-0.0637	0.0001	0.095	-0.0089	0.0010	0.415
Calories				0.0001	0.00005	0.009	0.0000	0.0019	<0.001
SSB (liters/year)							0.0046	0.0006	<0.001
UPF (kg/year)							0.0017	0.0008	0.044
σ^2	0.01			0.01			0.01		
τ_{00}	1.07_{country}			1.05_{country}			0.97_{country}		
ICC	0.99			0.99			0.99		
N	90_{country}			90_{country}			90_{country}		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.732 / 0.998			0.735 / 0.998			0.752 / 0.998		
AIC	-951.82			-956.75			-1024.89		

Table 4.10.C: Adult Male BMI, Physical Inactivity

	Model 1 (Demographic)			**Model 2 (Physical Activity)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	21.8683	0.4038	<0.001	20.8221	0.4620	<0.001	21.1840	0.4469	<0.001
Year	0.0713	0.0012	0.739	0.0722	0.0021	<0.001	0.0742	0.0037	<0.001
Europe	2.5139	0.3583	<0.001	2.4224	0.4206	<0.001	2.3578	0.5045	0.020
LAC	2.1811	0.4392	<0.001	1.8047	0.7371	<0.001	1.4896	0.4361	0.158
MENA	2.5672	0.4394	<0.001	2.1717	0.5259	0.023	2.2198	0.0037	0.002

North America	3.7151	0.7914	<0.001	3.5488	0.4545	0.213	3.1424	0.7101	0.384
South Asia	-1.3982	0.5631	0.015	-1.2209	0.5257	0.001	-1.1960	0.5044	0.641
Sub-Saharan Africa	-0.8806	0.4816	0.071	-0.5708	0.0001	0.003	-0.6220	0.4361	0.185
Urban Pop. %	0.0153	0.0038	<0.001	0.0133	0.0012	0.587	0.0114	0.4045	<0.001
GDP ($1000s)	-0.0004	0.0001	0.003	-0.0006	0.0011	<0.001	-0.0016	0.0007	0.185
Calories	0.0002	0.0021	<0.001	0.0002	0.0022	<0.001	0.0001	0.0021	<0.001
Physical Inactivity %				0.0488	0.0128	<0.001	0.0465	0.0122	0.002
SSB (liters/year)							0.0052	0.0007	0.641
UPF (kg/year)							0.0005	0.0009	<0.001
σ^2	0.01			0.01			0.01		
τ_{00}	1.04_{country}			0.89_{country}			0.82_{country}		
ICC	0.99			0.99			0.99		
N	82_{country}			82_{country}			82_{country}		
Observations	634			634			634		
Marginal R^2 / Conditional R^2	0.747 / 0.998			0.791 / 0.998			0.805 / 0.998		
AIC	-612.096			-617.097			-640.960		

Table 4.11.A: Adult Female BMI

	Model 1 (Unconditional Growth)			Model 2 (Demographic)			Model 3 (UPF and SSB)			Model 4 (Interaction)		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	25.296	0.213	<0.001	21.527	0.459	<0.001	21.584	0.455	<0.001	22.324	0.450	<0.001
Year	0.069	0.002	<0.001	0.058	0.566	0.159	0.061	0.004	<0.001	0.084	0.004	0.001

Europe				1.737	0.002	<0.001	1.301	0.450	0.005	1.586	0.455	0.001
LAC				2.712	0.002	0.027	2.389	0.506	<0.001	2.968	0.513	<0.001
MENA				3.669	0.445	<0.001	3.495	0.540	<0.001	3.859	0.547	<0.001
North America				3.066	0.505	<0.001	2.234	0.994	0.027	2.944	1.007	0.004
South Asia				-0.464	0.540	<0.001	-0.390	0.704	0.581	-0.868	0.711	0.226
Sub-Saharan Africa				0.804	0.991	0.003	0.897	0.566	0.117	0.649	0.572	0.260
Urban Pop. %				0.033	0.705	0.513	0.026	0.002	0.001	0.013	0.002	<0.001
GDP ($1000s)				-0.003	0.004	<0.001	-0.005	0.001	<0.001	0.010	0.001	0.839
UPF (kg/year)							0.005	0.002	<0.001	0.004	0.002	<0.001
SSB (liters/year)							0.005	0.001	<0.001	0.000	0.001	<0.001
Year * GDP ($1000s)										-0.001	0.000	<0.001
Random Effects												
σ^2	0.02			0.02			0.02			0.02		
τ_{00}	4.12 $_{\text{country}}$			1.64 $_{\text{country}}$			1.64 $_{\text{country}}$			1.68 $_{\text{country}}$		
ICC	0.99			0.99			0.99			0.99		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.011 / 0.994			0.620 / 0.995			0.628 / 0.995			0.606 / 0.996		
AIC	-168.430			-284.981			-330.764			-549.618		

Table 4.11.B: Adult Female BMI, Calorie Controlled

	Model 1	**Model 2**	**Model 3**

	(Demographic)			**(Calories)**			**(UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	21.6390	0.4594	<0.001	20.8370	0.4814	<0.001	21.1600	0.4787	<0.001
Year	0.0630	0.5719	0.185	0.0607	0.0015	<0.001	0.0636	0.0001	<0.001
Europe	1.8267	0.0026	<0.001	1.5919	0.4390	<0.001	1.2846	0.4416	<0.001
LAC	2.6587	0.0015	<0.001	2.7695	0.4961	<0.001	2.5096	0.9738	0.017
MENA	3.6955	0.4370	<0.001	3.5531	0.5307	<0.001	3.4377	0.5295	0.432
North America	3.2428	0.4960	<0.001	2.8996	0.9747	0.004	2.3625	0.5696	0.114
South Asia	-0.5945	0.5305	<0.001	-0.6141	0.6927	0.378	-0.5439	0.6895	<0.001
Sub-Saharan Africa	0.7633	0.9732	0.001	0.8629	0.5717	0.135	0.9090	0.0012	<0.001
Urban Pop. %	0.0321	0.6935	0.393	0.0280	0.0045	<0.001	0.0237	0.0045	<0.001
GDP ($1000s)	-0.0078	0.0045	<0.001	-0.0080	0.0001	<0.001	-0.0096	0.0008	<0.001
Calories				0.0004	0.0026	<0.001	0.0003	0.0026	<0.001
SSB (liters/year)							0.0032	0.0015	<0.001
UPF (kg/year)							0.0050	0.0012	<0.001
σ^2	0.01			0.01			0.01		
τ_{00}	1.58_{country}			1.58_{country}			1.56_{country}		
ICC	0.99			0.99			0.99		
N	90_{country}			90_{country}			90_{country}		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.626 / 0.997			0.628 / 0.997			0.634 / 0.997		

AIC	-482.46	-508.35	-548.61

Table 4.11.C: Adult Female BMI, Physical Inactivity

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	20.9734	0.5170	<0.001	20.3284	0.5955	<0.001	20.6467	0.5976	<0.001
Year	0.0581	0.0016	<0.001	0.0588	0.0028	<0.001	0.0616	0.0124	<0.001
Europe	1.5534	0.4511	0.001	1.4931	0.5656	<0.001	1.2826	04465	0.005
LAC	2.6530	0.5528	<0.001	2.4225	0.9795	0.007	2.2063	0.5936	0.000
MENA	3.7554	0.5531	<0.001	3.4114	0.7008	<0.001	3.3562	0.5652	<0.001
North America	2.9049	0.9961	0.005	2.6951	0.5952	0.076	2.3306	0.9823	0.019
South Asia	-0.6529	0.7094	0.360	-0.8519	0.7006	0.228	-0.7859	0.6985	0.264
Sub-Saharan Africa	0.9713	0.6064	0.113	1.0703	0.5951	0.076	1.0776	0.5934	0.073
Urban Pop. %	0.0260	0.0050	<0.001	0.0242	0.0016	<0.001	0.0214	0.0050	<0.001
GDP ($1000s)	-0.0061	0.0001	<0.001	-0.0063	0.0124	0.041	-0.0078	0.0015	<0.001
Calories	0.0004	0.0028	<0.001	0.0004	0.0028	<0.001	0.0003	0.0029	<0.001
Physical Inactivity %				0.0258	0.012	<0.001	0.0239	0.0123	0.057
SSB (liters/year)							0.0025	0.0001	0.014
UPF (kg/year)							0.0036	0.0013	0.008

σ^2	0.01	0.01	0.01
τ_{00}	1.64 $_{\text{country}}$	1.57 $_{\text{country}}$	1.56 $_{\text{country}}$
ICC	0.99	0.99	0.99
N	82 $_{\text{country}}$	82 $_{\text{country}}$	82 $_{\text{country}}$
Observations	634	634	634
Marginal R^2 / Conditional R^2	0.640 / 0.997	0.661 / 0.997	0.663 / 0.997
AIC	-268.847	-264.166	-254.055

Table 4.12.A: Child and Adolescent Less Than 19 Years BMI

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	19.146	0.126	<0.001	17.110	0.267	<0.001	17.219	0.259	<0.001	17.981	0.267	<0.001
Year	0.025	0.001	<0.001	0.014	0.290	0.015	0.015	0.279	0.010	0.039	0.001	<0.001
Europe				0.495	0.002	<0.001	0.396	0.002	<0.001	0.840	0.236	0.001
LAC				0.758	0.001	0.302	0.509	0.001	0.534	0.845	0.269	0.002
MENA				0.688	0.226	0.031	0.692	0.219	0.074	0.990	0.287	0.001
North America				1.422	0.258	0.004	0.987	0.251	0.046	1.892	0.529	0.001
South Asia				-1.027	0.276	0.014	-1.049	0.266	0.011	-1.561	0.376	<0.001
Sub-Saharan Africa				-0.720	0.505	0.006	-0.739	0.491	0.047	-0.955	0.300	0.002
Urban Pop. %				0.028	0.364	0.006	0.023	0.003	<0.001	0.010	0.003	0.002
GDP ($1000s)				0.001	0.003	<0.001	0.001	0.001	<0.001	0.001	0.001	0.016

SSB (liters/year)							0.005	0.000	<0.001	0.002	0.004	<0.001
Year * Europe										-0.046	0.004	<0.001
Year * LAC										0.011	0.004	0.011
Year * MENA										-0.003	0.004	0.450
Year * North America										-0.052	0.008	<0.001
Year * South Asia										0.003	0.006	0.656
Year * Sub-Saharan Africa										-0.013	0.005	0.005
Random Effects												
σ^2	0.02			0.02			0.02			0.01		
τ_{00}	1.44 $_{\text{country}}$			0.42 $_{\text{country}}$			0.39 $_{\text{country}}$			0.45 $_{\text{country}}$		
ICC	0.99			0.96			0.96			0.97		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.004 / 0.987			0.711 / 0.988			0.728 / 0.988			0.670 / 0.991		
AIC	-476.444			-595.613			-625.000			-877.113		

Table 4.12.B: Child and Adolescent Less Than 19 BMI, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	17.2396	0.2653	<0.001	16.7568	0.2956	<0.001	17.9613	0.3043	<0.001
Year	0.0194	0.0021	<0.001	0.0181	0.0013	<0.001	0.0408	0.0042	<0.001
Europe	0.4881	0.0021	<0.001	0.3600	0.2220	0.108	0.8518	0.2900	0.001

LAC	0.5463	0.0013	0.508	0.6435	0.2528	0.013	0.8299	0.5349	0.001
MENA	0.7166	0.2210	0.030	0.6343	0.2678	0.020	0.9556	0.3786	<0.001
North America	1.2051	0.2535	0.034	1.0544	0.4937	0.035	1.9225	0.3112	0.004
South Asia	-1.0995	0.2691	0.009	-1.1187	0.3525	0.002	-1.5342	0.0011	0.558
Sub-Saharan Africa	-0.7540	0.4962	0.017	-0.6971	0.2883	0.018	-0.9322	0.0042	<0.001
Urban Pop. %	0.0234	0.0033	<0.001	0.0212	0.0033	<0.001	0.0115	0.0032	<0.001
GDP ($1000s)	-0.0008	0.0019	<0.001	-0.0010	0.0001	<0.001	0.0007	0.0001	0.558
SSB (liters/year)	0.0038	0.0007	<0.001	0.0032	0.0007	<0.001	0.0014	0.0006	0.034
Calories				0.0002	0.0021	<0.001	-0.0000	0.0000	0.694
Year * Europe							-0.0437	0.0043	<0.001
Year * LAC							0.0090	0.0047	0.057
Year * MENA							0.0044	0.0049	0.369
Year * North America							-0.0477	0.0093	<0.001
Year * South Asia							0.0031	0.0064	0.627
Year * Sub-Saharan Africa							-0.0170	0.0053	0.002
σ^2	0.01			0.01			0.01		
τ_{00}	0.40_{country}			0.39_{country}			0.46_{country}		
ICC	0.97			0.97			0.98		
N	90_{country}			90_{country}			90_{country}		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.720 / 0.992			0.725 / 0.992			0.667 / 0.994		

AIC	-716.710	-710.092	-887.861

Table 4.12.C: Child and Adolescent Less Than 19 BMI, Physical Inactivity Controlled

	Model 1 (Demographic & Calories)			**Model 2 (Physical Activity)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	16.4099	0.3439	<0.001	17.1788	1.2871	<0.001	17.4739	1.2537	<0.001
Year	0.0173	0.0014	0.782	0.0169	0.2744	0.534	0.0181	0.0140	0.496
Europe	0.2250	0.2586	0.387	0.1711	0.3101	0.068	0.2084	0.3789	0.003
LAC	0.8331	0.3074	0.009	0.8204	0.5599	0.067	0.5184	0.3968	0.043
MENA	0.5946	0.3066	0.057	0.5762	0.3905	0.003	0.6782	0.0039	<0.001
North America	1.1437	0.5305	0.035	1.0395	0.4088	0.060	0.7212	0.5330	0.001
South Asia	-1.1471	0.3804	0.004	-1.1938	0.0040	<0.001	-1.1839	0.3669	0.206
Sub-Saharan Africa	-0.7770	0.4058	0.060	-0.7835	0.0001	<0.001	-0.8179	0.0014	0.628
Urban Pop. %	0.0233	0.0040	<0.001	0.0232	0.0014	0.872	0.0221	0.0037	0.095
GDP ($1000s)	-0.0004	0.0001	<0.001	-0.0002	0.0144	0.532	-0.0003	0.0013	0.811
Calories	0.0004	0.0024	<0.001	0.0004	0.0025	<0.001	0.0003	0.0000	<0.001
Physical Inactivity				-0.0047	0.0138	0.731	-0.0094	0.0013	0.591
SSB (liters/year)							0.0053	0.0008	<0.001
σ^2	0.01			0.01			0.01		
τ_{00}	0.44_{country}			0.45_{country}			0.42_{country}		
ICC	0.97			0.97			0.97		
N	69_{country}			69_{country}			69_{country}		

Observations	621	621	621
Marginal R^2 / Conditional R^2	0.722 / 0.992	0.719 / 0.992	0.733 / 0.993
AIC	-487.524	-479.244	-486.341

Table 4.13.A: Male Child and Adolescent Less Than 19 BMI

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	19.032	0.140	<0.001	16.883	0.299	<0.001	17.017	0.292	<0.001	17.836	0.299	<0.001
Year	0.035	0.002	<0.001	0.024	0.316	0.001	0.025	0.308	0.001	0.051	0.001	0.107
Europe				0.623	0.002	<0.001	0.499	0.002	<0.001	1.014	0.258	<0.001
LAC				0.551	0.002	0.211	0.240	0.002	0.432	0.601	0.295	0.045
MENA				0.626	0.246	0.013	0.629	0.241	0.041	0.964	0.314	0.003
North America				1.373	0.281	0.053	0.834	0.278	0.390	1.928	0.580	0.001
South Asia				-1.156	0.301	0.041	-1.183	0.294	0.035	-1.717	0.412	<0.001
Sub-Saharan Africa				-1.089	0.550	0.014	-1.112	0.543	0.128	-1.331	0.328	<0.001
Urban Pop. %				0.030	0.398	0.005	0.025	0.004	<0.001	0.010	0.004	0.004
GDP ($1000s)				0.002	0.004	<0.001	0.001	0.001	0.431	0.002	0.001	0.022
SSB (liters/year)							0.006	0.000	<0.001	0.002	0.004	<0.001
Year * Europe										-0.053	0.005	<0.001
Year * LAC										0.020	0.005	<0.001
Year * MENA										-0.005	0.005	0.355

Year * North America										-0.066	0.010	<0.001
Year * South Asia										-0.002	0.007	0.783
Year * Sub-Saharan Africa										-0.018	0.006	0.002
Random Effects												
σ^2	0.03			0.03			0.03			0.02		
τ_{00}	1.78 $_{\text{country}}$			0.49 $_{\text{country}}$			0.47 $_{\text{country}}$			0.53 $_{\text{country}}$		
ICC	0.98			0.95			0.95			0.97		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.007 / 0.984			0.722 / 0.985			0.735 / 0.986			0.684 / 0.990		
AIC	-97.705			-215.555			-247.627			-515.321		

Table 4.13.B: Male Child and Adolescent Less Than 19 BMI, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	17.0700	0.2976	<0.001	16.4595	0.3379	<0.001	17.8278	0.3466	<0.001
Year	0.0300	0.3181	<0.001	0.0284	0.0015	0.454	0.0532	0.2662	<0.001
Europe	0.6240	0.0025	<0.001	0.4617	0.2449	0.063	1.0377	0.3201	0.004
LAC	0.2996	0.0016	0.522	0.4238	0.2793	0.132	0.6232	0.5910	0.001
MENA	0.6694	0.2420	0.012	0.5657	0.2951	0.058	0.9354	0.4182	<0.001
North America	1.1477	0.2784	0.285	0.9577	0.5445	0.082	2.0284	0.3433	<0.001
South Asia	-1.2609	0.2949	0.026	-1.2874	0.3888	0.001	-1.7262	0.0014	0.518

Sub-Saharan Africa	-1.1575	0.5442	0.038	-1.0864	0.3174	0.001	-1.3417	0.0051	<0.001
Urban Pop. %	0.0246	0.0038	<0.001	0.0216	0.0039	<0.001	0.0111	0.0038	0.003
GDP ($1000s)	-0.0010	0.0009	<0.001	-0.0012	0.0001	<0.001	0.0009	0.0001	0.980
SSB (liters/year)	0.0045	0.3902	0.002	0.0038	0.0009	<0.001	0.0011	0.0008	0.176
Calories				0.0003	0.0025	<0.001	0.0000	0.0001	0.041
Year * Europe							-0.0504	0.0052	<0.001
Year * LAC							0.0212	0.0057	<0.001
Year * MENA							0.0044	0.0060	0.466
Year * North America							-0.0609	0.0113	<0.001
Year * South Asia							-0.0041	0.0078	0.599
Year * Sub-Saharan Africa							-0.0217	0.0065	0.001
σ^2	0.02			0.02			0.01		
τ_{00}	0.47 $_{\text{country}}$			0.47 $_{\text{country}}$			0.55 $_{\text{country}}$		
ICC	0.96			0.96			0.98		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.729 / 0.990			0.732 / 0.990			0.677 / 0.993		
AIC	-409.227			-404.225			-596.286		

Table 4.14.A: Female Child and Adolescent Less Than 19 BMI

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*

(Intercept)	19.258	0.117	<0.001	17.461	0.264	<0.001	17.546	0.256	<0.001	18.170	0.268	<0.001
Year	0.014	0.001	<0.001	0.006	0.293	0.205	0.007	0.282	0.172	0.026	0.001	<0.001
Europe				0.400	0.002	0.001	0.319	0.002	<0.001	0.665	0.238	0.006
LAC				1.012	0.001	0.769	0.812	0.001	0.975	1.094	0.272	<0.001
MENA				0.798	0.229	0.085	0.800	0.221	0.152	1.038	0.289	0.001
North America				1.542	0.261	<0.001	1.191	0.253	0.002	1.849	0.534	0.001
South Asia				-0.965	0.279	0.005	-0.980	0.269	0.004	-1.420	0.379	<0.001
Sub-Saharan Africa				-0.375	0.512	0.003	-0.388	0.495	0.018	-0.575	0.303	0.060
Urban Pop. %				0.023	0.368	0.010	0.020	0.003	<0.001	0.008	0.003	0.008
GDP ($1000s)				0.000	0.003	<0.001	-0.000	0.001	<0.001	0.000	0.001	0.008
SSB (liters/year)							0.004	0.000	<0.001	0.002	0.000	<0.001
Year * Europe										-0.036	0.004	<0.001
Year * LAC										0.002	0.004	0.690
Year * MENA										-0.002	0.004	0.637
Year * North America										-0.035	0.008	<0.001
Year * South Asia										0.007	0.006	0.227
Year * Sub-Saharan Africa										-0.009	0.005	0.061
Random Effects												
σ^2	0.02			0.02			0.02			0.01		
τ_{00}	1.25 $_{\text{country}}$			0.43 $_{\text{country}}$			0.40 $_{\text{country}}$			0.46 $_{\text{country}}$		
ICC	0.99			0.97			0.96			0.97		

N	91_{country}	91_{country}	91_{country}	91_{country}
Observations	1001	1001	1001	1001
Marginal R^2 / Conditional R^2	0.002 / 0.987	0.652 / 0.988	0.672 / 0.988	0.615 / 0.990
AIC	-662.129	-752.544	-770.900	-902.443

Table 4.14.B: Female Child and Adolescent Less Than 19 BMI, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	17.5321	0.2621	<0.001	17.1244	0.2881	<0.001	18.0480	0.3011	<0.001
Year	0.0088	0.2926	0.214	0.0077	0.0012	0.597	0.0281	0.2382	0.008
Europe	0.3719	0.0019	<0.001	0.2638	0.2229	0.240	0.6410	0.2868	0.001
LAC	0.8339	0.0012	0.650	0.9151	0.2536	0.001	1.0763	0.5290	0.001
MENA	0.8054	0.2229	0.099	0.7356	0.2690	0.008	0.9965	0.3744	0.001
North America	1.2954	0.2552	0.002	1.1676	0.4957	0.021	1.7810	0.3077	0.104
South Asia	-1.0039	0.2713	0.004	-1.0187	0.3537	0.005	-1.3492	0.0011	0.627
Sub-Saharan Africa	-0.3661	0.4998	0.011	-0.3175	0.2897	0.276	-0.5054	0.0042	<0.001
Urban Pop. %	0.0199	0.0032	<0.001	0.0180	0.0032	<0.001	0.0101	0.0032	0.002
GDP ($1000s)	-0.0005	0.0007	<0.001	-0.0006	0.0001	0.001	0.0005	0.0001	0.981
SSB (liters/year)	0.0033	0.3577	0.006	0.0028	0.0007	<0.001	0.0018	0.0006	0.004
Calories				0.0002	0.0000	0.001	0.000	0.000	0.981
Year * Europe							-0.0360	0.0043	<0.001
Year * LAC							-0.0032	0.0047	0.499

Year * MENA							0.0001	0.0049	0.987
Year * North America							-0.0339	0.0092	<0.001
Year * South Asia							0.0042	0.0064	0.515
Year * Sub-Saharan Africa							-0.0119	0.0053	0.024
σ^2	0.01			0.01			0.01		
τ_{00}	0.40 $_{\text{country}}$			0.40 $_{\text{country}}$			0.45 $_{\text{country}}$		
ICC	0.98			0.98			0.98		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.667 / 0.992			0.674 / 0.992			0.623 / 0.993		
AIC	-891.98			-900.77			-1029.65		

Table 4.15.A: Adult Obesity Prevalence

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	15.615	0.868	<0.001	1.291	1.457	0.377	1.236	1.464	0.400	0.047	1.352	0.972
Year	0.416	0.005	<0.001	0.375	1.801	0.467	0.375	0.005	0.002	0.245	0.003	0.005
Europe				9.979	0.007	<0.001	10.020	1.440	<0.001	9.133	1.387	<0.001
LAC				10.642	0.005	0.002	10.780	1.620	<0.001	9.078	1.572	<0.001
MENA				16.659	1.416	<0.001	16.650	1.730	<0.001	14.690	1.679	<0.001
North America				17.711	1.607	<0.001	17.943	3.183	<0.001	15.491	3.084	<0.001
South Asia				-2.021	1.718	<0.001	-2.010	2.254	0.375	-0.598	2.181	0.785

Sub-Saharan Africa				1.316	3.154	<0.001	1.328	1.810	0.465	1.862	1.758	0.292
Urban Pop. %				0.093	2.243	0.370	0.096	0.014	<0.001	0.127	0.012	<0.001
GDP ($1000s)				0.015	0.014	<0.001	0.016	0.004	0.005	0.010	0.011	<0.001
UPF (kg/year)							0.000	0.003	0.943	/	/	/
SSB (liters/year)							-0.003	0.003	0.320	/	/	/
Year * Europe										0.118	0.011	<0.001
Year * LAC										0.211	0.012	<0.001
Year * MENA										0.276	0.013	<0.001
Year * North America										0.331	0.024	<0.001
Year * South Asia										-0.087	0.017	<0.001
Year * Sub-Saharan Africa										-0.001	0.014	0.914
Random Effects												
σ^2	0.23			0.23			0.23			0.11		
τ_{00}	68.45 country			16.60 country			16.75 country			15.92 country		
ICC	1.00			0.99			0.99			0.99		
N	91 country			91 country			91 country			91 country		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.025 / 0.997			0.756 / 0.997			0.754 / 0.997			0.770 / 0.998		
AIC	2135.589			1987.717			2010.121			1336.634		

Table 4.15.B: Adult Obesity Prevalence, Calorie Controlled

	Model 1 (Demographic)	**Model 2 (Calories)**	**Model 3 (UPF and SSB)**

Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	0.9245	1.4723	0.530	1.0249	1.5554	0.510	0.8752	1.5695	0.577
Year	0.3626	1.8246	0.356	0.3629	0.0049	0.001	0.3626	0.0002	0.995
Europe	9.7885	0.0084	<0.001	9.8179	1.4028	<0.001	9.8168	1.7065	<0.001
LAC	10.3268	0.0049	0.001	10.3129	1.5849	<0.001	10.4644	3.1378	<0.001
MENA	16.2388	1.3941	<0.001	16.2566	1.6960	<0.001	16.2222	2.2239	0.465
North America	17.1965	1.5822	<0.001	17.2394	3.1142	<0.001	17.4288	1.8351	0.354
South Asia	-1.6426	1.6924	<0.001	-1.6400	2.2149	0.461	-1.6310	0.0151	<0.001
Sub-Saharan Africa	1.6918	3.1046	<0.001	1.6794	1.8270	0.360	1.7087	0.0040	0.893
Urban Pop. %	0.1022	2.2132	0.460	0.1027	0.0149	<0.001	0.1042	1.4244	<0.001
GDP ($1000s)	0.0159	0.0146	<0.001	0.0159	0.0002	0.841	0.0160	0.0028	0.311
Calories				-0.0000	0.0086	<0.001	-0.0000	0.0087	0.995
SSB (liters/year)							-0.0028	0.0050	0.311
UPF (kg/year)							0.0005	0.0039	0.893
σ^2	0.16			0.16			0.16		
τ_{00}	16.05 $_{\text{country}}$			16.07 $_{\text{country}}$			16.20 $_{\text{country}}$		
ICC	0.99			0.99			0.99		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.755 / 0.998			0.755 / 0.998			0.753 / 0.998		
AIC	1431.375			1448.165			1470.338		

Table 4.15.C: Adult Obesity Prevalence, Physical Inactivity Controlled

	Model 1 (Demographic & Calories)			**Model 2 (Physical Activity)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	2.421	1.524	0.114	0.387	1.941	0.843	0.353	1.994	0.860
Year	0.362	2.346	0.741	0.363	0.005	0.001	0.359	0.053	<0.001
Europe	9.208	0.009	<0.001	8.848	1.465	<0.001	9.536	1.878	<0.001
LAC	10.051	0.005	0.001	9.286	1.815	<0.001	9.811	3.162	<0.001
MENA	15.643	1.465	<0.001	14.835	1.817	<0.001	15.073	2.233	0.163
North America	16.525	1.775	<0.001	15.927	3.046	<0.001	16.984	2.484	0.928
South Asia	-2.839	1.770	<0.001	-3.022	2.169	0.168	-3.152	2.313	<0.001
Sub-Saharan Africa	-0.780	3.058	<0.001	0.304	2.410	0.900	0.225	1.990	0.092
Urban Pop. %	0.091	2.189	0.199	0.087	0.017	<0.001	0.094	0.016	<0.001
GDP ($1000s)	0.018	0.017	<0.001	0.017	0.052	0.103	0.020	0.003	0.116
Physical Inactivity %				0.086	0.009	<0.001	0.114	0.049	0.022
SSB (liters/year)							-0.005	0.005	0.015
UPF (kg/year)							-0.007	1.880	0.068
σ^2	0.16			0.16			0.16		
τ_{00}	15.19 $_{\text{country}}$			14.86 $_{\text{country}}$			15.80 $_{\text{country}}$		
ICC	0.99			0.99			0.99		
N	69 $_{\text{country}}$			69 $_{\text{country}}$			69 $_{\text{country}}$		
Observations	621			621			621		
Marginal R^2 / Conditional R^2	0.782 / 0.998			0.789 / 0.998			0.778 / 0.998		

AIC	1107.340	1110.706	1126.085

Table 4.16.A: Adult Obesity Prevalence, Male

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	12.821	0.833	<0.001	4.026	1.518	0.009	3.979	1.548	0.011	0.279	1.264	0.826
Year	0.436	0.006	<0.001	0.415	1.817	0.079	0.415	1.867	0.085	0.249	0.003	<0.001
Europe				10.497	0.008	<0.001	10.715	0.008	<0.001	8.951	1.287	<0.001
LAC				8.326	0.006	<0.001	8.827	0.006	<0.001	6.365	1.460	<0.001
MENA				13.106	1.427	<0.001	13.144	1.468	<0.001	10.202	1.557	<0.001
North America				19.267	1.621	<0.001	20.168	1.672	<0.001	16.611	2.868	<0.001
South Asia				-4.410	1.733	<0.001	-4.461	1.780	<0.001	-1.384	2.023	0.496
Sub-Saharan Africa				-3.235	3.180	<0.001	-3.256	3.278	<0.001	-1.375	1.630	0.401
Urban Pop. %				0.021	2.268	0.055	0.027	0.016	0.084	0.105	0.011	<0.001
GDP ($1000s)				0.030	0.015	0.160	0.030	0.003	0.003	0.018	0.002	0.011
SSB (liters/year)							-0.009	0.003	0.002	-0.005	0.001	<0.001
Year * Europe										0.206	0.011	<0.001
Year * LAC										0.206	0.012	<0.001
Year * MENA										0.303	0.013	<0.001
Year * North America										0.346	0.024	<0.001

Predictors	Estimates	std. Error	p	Estimates	std. Error	p	Estimates	std. Error	p	Estimates	std. Error	p
Year * South Asia										-0.134	0.017	<0.001
Year * Sub-Saharan Africa										-0.112	0.013	<0.001
Random Effects												
σ^2	0.31			0.31			0.31			0.10		
τ_{00}	63.00 $_{country}$			16.81 $_{country}$			17.76 $_{country}$			13.67 $_{country}$		
ICC	1.00			0.98			0.98			0.99		
N	91 $_{country}$			91 $_{country}$			91 $_{country}$			91 $_{country}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.029 / 0.995			0.730 / 0.995			0.719 / 0.995			0.780 / 0.998		
AIC	2391.4			2261.413			2255.508			1286.206		

Table 4.16.B: Adult Obesity Prevalence, Male, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	2.5976	1.4710	0.079	4.8584	1.5922	0.003	4.6160	1.6169	0.005	0.8562	1.3390	0.523
Year	0.3876	1.7533	0.163	0.3946	0.0054	<0.001	0.3940	0.0054	<0.001	0.2279	1.2813	<0.001
Europe	9.9947	0.0093	<0.001	10.6422	1.3774	<0.001	10.7121	1.3981	<0.001	9.0902	1.5471	<0.001
LAC	7.8438	0.0055	<0.001	7.5766	1.5551	<0.001	7.9008	1.5873	<0.001	6.3127	2.8481	<0.001
MENA	12.3516	1.3373	<0.001	12.7685	1.6653	<0.001	12.7525	1.6901	<0.001	10.3017	2.0085	0.501
North America	18.1480	1.5187	<0.001	19.1154	3.0561	<0.001	19.5763	3.1102	<0.001	16.8125	1.6639	0.417
South Asia	-3.3230	1.6259	<0.001	-3.3409	2.1792	0.129	-3.3769	2.2108	0.130	-1.3578	0.0033	<0.001
Sub-Saharan Africa	-2.4687	2.9794	<0.001	-2.7765	1.7938	0.125	-2.7589	1.8206	0.133	-1.3560	0.0128	<0.001

Urban Pop. %	0.0480	2.1326	0.123	0.0567	0.0161	<0.001	0.0588	0.0162	<0.001	0.1088	0.0111	<0.001
GDP ($1000s)	0.0361	0.0158	0.002	0.0364	0.0003	<0.001	0.0367	0.0003	0.001	0.0215	0.0002	<0.001
Calories				-0.0010	0.0094	<0.001	-0.0009	0.0094	<0.001	-0.0003	0.0001	0.094
SSB (liters/year)							-0.0055	0.0030	0.069	-0.0055	0.0019	0.003
Year * Europe										0.2103	0.0125	<0.001
Year * LAC										0.2179	0.0134	<0.001
Year * MENA										0.3038	0.0140	<0.001
Year * North America										0.3477	0.0266	<0.001
Year * South Asia										-0.1203	0.0183	<0.001
Year * Sub-Saharan Africa										-0.0952	0.0151	<0.001
σ^2	0.20			0.20			0.20			0.07		
τ_{00}	14.71 $_{\text{country}}$			15.40 $_{\text{country}}$			15.87 $_{\text{country}}$			13.43 $_{\text{country}}$		
ICC	0.99			0.99			0.99			1.00		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.746 / 0.997			0.737 / 0.997			0.731 / 0.997			0.771 / 0.999		
AIC	1599.677			1591.025			1590.523			864.036		

Table 4.17.A: Adult Obesity Prevalence, Female

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	18.347	1.008	<0.001	-2.148	1.743	0.220	-2.234	1.735	0.200	-0.656	1.671	0.695

Year	0.393	0.005	<0.001	0.329	2.236	0.010	0.331	0.005	<0.001	0.235	0.013	<0.001
Europe				9.129	0.008	<0.001	8.579	1.767	<0.001	8.444	2.108	<0.001
LAC				12.611	0.005	0.312	12.501	1.987	<0.001	11.604	3.875	0.001
MENA				21.293	1.761	<0.001	20.998	2.126	<0.001	20.122	2.733	0.831
North America				15.829	1.998	<0.001	15.207	3.908	<0.001	14.007	2.204	0.020
South Asia				0.806	2.134	<0.001	0.959	2.764	0.729	0.585	2.732	0.772
Sub-Saharan Africa				5.905	3.920	<0.001	6.085	2.225	0.008	5.206	2.204	0.020
Urban Pop. %				0.175	2.778	0.772	0.171	0.015	<0.001	0.152	0.013	<0.001
GDP ($1000s)				0.005	0.014	<0.001	0.003	0.005	0.588	0.001	0.003	<0.001
UPF (kg/year)							0.008	0.003	0.019	0.010	0.002	<0.001
Year * Europe										0.043	0.013	0.001
Year * LAC										0.223	0.014	<0.001
Year * MENA										0.229	0.015	<0.001
Year * North America										0.307	0.028	<0.001
Year * South Asia										-0.041	0.019	0.035
Year * Sub-Saharan Africa										0.111	0.016	<0.001
Random Effects												
σ^2	0.28			0.24			0.24			0.14		
τ_{00}	92.32 country			25.74 country			25.46 country			25.08 country		
ICC	1.00			0.99			0.99			0.99		
N	91 country			91 country			91 country			91 country		

Observations	1001	1001	1001	1001
Marginal R^2 / Conditional R^2	0.016 / 0.997	0.735 / 0.998	0.738 / 0.998	0.739 / 0.999
AIC	2308.765	2069.9	2068.350	1661.101

Table 4.17.B: Adult Obesity Prevalence, Female, Calorie Controlled

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	-1.5411	1.7580	0.382	-3.2119	1.8256	0.080	-3.0246	1.8203	0.098
Year	0.3290	2.2665	0.011	0.3242	0.0050	0.775	0.3273	0.009	<0.001
Europe	9.2272	0.0089	<0.001	8.7390	1.7351	<0.001	8.3360	1.7394	<0.001
LAC	12.4391	0.0051	0.827	12.6673	1.9621	<0.001	12.5501	1.9252	<0.001
MENA	21.1975	1.7345	<0.001	20.8999	2.0976	<0.001	20.6955	2.0888	0.825
North America	15.8944	1.9676	<0.001	15.1792	3.8543	<0.001	14.7560	3.8396	0.007
South Asia	0.5299	2.1029	<0.001	0.4936	2.7325	0.857	0.6039	2.7179	<0.001
Sub-Saharan Africa	5.8999	3.8612	<0.001	6.1092	2.2596	0.008	6.2158	2.2476	0.006
Urban Pop. %	0.1681	2.7420	0.847	0.1598	0.0159	<0.001	0.1565	0.0052	0.489
GDP ($1000s)	-0.0011	0.0158	<0.001	-0.0014	0.0002	0.001	-0.0036	0.0040	0.068
Calories				0.0008	0.0090	<0.001	0.0007	0.0002	0.006
UPF (kg/year)							0.0072	0.0039	0.068
σ^2	0.17			0.16			0.16		
τ_{00}	24.93 country			24.76 country			24.47 country		
ICC	0.99			0.99			0.99		

N	90_{country}	90_{country}	90_{country}
Observations	809	809	809
Marginal R^2 / Conditional R^2	0.735 / 0.998	0.737 / 0.998	0.740 / 0.998
AIC	1507.1	1498.6	1497.2

Table 4.18.A: Child and Adolescent Less Than 19 Obesity Prevalence

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	5.827	0.442	<0.001	-1.023	0.997	0.305	-0.764	0.964	0.428	-1.422	0.969	0.143
Year	0.282	0.005	<0.001	0.248	0.007	<0.001	0.250	0.007	0.013	0.259	0.005	<0.001
Europe				-0.616	0.859	0.476	-0.831	0.007	<0.001	-0.736	0.014	<0.001
LAC				1.378	0.978	0.162	0.839	0.005	0.075	0.475	0.004	<0.001
MENA				3.867	0.860	0.476	3.882	0.824	0.316	3.225	0.845	0.386
North America				6.959	1.918	<0.001	6.011	0.945	0.377	6.141	0.965	0.624
South Asia				-1.262	1.379	0.362	-1.320	1.002	<0.001	-0.469	1.026	0.002
Sub-Saharan Africa				-2.624	1.099	0.019	-2.670	1.849	0.002	-1.822	1.896	0.002
Urban Pop. %				0.107	1.381	0.363	0.098	0.012	<0.001	0.111	0.011	<0.001
GDP ($1000s)				-0.007	0.012	<0.001	-0.009	0.003	<0.001	-0.016	0.003	<0.001
SSB (liters/year)							0.011	0.002	<0.001	0.009	0.003	<0.001
Year * Europe										-0.018	0.015	0.204
Year * LAC										0.044	0.016	0.006
Year * MENA										0.089	0.017	<0.001

Year * North America										0.002	0.032	0.946
Year * South Asia										-0.116	0.022	<0.001
Year * Sub-Saharan Africa										-0.147	0.018	<0.001
Random Effects												
σ^2	0.25			0.23			0.23			0.18		
τ_{00}	17.68 $_{\text{country}}$			6.05 $_{\text{country}}$			5.52 $_{\text{country}}$			5.74 $_{\text{country}}$		
ICC	0.99			0.96			0.96			0.97		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.043 / 0.987			0.681 / 0.988			0.700 / 0.988			0.699 / 0.991		
AIC	2057.866			1898.2			1883.2			1740.219		

Table 4.18.B: Child and Adolescent Less Than 19 Obesity Prevalence, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	-1.133	0.995	0.255	-2.254	1.082	0.038	-1.848	1.072	0.086	-1.855	1.083	0.087
Year	0.239	1.118	0.037	0.236	0.004	0.016	0.237	0.012	<0.001	0.242	0.012	<0.001
Europe	-0.580	0.007	<0.001	-0.912	0.850	0.287	-0.977	0.827	0.241	-0.812	1.023	0.003
LAC	1.267	0.004	0.020	1.434	0.957	0.138	1.063	0.941	0.262	0.756	1.887	0.001
MENA	3.731	0.851	0.497	3.536	1.027	0.001	3.589	0.999	0.001	3.166	1.335	0.634
North America	7.041	0.967	0.194	6.563	1.882	0.001	6.050	1.840	0.001	6.325	1.097	0.104
South Asia	-1.103	1.037	0.001	-1.152	1.350	0.395	-1.172	1.313	0.374	-0.638	1.335	<0.001

Sub-Saharan Africa	-2.363	1.897	<0.001	-2.232	1.106	0.047	-2.293	1.075	0.036	-1.802	1.097	0.104
Urban Pop. %	0.110	1.366	0.421	0.104	0.012	<0.001	0.099	0.004	0.011	0.107	0.850	0.342
GDP ($1000s)	-0.010	0.012	<0.001	-0.011	0.000	0.012	-0.011	0.002	0.007	-0.019	0.002	<0.001
Calories				0.0005	0.0002	0.012	0.0004	0.0002	0.055	0.0003	0.0002	0.127
SSB (liters/year)							0.007	0.002	0.006	0.005	0.002	0.026
Year * Europe										-0.009	0.016	0.544
Year * LAC										0.053	0.017	0.002
Year * MENA										0.092	0.018	<0.001
Year * North America										0.021	0.034	0.535
Year * South Asia										-0.116	0.023	<0.001
Year * Sub-Saharan Africa										-0.129	0.019	<0.001
σ^2	0.14			0.14			0.14			0.11		
τ_{00}	5.91_{country}			5.76_{country}			5.44_{country}			5.66_{country}		
ICC	0.98			0.98			0.98			0.98		
N	90_{country}			90_{country}			90_{country}			90_{country}		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.675 / 0.993			0.682 / 0.993			0.693 / 0.992			0.687 / 0.994		
AIC	1242.3			1237.8			1232.1			1065.1		

Table 4.18.C: Child and Adolescent Less Than 19 Obesity Prevalence, Physical Inactivity Controlled

	Model 1 (Demographic & Calories)			**Model 2 (Physical Activity)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*

(Intercept)	-2.307	1.195	0.054	7.642	4.308	0.075	8.264	4.262	0.052
Year	0.240	0.004	0.008	0.235	0.008	0.043	0.238	0.000	<0.001
Europe	-1.417	0.963	0.146	-2.086	1.013	0.027	-2.180	0.989	0.019
LAC	0.856	1.151	0.460	0.711	1.167	0.036	0.171	1.151	0.066
MENA	2.860	1.149	0.015	2.645	1.666	0.151	2.737	1.137	0.146
North America	5.754	1.988	0.005	4.452	2.084	0.152	3.808	1.502	0.134
South Asia	-1.496	1.423	0.297	-2.126	1.463	<0.001	-2.099	1.427	<0.001
Sub-Saharan Africa	-2.121	1.521	0.168	-2.234	1.541	0.006	-2.279	1.502	0.013
Urban Pop. %	0.111	0.013	<0.001	0.108	0.004	0.030	0.105	.0131	0.031
GDP ($1000s)	-0.012	0.000	0.010	-0.010	0.048	0.016	-0.011	0.004	0.003
Calories	0.001	0.008	<0.001	0.001	0.008	<0.001	0.0004	0.0002	0.0497
Physical Inactivity %				-0.115	0.047	0.545	-0.116	0.045	0.006
SSB (liters/year)							0.008	0.003	0.003
σ^2	0.12			0.12			0.12		
τ_{00}	6.26 $_{\text{country}}$			6.43 $_{\text{country}}$			6.10 $_{\text{country}}$		
ICC	0.98			0.98			0.98		
N	69 $_{\text{country}}$			69 $_{\text{country}}$			69 $_{\text{country}}$		
Observations	621			621			621		
Marginal R^2 / Conditional R^2	0.668 / 0.994			0.660 / 0.994			0.673 / 0.994		
AIC	913.899			914.347			917.326		

Table 4.19.A: Child and Adolescent Less Than 19 Obesity Prevalence, Male

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	6.558	0.494	<0.001	-0.022	1.122	0.984	0.238	1.087	0.827	-1.212	1.079	0.262
Year	0.327	0.006	<0.001	0.289	1.213	<0.001	0.291	1.163	<0.001	0.334	1.176	0.010
Europe				-0.681	0.008	<0.001	-0.931	0.008	<0.001	-0.869	0.017	<0.001
LAC				0.593	0.006	0.707	-0.028	0.658	0.540	-0.539	0.005	0.001
MENA				3.132	0.947	0.474	3.138	0.910	0.309	2.523	0.925	0.350
North America				7.043	1.079	0.584	5.956	1.047	0.979	5.854	1.057	0.611
South Asia				-2.095	1.156	0.008	-2.143	1.108	0.006	-0.739	1.123	0.027
Sub-Saharan Africa				-4.634	2.114	0.001	-4.677	2.045	0.005	-3.075	2.077	0.006
Urban Pop. %				0.110	1.525	0.173	0.100	0.013	<0.001	0.124	0.013	<0.001
GDP ($1000s)				-0.002	0.013	<0.001	-0.004	0.003	<0.001	-0.017	0.003	<0.001
SSB (liters/year)							0.012	0.006	<0.001	0.012	0.004	<0.001
Year * Europe										-0.034	0.017	0.050
Year * LAC										0.008	0.019	0.692
Year * MENA										0.035	0.020	0.082
Year * North America										-0.012	0.038	0.749
Year * South Asia										-0.163	0.026	<0.001
Year * Sub-Saharan Africa										-0.267	0.021	<0.001

Random Effects				
σ^2	0.35	0.34	0.33	0.25
τ_{00}	22.14_{country}	7.32_{country}	6.72_{country}	6.84_{country}
ICC	0.98	0.96	0.95	0.96
N	91_{country}	91_{country}	91_{country}	91_{country}
Observations	1001	1001	1001	1001
Marginal R^2 / Conditional R^2	0.045 / 0.985	0.678 / 0.986	0.697 / 0.986	0.707 / 0.990
AIC	2387.8	2261.8	2248.6	1999.7

Table 4.19.B: Child and Adolescent Less Than 19 Male Obesity Prevalence, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	-0.361	1.118	0.747	-1.282	1.234	0.299	-0.175	1.090	0.872	-0.807	1.224	0.509
Year	0.275	0.009	0.001	0.273	0.005	0.337	0.277	0.009	0.001	0.275	0.014	<0.001
Europe	-0.660	1.232	<0.001	-0.932	0.942	0.325	-0.847	1.191	<0.001	-1.015	0.916	0.271
LAC	0.478	0.005	0.368	0.615	1.060	0.563	0.028	1.459	0.282	0.155	1.044	0.883
MENA	2.993	0.936	0.483	2.833	1.137	0.015	2.998	0.907	0.353	2.891	1.105	0.010
North America	7.080	1.065	0.655	6.688	2.084	0.002	6.251	1.040	0.979	6.052	2.038	0.004
South Asia	-1.774	1.142	0.010	-1.814	1.497	0.228	-1.803	1.104	0.008	-1.828	1.455	0.212
Sub-Saharan Africa	-4.232	2.088	0.001	-4.125	1.224	0.001	-4.267	2.036	0.003	-4.192	1.190	0.001
Urban Pop. %	0.117	1.508	0.242	0.111	0.014	<0.001	0.109	0.014	<0.001	0.106	0.005	0.270
GDP ($1000s)	-0.005	0.014	<0.001	-0.005	0.000	0.086	-0.006	0.003	0.002	-0.006	0.003	0.006

Calories				0.000	0.009	<0.001				0.000	0.009	<0.001
SSB (liters/year)							0.009	0.005	0.220	0.008	0.000	<0.001
σ^2	0.20			0.20			0.20			0.20		
τ_{00}	7.14_{country}			7.03_{country}			6.67_{country}			6.63_{country}		
ICC	0.97			0.97			0.97			0.97		
N	90_{country}			90_{country}			90_{country}			90_{country}		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.673 / 0.991			0.678 / 0.991			0.689 / 0.991			0.690 / 0.991		
AIC	1530.6			1529.5			1522.9			1523.5		

Table 4.20.A: Child and Adolescent Less Than 19 Female Obesity Prevalence

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	5.049	0.412	<0.001	-2.133	0.967	0.029	-1.881	0.939	0.047	-1.583	0.941	0.094
Year	0.235	0.004	<0.001	0.203	0.005	<0.001	0.205	0.005	<0.001	0.184	1.074	0.635
Europe				-0.581	0.006	<0.001	-0.771	0.829	<0.001	-0.597	0.013	<0.001
LAC				2.200	0.004	0.005	1.724	0.949	0.002	1.557	0.004	<0.001
MENA				4.615	0.861	0.502	4.635	1.008	<0.001	4.031	0.846	0.482
North America				6.822	0.979	0.027	5.981	1.859	0.073	6.464	0.964	0.110
South Asia				-0.358	1.048	<0.001	-0.421	1.329	0.751	-0.214	1.026	<0.001
Sub-Saharan Africa				-0.506	1.921	0.001	-0.554	1.057	0.602	-0.512	1.893	0.001
Urban Pop. %				0.105	1.378	0.796	0.096	0.010	<0.001	0.096	0.011	<0.001

GDP ($1000s)				-0.012	0.011	<0.001	-0.013	0.004	<0.001	-0.015	0.002	0.014
SSB (liters/year)							0.010	0.002	<0.001	0.005	1.343	0.874
Year * Europe										-0.005	0.013	0.682
Year * LAC										0.082	0.014	<0.001
Year * MENA										0.134	0.015	<0.001
Year * North America										0.011	0.028	0.702
Year * South Asia										-0.072	0.020	<0.001
Year * Sub-Saharan Africa										-0.028	0.016	0.082
Random Effects												
σ^2	0.20			0.18			0.18			0.14		
τ_{00}	15.40 country			6.09 country			5.63 country			5.78 country		
ICC	0.99			0.97			0.97			0.98		
N	91 country			91 country			91 country			91 country		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.034 / 0.988			0.650 / 0.990			0.667 / 0.990			0.659 / 0.992		
AIC	1831.1			1662.8			1647.4			1445.8		

Table 4.20.B: Female Child and Adolescent Less Than 19 Obesity Prevalence, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	-2.015	0.968	0.039	-3.211	1.040	0.002	-1.839	0.947	0.053

Year	0.200	1.113	0.730	0.196	0.004	<0.001	0.201	1.080	0.697
Europe	-0.532	0.007	<0.001	-0.886	0.844	0.297	-0.674	0.007	<0.001
LAC	2.099	0.004	<0.001	2.278	0.951	0.019	1.756	0.004	<0.001
MENA	4.494	0.848	0.532	4.286	1.020	<0.001	4.508	0.824	0.416
North America	6.958	0.964	0.032	6.447	1.870	0.001	6.320	0.941	0.065
South Asia	-0.358	1.032	<0.001	-0.410	1.338	0.760	-0.397	1.002	<0.001
Sub-Saharan Africa	-0.386	1.890	<0.001	-0.246	1.098	0.823	-0.422	1.844	0.001
Urban Pop. %	0.104	1.358	0.793	0.098	0.011	<0.001	0.098	0.011	<0.001
GDP ($1000s)	-0.015	0.011	<0.001	-0.015	0.000	0.003	-0.016	0.002	0.002
Calories				0.001	0.007	<0.001	0.000	0.007	<0.001
SSB (liters/year)							0.007	1.318	0.764
σ^2	0.11			0.11			0.11		
τ_{00}	5.89 country			5.72 country			5.54 country		
ICC	0.98			0.98			0.98		
N	90 country			90 country			90 country		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.646 / 0.993			0.654 / 0.993			0.660 / 0.993		
AIC	1092.1			1085.1			1083.7		

Table 4.21.A: Adult Overweight Prevalence

	Model 1 (Unconditional Growth)	**Model 2 (Demographic)**	**Model 3 (UPF and SSB)**	**Model 4 (Interaction)**

Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	45.434	1.606	<0.001	11.880	1.782	<0.001	11.840	1.738	<0.001	13.882	1.745	<0.001
Year	0.555	0.005	<0.001	0.451	2.429	0.824	0.455	0.011	<0.001	0.511	0.010	<0.001
Europe				20.458	0.006	<0.001	19.387	1.878	<0.001	20.461	2.281	<0.001
LAC				19.560	0.004	0.323	18.982	2.123	<0.001	19.568	4.200	<0.001
MENA				25.217	1.918	<0.001	24.722	2.265	<0.001	25.473	2.954	0.167
North America				24.765	2.174	<0.001	23.025	4.169	<0.001	24.554	2.387	0.880
South Asia				-3.177	2.320	<0.001	-2.918	2.935	0.323	-4.113	0.003	<0.001
Sub-Saharan Africa				0.540	4.267	<0.001	0.834	2.370	0.726	0.360	0.011	<0.001
Urban Pop. %				0.300	3.008	0.294	0.287	0.004	0.032	0.252	1.892	<0.001
GDP ($1000s)				-0.004	0.011	<0.001	-0.008	0.002	<0.001	-0.012	0.002	0.090
UPF (kg/year)							0.014	0.005	<0.001	0.012	2.138	<0.001
SSB (liters/year)							0.008	0.003	<0.001	0.003	0.002	<0.001
Year * Europe										-0.094	0.011	<0.001
Year * LAC										0.029	0.012	0.013
Year * MENA										-0.004	0.012	0.732
Year * North America										0.004	0.023	0.875
Year * South Asia										-0.028	0.016	0.072
Year * Sub-Saharan Africa										-0.068	0.013	<0.001
Random Effects												
σ^2	0.22			0.12			0.11			0.09		

τ_{00}	234.64_{country}	30.67_{country}	29.18_{country}	29.58_{country}
ICC	1.00	1.00	1.00	1.00
N	91_{country}	91_{country}	91_{country}	91_{country}
Observations	1001	1001	1001	1001
Marginal R^2 / Conditional R^2	0.013 / 0.999	0.871 / 0.999	0.878 / 1.000	0.873 / 1.000
AIC	2187.987	1460.312	1428.566	1264.115

Table 4.21.B Adult Overweight Prevalence, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	12.548	1.799	<0.001	9.819	1.809	<0.001	10.247	1.784	<0.001
Year	0.459	2.499	0.807	0.451	0.003	0.001	0.456	0.000	<0.001
Europe	20.742	0.006	<0.001	19.947	1.901	<0.001	19.303	1.875	<0.001
LAC	19.624	0.004	0.002	19.986	2.152	<0.001	19.615	2.119	0.648
MENA	25.422	1.918	<0.001	24.933	2.297	<0.001	24.637	2.260	<0.001
North America	25.262	2.174	<0.001	24.092	4.225	<0.001	23.181	4.159	<0.001
South Asia	-3.608	2.320	<0.001	-3.648	2.978	0.224	-3.458	2.929	0.2410
Sub-Saharan Africa	0.614	4.267	<0.001	0.963	2.474	0.698	1.113	2.433	0.648
Urban Pop. %	0.289	3.010	0.234	0.276	0.011	<0.001	0.270	0.011	<0.001
GDP ($1000s)	-0.011	0.012	<0.001	-0.011	0.000	<0.001	-0.015	0.002	<0.001
Calories				0.001	0.006	<0.001	0.001	0.0001	<0.001
UPF (kg/year)							0.011	0.002	<0.001

SSB (liters/year)							0.003	0.001	0.083
σ^2	0.08			0.07			0.07		
τ_{00}	30.64 $_{\text{country}}$			30.02 $_{\text{country}}$			29.20 $_{\text{country}}$		
ICC	1.00			1.00			1.00		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.869 / 1.000			0.871 / 1.000			0.875 / 1.000		
AIC	1001.522			961.180			953.013		

Table 4.21.C: Adult Overweight Prevalence, Physical Inactivity Controlled

	Model 1 (Demographic & Calories)			**Model 2 (Physical Activity)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	11.017	1.885	<0.001	8.104	2.575	0.002	8.522	2.545	0.001
Year	0.448	0.004	0.013	0.448	1.995	<0.001	0.452	0.070	0.104
Europe	18.487	1.994	<0.001	17.946	2.482	<0.001	17.491	1.976	0.079
LAC	18.149	2.413	<0.001	17.052	2.474	<0.001	16.645	2.444	0.919
MENA	23.550	2.412	<0.001	22.402	2.482	0.079	22.246	2.448	<0.001
North America	22.438	4.177	<0.001	21.539	4.159	0.924	20.905	4.105	<0.001
South Asia	-5.070	2.962	0.092	-5.223	2.925	<0.001	-5.145	2.884	0.034
Sub-Saharan Africa	-1.233	3.192	0.701	0.314	3.289	<0.001	0.329	3.242	0.002
Urban Pop. %	0.276	0.013	<0.001	0.274	0.004	0.011	0.270	0.001	<0.001
GDP ($1000s)	-0.009	0.000	<0.001	-0.009	0.071	0.107	-0.012	0.002	0.201

Calories	0.001	0.007	<0.001	0.001	0.000	<0.001	0.001	0.000	<0.001
Physical Inactivity %				0.116	0.007	<0.001	0.115	0.007	<0.001
SSB (liters/year)							0.003	0.002	<0.001
UPF (kg/year)							0.007	0.003	<0.001
σ^2	0.07			0.07			0.07		
τ_{00}	28.79 $_{\text{country}}$			28.04 $_{\text{country}}$			27.24 $_{\text{country}}$		
ICC	1.00			1.00			1.00		
N	69 $_{\text{country}}$			69 $_{\text{country}}$			69 $_{\text{country}}$		
Observations	621			621			621		
Marginal R^2 / Conditional R^2	0.883 / 1.000			0.887 / 1.000			0.890 / 1.000		
AIC	729.29			728.32			724.13		

Table 4.22.A: Adult Male Overweight Prevalence

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	45.273	1.909	<0.001	12.859	2.032	<0.001	13.117	1.958	<0.001	11.936	1.910	<0.001
Year	0.618	0.005	<0.001	0.517	2.722	0.004	0.522	0.014	<0.001	0.565	0.011	<0.001
Europe				25.137	0.007	<0.001	24.337	2.074	<0.001	24.571	2.501	<0.001
LAC				17.642	0.005	0.272	16.675	2.342	<0.001	16.215	4.604	<0.001
MENA				22.807	2.147	<0.001	22.575	2.499	<0.001	22.123	3.237	0.096
North America				30.239	2.435	<0.001	28.168	4.600	<0.001	28.657	2.616	0.017

South Asia				-6.584	2.598	<0.001	-6.502	3.242	0.048	-5.444	0.004	0.004
Sub-Saharan Africa				-7.976	4.778	<0.001	-7.874	2.616	0.003	-6.349	0.012	<0.001
Urban Pop. %				0.277	3.373	0.054	0.260	0.005	0.621	0.281	2.074	<0.001
GDP ($1000s)				0.005	0.014	<0.001	0.002	0.003	<0.001	-0.010	0.002	<0.001
UPF (kg/year)							0.007	0.007	<0.001	0.007	2.344	<0.001
SSB (liters/year)							0.017	0.003	0.051	0.014	0.003	0.006
Year * Europe										-0.048	0.012	<0.001
Year * LAC										0.050	0.013	<0.001
Year * MENA										0.020	0.013	0.121
Year * North America										-0.046	0.025	0.064
Year * South Asia										-0.127	0.017	<0.001
Year * Sub-Saharan Africa										-0.268	0.014	<0.001
Random Effects												
σ^2	0.28			0.20			0.19			0.11		
τ_{00}	331.43 $_{\text{country}}$			38.40 $_{\text{country}}$			35.43 $_{\text{country}}$			35.55 $_{\text{country}}$		
ICC	1.00			0.99			0.99			1.00		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.011 / 0.999			0.880 / 0.999			0.889 / 0.999			0.889 / 1.000		
AIC	2439.979			1963.214			1928.642			1427.416		

Table 4.22.B: Adult Male Overweight Prevalence, Calorie Controlled

	Model 1 (Demographic)			Model 2 (Calories)			Model 3 (UPF and SSB)			Model 4 (Interaction)		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	12.555	2.072	<0.001	10.401	2.104	<0.001	10.573	2.083	<0.001	11.218	2.059	<0.001
Year	0.517	2.822	0.009	0.511	0.005	0.838	0.514	0.015	<0.001	0.515	0.005	0.002
Europe	25.207	0.008	<0.001	24.580	2.147	<0.001	24.102	2.564	<0.001	24.243	3.283	0.057
LAC	17.496	0.005	0.777	17.785	2.430	<0.001	17.640	4.716	<0.001	17.019	2.371	0.009
MENA	22.715	2.164	<0.001	22.330	2.595	<0.001	22.079	3.327	0.064	22.308	0.005	0.854
North America	30.374	2.454	<0.001	29.451	4.772	<0.001	28.937	2.760	0.011	28.255	4.655	<0.001
South Asia	-6.353	2.619	<0.001	-6.391	3.369	0.061	-6.237	2.129	<0.001	-6.332	3.282	<0.001
Sub-Saharan Africa	-7.543	4.816	<0.001	-7.270	2.795	0.011	-7.130	0.000	<0.001	-7.306	2.723	0.306
Urban Pop. %	0.282	3.403	0.065	0.272	0.015	<0.001	0.269	0.005	0.761	0.263	0.001	<0.001
GDP ($1000s)	0.001	0.015	<0.001	0.001	0.000	<0.001	-0.001	0.004	0.020	-0.001	0.003	<0.001
Calories				0.001	0.008	<0.001	0.001	0.001	<0.001	0.001	0.008	<0.001
UPF (kg/year)							0.008	0.001	<0.001	0.004	0.003	<0.001
SSB (liters/year)										0.012	0.002	<0.001
σ^2	0.14			0.13			0.13			0.13		
τ_{00}	38.97 $_{\text{country}}$			38.20 $_{\text{country}}$			37.22 $_{\text{country}}$			36.24 $_{\text{country}}$		
ICC	1.00			1.00			1.00			1.00		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.876 / 1.000			0.878 / 1.000			0.881 / 1.000			0.884 / 1.000		

AIC	1406.7			1387.7			1384.1			1362.3		

Table 4.23.A: Adult Female Overweight Prevalence

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	45.527	1.464	<0.001	10.833	2.097	<0.001	10.505	2.092	<0.001	15.504	1.983	<0.001
Year	0.491	0.006	<0.001	0.383	0.008	0.002	0.387	0.005	<0.001	0.455	0.014	<0.001
Europe				15.878	2.207	<0.001	14.410	2.220	<0.001	16.227	2.120	<0.001
LAC				21.480	2.503	0.020	21.171	2.504	<0.001	22.452	2.392	<0.001
MENA				28.243	2.671	<0.001	27.436	2.675	<0.001	29.449	3.311	0.438
North America				19.537	4.912	<0.001	17.849	4.921	<0.001	19.816	4.701	0.012
South Asia				0.204	3.469	<0.001	0.667	3.470	0.848	-2.581	3.311	0.001
Sub-Saharan Africa				8.727	4.912	<0.001	9.238	2.800	0.001	6.873	2.673	<0.001
Urban Pop. %				0.321	0.015	0.953	0.312	0.014	<0.001	0.223	0.013	<0.001
GDP ($1000s)				-0.012	0.005	<0.001	-0.018	0.003	<0.001	-0.014	0.004	<0.001
UPF (kg/year)							0.022	0.007	<0.001	0.017	0.002	<0.001
Year * Europe										-0.132	0.014	<0.001
Year * LAC										0.005	0.014	0.751
Year * MENA										-0.052	0.016	0.001
Year * North America										0.071	0.029	0.013
Year * South Asia										0.063	0.020	0.002

Year * Sub-Saharan Africa										0.125	0.016	<0.001
Random Effects												
σ^2	0.35			0.23			0.22			0.15		
τ_{00}	194.90 $_{\text{country}}$			40.56 $_{\text{country}}$			40.61 $_{\text{country}}$			37.04 $_{\text{country}}$		
ICC	1.00			0.99			0.99			1.00		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.012 / 0.998			0.810 / 0.999			0.812 / 0.999			0.816 / 0.999		
AIC	2604.227			2063.935			2035.144			1713.239		

Table 4.23.B: Adult Female Overweight Prevalence, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	12.412	2.076	<0.001	9.261	2.117	<0.001	9.675	2.105	<0.001
Year	0.401	0.009	0.004	0.391	0.005	<0.001	0.399	0.008	<0.001
Europe	16.372	2.144	<0.001	15.457	2.144	<0.001	14.382	2.583	<0.001
LAC	21.722	2.427	<0.001	22.135	2.427	<0.001	21.810	4.751	<0.001
MENA	28.745	2.148	<0.001	28.178	2.591	<0.001	27.617	3.352	<0.001
North America	20.424	2.436	<0.001	19.073	4.765	<0.001	17.923	2.780	0.002
South Asia	-0.861	2.601	0.800	-0.899	3.366	0.790	-0.562	3.351	0.867
Sub-Saharan Africa	8.403	4.780	<0.001	8.810	2.791	0.002	9.119	2.780	<0.001
Urban Pop. %	0.295	0.002	<0.001	0.281	0.016	<0.001	0.273	0.005	<0.001

GDP ($1000s)	-0.024	0.005	<0.001	-0.024	0.000	<0.001	-0.030	0.015	<0.001
Calories				0.001	0.009	<0.001	0.001	0.002	<0.001
UPF (kg/year)							0.019	0.007	<0.001
σ^2	0.15			0.14			0.14		
τ_{00}	38.37_{country}			38.07_{country}			37.76_{country}		
ICC	1.00			1.00			1.00		
N	90_{country}			90_{country}			90_{country}		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.815 / 0.999			0.816 / 0.999			0.819 / 0.999		
AIC	1481.169			1458.293			1443.471		

Table 4.24.A: Child and Adolescent Less Than 19 Overweight Prevalence

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	19.032	0.921	<0.001	1.807	1.818	0.321	2.298	1.727	0.184	5.185	1.737	0.003
Year	0.516	0.008	<0.001	0.442	2.069	0.021	0.450	0.020	<0.001	0.558	0.019	<0.001
Europe				2.568	0.011	<0.001	1.373	1.557	0.380	2.656	1.604	0.101
LAC				4.872	0.008	<0.001	3.660	1.739	0.038	6.328	1.803	0.001
MENA				6.996	1.621	0.117	6.640	1.856	0.001	8.192	1.919	<0.001
North America				12.723	1.843	0.010	9.969	3.416	0.004	13.211	3.532	<0.001
South Asia				-3.946	1.973	0.001	-3.896	2.431	0.112	-5.834	2.508	0.022

Sub-Saharan Africa				-4.864	3.614	0.001	-4.731	1.940	0.017	-5.717	2.005	0.005
Urban Pop. %				0.249	2.592	0.131	0.221	0.008	<0.001	0.170	0.009	<0.001
GDP ($1000s)				-0.031	0.020	<0.001	-0.036	0.004	<0.001	0.038	0.004	0.513
UPF (kg/year)							0.012	0.011	<0.001	0.005	0.013	<0.001
SSB (liters/year)							0.021	0.006	0.038	-0.003	0.005	0.360
Year * GDP ($1000s)										-0.007	0.000	<0.001
σ^2	0.71			0.62			0.61			0.49		
τ_{00}	76.99 $_{\text{country}}$			21.58 $_{\text{country}}$			18.86 $_{\text{country}}$			20.28 $_{\text{country}}$		
ICC	0.99			0.97			0.97			0.98		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.033 / 0.991			0.736 / 0.993			0.763 / 0.993			0.734 / 0.994		
AIC	2079.5			2063.4			2052.9			2044.6		

Table 4.24.B: Child and Adolescent Less Than 19 Overweight Prevalence, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	1.900	1.855	0.306	-1.254	1.964	0.523	-0.002	1.913	0.999
Year	0.446	2.162	0.040	0.437	0.007	<0.001	0.447	0.125	<0.001
Europe	2.809	0.012	<0.001	1.880	1.623	0.250	0.920	1.574	0.107
LAC	4.726	0.007	<0.001	5.181	1.830	0.006	4.220	1.754	0.047

MENA	6.988	1.647	0.092	6.435	1.961	0.001	6.134	1.871	<0.001
North America	13.431	1.872	0.013	12.081	3.597	0.001	10.201	3.441	<0.001
South Asia	-4.027	2.005	0.001	-4.135	2.572	0.111	-3.980	2.447	0.107
Sub-Saharan Africa	-4.513	3.671	<0.001	-4.133	2.112	0.054	-4.049	2.009	0.47
Urban Pop. %	0.249	2.634	0.130	0.232	0.021	<0.001	0.215	0.021	<0.001
GDP ($1000s)	-0.046	0.021	<0.001	-0.046	0.000	<0.001	-0.052	0.004	0.002
Calories				0.002	0.012	<0.001	0.001	0.0003	0.003
UPF (kg/year)							0.015	0.006	0.010
SSB (liters/year)							0.013	0.004	0.001
σ^2	0.37			0.37			0.36		
τ_{00}	22.27 $_{\text{country}}$			21.21 $_{\text{country}}$			19.12 $_{\text{country}}$		
ICC	0.98			0.98			0.98		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809		
Marginal R^2 / Conditional R^2	0.721 / 0.995			0.732 / 0.995			0.754 / 0.995		
AIC	2079.5			2063.4			2044.6		

Table 4.24.C: Child and Adolescent Less Than 19 Overweight Prevalence, Physical Inactivity Controlled

	Model 1 (Demographic & Calories)			**Model 2 (Physical Inactivity)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	-1.698	2.194	0.439	-5.228	2.550	0.043	-3.608	2.456	0.144

Year	0.434	0.008	<0.001	0.438	1.792	0.687	0.452	0.059	0.011
Europe	1.327	1.847	0.475	0.725	2.196	0.119	-0.418	2.491	0.062
LAC	3.790	2.213	0.091	2.435	3.694	0.012	0.930	2.751	0.654
MENA	4.896	2.209	0.030	3.472	2.632	0.068	3.244	1.958	<0.001
North America	10.552	3.822	0.007	9.543	2.911	0.688	7.407	3.437	0.018
South Asia	-4.463	2.732	0.107	-4.880	0.024	<0.001	-4.722	2.446	0.014
Sub-Saharan Africa	-3.088	2.925	0.295	-1.174	0.000	<0.001	-1.240	0.008	<0.001
Urban Pop. %	0.249	0.024	<0.001	0.240	0.007	<0.001	0.212	0.022	<0.001
GDP ($1000s)	-0.045	0.000	<0.001	-0.045	0.063	0.015	-0.052	0.005	0.001
Calories	0.002	0.013	<0.001	0.002	0.013	<0.001	0.001	0.000	<0.001
Physical Inactivity %				0.157	2.194	0.271	0.156	0.051	0.016
SSB (liters/year)							0.016	0.005	0.000
UPF (kg/year)							0.016	0.006	0.016
σ^2	0.35			0.35			0.34		
τ_{00}	23.33_{country}			21.50_{country}			19.17_{country}		
ICC	0.99			0.98			0.98		
N	69_{country}			69_{country}			69_{country}		
Observations	621			621			621		
Marginal R^2 / Conditional R^2	0.719 / 0.996			0.746 / 0.996			0.769 / 0.996		
AIC	1563.4			1558.5			1539.5		

Table 4.25.A: <19 Male Overweight Prevalence

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	19.237	1.032	<0.001	3.024	2.045	0.140	3.619	1.931	0.062	6.418	1.975	0.001
Year	0.586	0.010	<0.001	0.509	2.250	<0.001	0.519	0.024	<0.001	0.635	0.023	<0.001
Europe				2.570	0.014	<0.001	1.005	1.689	0.553	2.302	1.762	0.194
LAC				2.260	0.010	0.009	0.785	1.880	0.677	3.601	1.976	0.072
MENA				5.417	1.759	0.148	4.921	2.005	0.016	6.488	2.100	0.003
North America				12.331	2.002	0.262	8.901	3.692	0.018	12.229	3.866	0.002
South Asia				-5.119	2.144	0.013	-5.039	2.630	0.058	-6.945	2.750	0.013
Sub-Saharan Africa				-10.27	3.924	0.002	-10.08	2.094	<0.001	11.033	2.192	<0.001
Urban Pop. %				0.253	2.825	0.073	0.219	0.010	0.001	0.168	0.011	<0.001
GDP ($1000s)				-0.026	0.024	<0.001	-0.033	0.006	<0.001	0.048	0.006	0.902
UPF (kg/year)							0.016	0.014	<0.001	0.009	0.016	<0.001
SSB (liters/year)							0.026	0.007	0.021	0.001	0.007	0.163
Year * GDP ($1000s)										-0.007	0.001	<0.001
Random Effects												
σ^2	1.07			0.98			0.96			0.82		
τ_{00}	96.51_{country}			25.31_{country}			21.79_{country}			24.02_{country}		
ICC	0.99			0.96			0.96			0.97		
N	91_{country}			91_{country}			91_{country}			91_{country}		

Observations	1001	1001	1001	1001
Marginal R^2 / Conditional R^2	0.034 / 0.989	0.744 / 0.990	0.774 / 0.990	0.744 / 0.992
AIC	3541.6	3352.9	3321.8	3180.1

Table 4.25.B: Overweight Prevalence Child and Adolescent Less Than 19 Male, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	2.739	2.085	0.190	-1.224	2.244	0.585	0.346	2.181	0.874
Year	0.507	2.347	<0.001	0.496	0.009	<0.001	0.509	0.000	0.003
Europe	2.811	0.015	<0.001	1.642	1.764	0.354	0.400	2.019	0.815
LAC	2.094	0.009	<0.001	2.672	1.987	0.182	1.497	3.714	0.043
MENA	5.313	1.785	0.119	4.620	2.131	0.033	4.220	2.644	0.040
North America	12.998	2.030	0.305	11.306	3.906	0.005	8.961	2.166	0.017
South Asia	-4.965	2.176	0.017	-5.116	2.801	0.071	-4.927	0.024	0.066
Sub-Saharan Africa	-9.802	3.980	0.002	-9.331	2.294	<0.001	-9.219	0.007	0.001
Urban Pop. %	0.259	2.867	0.087	0.237	0.025	<0.001	0.215	1.708	<0.001
GDP ($1000s)	-0.041	0.025	<0.001	-0.042	0.000	<0.001	-0.050	0.005	0.003
Calories				0.002	0.015	<0.001	0.001	0.015	<0.001
SSB (liters/year)							0.016	0.009	<0.001
UPF (kg/year)							0.020	1.895	0.003

σ^2	0.60	0.59	0.58
τ_{00}	26.05_{country}	24.82_{country}	22.00_{country}
ICC	0.98	0.98	0.97
N	90_{country}	90_{country}	90_{country}
Observations	809	809	809
Marginal R^2 / Conditional R^2	0.730 / 0.994	0.741 / 0.994	0.765 / 0.994
AIC	2431.8	2415.5	2396.6

Table 4.26.A: Female Child and Adolescent Less Than 19 Overweight Prevalence

	Model 1 (Unconditional Growth)			**Model 2 (Demographic)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	18.792	0.866	<0.001	0.414	1.756	0.814	0.803	1.693	0.636	3.757	1.667	0.026
Year	0.442	0.007	<0.001	0.372	2.088	0.729	0.377	0.018	<0.001	0.477	0.017	<0.001
Europe				2.580	0.010	<0.001	1.780	1.595	0.267	3.021	1.608	0.063
LAC				7.591	0.007	<0.001	6.616	1.788	<0.001	9.106	1.811	<0.001
MENA				8.638	1.640	0.119	8.436	1.910	<0.001	9.954	1.930	<0.001
North America				13.155	1.862	<0.001	11.073	3.514	0.002	14.168	3.551	<0.001
South Asia				-2.666	1.992	<0.001	-2.652	2.494	0.290	-4.602	2.516	0.071
Sub-Saharan Africa				0.725	3.653	0.001	0.788	1.998	0.694	-0.224	2.018	0.912
Urban Pop. %				0.246	2.608	0.309	0.226	0.007	<0.001	0.174	0.007	<0.001
GDP ($1000s)				-0.037	0.018	<0.001	-0.041	0.004	<0.001	0.026	0.004	0.250

UPF (kg/year)							0.007	0.010	<0.001	-0.000	0.011	0.995
SSB (liters/year)							0.018	0.005	<0.001	-0.004	0.004	0.250
Year * GDP ($1000s)										-0.006	0.000	<0.001
Random Effects												
σ^2	0.53			0.43			0.42			0.33		
τ_{00}	68.06 $_{\text{country}}$			22.18 $_{\text{country}}$			20.21 $_{\text{country}}$			20.72 $_{\text{country}}$		
ICC	0.99			0.98			0.98			0.98		
N	91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$			91 $_{\text{country}}$		
Observations	1001			1001			1001			1001		
Marginal R^2 / Conditional R^2	0.028 / 0.992			0.706 / 0.994			0.726 / 0.994			0.702 / 0.995		
AIC	2875.6			2593.2			2566.9			2333.2		

Table 4.26.B: Female Child and Adolescent Less Than 19 Overweight Prevalence, Calorie Controlled

	Model 1 (Demographic)			**Model 2 (Calories)**			**Model 3 (UPF and SSB)**			**Model 4 (Interaction)**		
Predictors	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*	*Estimates*	*std. Error*	*p*
(Intercept)	0.899	1.785	0.615	-1.343	1.870	0.473	-0.353	1.836	0.847	3.236	1.803	0.074
Year	0.382	0.006	<0.001	0.376	0.006	<0.001	0.383	0.010	<0.001	0.462	0.000	0.922
Europe	2.822	0.011	<0.001	2.162	1.635	0.189	1.510	1.915	<0.001	2.879	1.921	<0.001
LAC	7.468	0.006	<0.001	7.786	1.846	<0.001	6.981	1.793	0.002	8.711	3.531	<0.001

MENA	8.738	1.654	0.092	8.343	1.977	<0.001	8.170	2.499	0.240	9.675	2.501	0.099
North America	13.911	1.878	<0.001	12.951	3.628	0.001	11.483	3.520	0.549	14.033	2.063	0.827
South Asia	-2.994	2.010	<0.001	-3.061	2.585	0.239	-2.955	2.499	<0.001	-4.164	0.018	<0.001
Sub-Saharan Africa	0.930	3.685	<0.001	1.205	2.129	0.573	1.238	2.058	0.055	0.453	0.005	0.690
Urban Pop. %	0.241	0.019	<0.001	0.229	0.019	<0.001	0.216	0.019	<0.001	0.186	0.005	0.076
GDP ($1000s)	-0.051	0.011	<0.001	-0.052	0.000	<0.001	-0.055	0.004	0.001	0.012	0.003	0.131
Calories				0.001	0.011	<0.001	0.001	0.011	<0.001	-0.000	0.012	<0.001
SSB (liters/year)							0.012	0.003	<0.001	-0.003	0.008	0.339
UPF (kg/year)							0.010	0.005	<0.001	0.002	0.004	0.689
Year * GDP ($1000s)										-0.006	0.000	<0.001
σ^2	0.26			0.26			0.26			0.21		
τ_{00}	22.56 $_{\text{country}}$			21.73 $_{\text{country}}$			20.25 $_{\text{country}}$			20.41 $_{\text{country}}$		
ICC	0.99			0.99			0.99			0.99		
N	90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$			90 $_{\text{country}}$		
Observations	809			809			809			809		
Marginal R^2 / Conditional R^2	0.694 / 0.996			0.703 / 0.996			0.718 / 0.996			0.703 / 0.997		
AIC	1831.8			1821.3			1805.7			1662.6		