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Food and Agricultural Policy and the Prevention of Cardiometabolic Disease

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Abstract

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By Karen Rae Siegel

The global burdens of obesity and cardiometabolic diseases (diabetes and cardiovascular diseases) are large and rising. Unhealthy diets – those high in calories, saturated fats and refined carbohydrates and sugars, but low in fruits, vegetables and fiber –are strong modifiable risk factors for cardiometabolic diseases, but less is known about how societal factors influence these risk factors at the individual level. The main objective of this dissertation was to expand upon knowledge of the role of societal drivers of cardiometabolic disease in the United States (US) and globally. I focused primarily on food and agricultural policy as it relates to risk, and more specifically on food availability and agricultural subsidies. I conducted three studies to (1) quantify associations between national diabetes prevalence and societal factors using global, macro-level data from the World Health Organization, World Bank, and Food and Agricultural Organization (FAO), (2) derive a methodology to estimate an individual's consumption of foods derived from subsidized food commodities and examine associations between this consumption and cardiometabolic risk factors using nationally representative data on 18-64 year old respondents to the National Health and Nutrition Examination Surveys (NHANES) 2001-2006, and (3) using food production data from the FAO, investigate whether, at the global level, there is actually sufficient supply of fruits and vegetables to meet population nutritional needs for preventing cardiometabolic disease (i.e., 5 servings of fruits and vegetables per person per day). The global macro-level analysis showed that higher availability of sugar and sweeteners and animal fats as a percentage of total calories is associated with higher diabetes prevalence, while higher availability of fruits and vegetables is associated with lower diabetes prevalence. The NHANES analysis found that more than half (56.7%) of calories consumed in the US are derived from subsidized food commodities, and that younger, less-educated, and poorer individuals tend to consume diets with significantly higher proportions of subsidized commodities. Moreover, individuals who consume a diet with a higher proportion of calories from subsidized food commodities have worse cardiometabolic health outcomes – specifically, higher prevalence of obesity, abdominal adiposity, elevated lipids, and dysglycemia. Subsidized food commodities consumed in the form of meat products (for example, grains used as feed instead of other uses, as well as the livestock subsidy) appeared to be the main drivers of the associations for obesity, abdominal adiposity, and elevated lipids. Lastly, results from the third study highlight a 22% global gap in supply of fruits and vegetables relative to need, and this ranged from 58% in low-income countries to no gap in high-income countries. These results underscore the importance of aligning food and agricultural policies with nutrition recommendations and population needs. Based on these findings, recommendations for future studies are proposed.

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Chapter 1 - Introduction

The global burdens of obesity and associated cardiometabolic diseases (diabetes and cardiovascular diseases) are large and rising. From 1980 to 2013, the number of overweight and obese individuals worldwide rose from 857 million to 2.1 billion, or approximately one third of the global population [1]. In 2013, an estimated 382 million adults aged 20-79 years had diabetes globally [2], and as of 2010, cardiovascular diseases (coronary heart disease, stroke, peripheral vascular disease) were the leading causes of death and disability worldwide, accounting for 30% of global mortality, or over 15.6 million deaths each year [3].

Unhealthy diets – those high in calories, saturated fats and refined carbohydrates and sugars, but low in fruits, vegetables and fiber – and physical inactivity are strong modifiable risk factors for cardiometabolic diseases [3, 4]. While research has traditionally focused on individual behavioral lifestyle choices and associations with cardiometabolic disease, more recent work has begun to focus on societal influences of the associations with disease [5]. These societal factors are often called "upstream drivers" because they affect the environments in which people live and the policies under which they live. For example, food and agricultural policies have the potential to impact everything from the choice of crops that are grown in a country to ways in which those crops are processed and turned into foods that people eat to the pricing of those foods in the market.

Ecological studies highlight relatively strong positive associations between changes in the US food supply and obesity and diabetes [6]. Concurrent to increasing prevalence of obesity and diabetes, food supply - the amount of calories (kcal) available to the population - has increased from 2,169 kcal/person/day in 1970 to 2,594 kcal/person/day in 2009, with the largest increases coming from refined grains (187 kcal) and added fats and oils (168 kcal) [7]. At the same time, the US does not produce enough healthy foods (whole grains, fruits and vegetables) to meet the nutritional needs of the population in accordance with federal recommendations [8]. Moreover, the relatively high cost of healthy food compared to unhealthier foods (due to cheap grains) and price elasticity of demand has been thought to play a role in consumption patterns [9]. In **Chapter 2**, I explore the existing body of knowledge around these issues in more detail.

In **Chapter 3**, I further investigate associations between societal-level drivers and health, using diabetes prevalence as one example. Using publicly available macro-level data from the World Health Organization, World Bank, and the Food and Agricultural Organization (FAO), my co-authors and I performed a modeling analysis to better understand how upstream drivers of diet and physical inactivity are associated with diabetes prevalence at the national level. We used proxy measures to define drivers of diet and physical inactivity as: food availability as measured by production and trade; proportion of population in sedentary office-based jobs; and foreign direct investment – a marker of a country’s integration into the global economy and exposure to packaged and processed foods. The work presented in **Chapter 3** was published in *Diabetes Research and Clinical Practice* in 2012 [10] and was later bolstered by other researchers’ econometric models of repeated cross-sectional data which found that increases in sugar availability were associated with concurrent increases in diabetes prevalence [11].

This research laid the groundwork for my dissertation aims, discussed below, which are directly addressed in **Chapters 4-6.** Please note that **Chapters 4 and 5** contain preliminary data with plans for publication in peer-reviewed journals.

Research Aim 1 (Chapter 4):

Estimate the proportion of total daily dietary caloric intake in 2001-2006 that comes from commodities that received the most $US from 1995-2010 (corn, soybeans, wheat, rice, sorghum, dairy, livestock) and assess the extent to which distribution of dietary intake of subsidized commodities across the US population varies by age, sex, race, and socio-economic status.

a. In the process, develop a scoring algorithm to transform NHANES dietary intake data into a score that estimates the proportion of total calories from foods derived from subsidized commodities in an individual's diet.

While previous research has explored the influence of agricultural policy and food availability on health at the *ecological* level using aggregated data, no study has empirically examined the influence of US agricultural subsidies on cardiometabolic health at the *individual* level. Drawing upon the finding that country-level food availability is significantly associated with diabetes prevalence [10], I sought to investigate how agricultural policy, a key determinant of food availability, impacts individual-level food consumption in the US. I chose the US for two main reasons: (1) the enormous burden that poor diet has on death and disability – 26% of all deaths and 14% of all disability in the US [12] – and (2) the availability of a large and rich data set of dietary, health, and demographic information and relatively abundant and accessible information about food and agricultural policy.

Specifically, I used data from the National Health and Nutrition Examination Survey (NHANES) 2001-2006 to estimate individual-level consumption of foods derived from subsidized food commodities (corn, soybeans, wheat, rice, sorghum, dairy, and livestock) and to then examine the distribution of consumption of subsidized foods across the US adult population. NHANES is a continuous, cross-sectional study of the US population with data collected in 2-years cycles by the National Center for Health Statistics at the Centers for Disease Control and Prevention and provides a robust approach to individual-level dietary data. The survey uses stratified multistage probability cluster sampling to ensure adequate representation of the nation's non-institutionalized civilian population.

Research Aim 2 (Chapter 5):

Examine associations between dietary intake of subsidized commodities and an individual's cardiometabolic risk factors (generalized obesity, abdominal adiposity, dyslipidemia, glucose dysregulation, and hypertension); and the extent to which these associations vary by age, sex, race, educational attainment, and socio-economic status.

Using the scoring system developed in Aim 1, I used the NHANES 2001-2006 dataset to investigate associations between consumption of subsidized food commodities and cardiometabolic risk factors: obesity, abdominal adiposity, hypertension, hyperlipidemia, and dysglycemia. An additional benefit of the NHANES data for Aim 2 was the availability of objectively measured health markers, rather than simply self-report.

Research Aim 3 (Chapter 6):

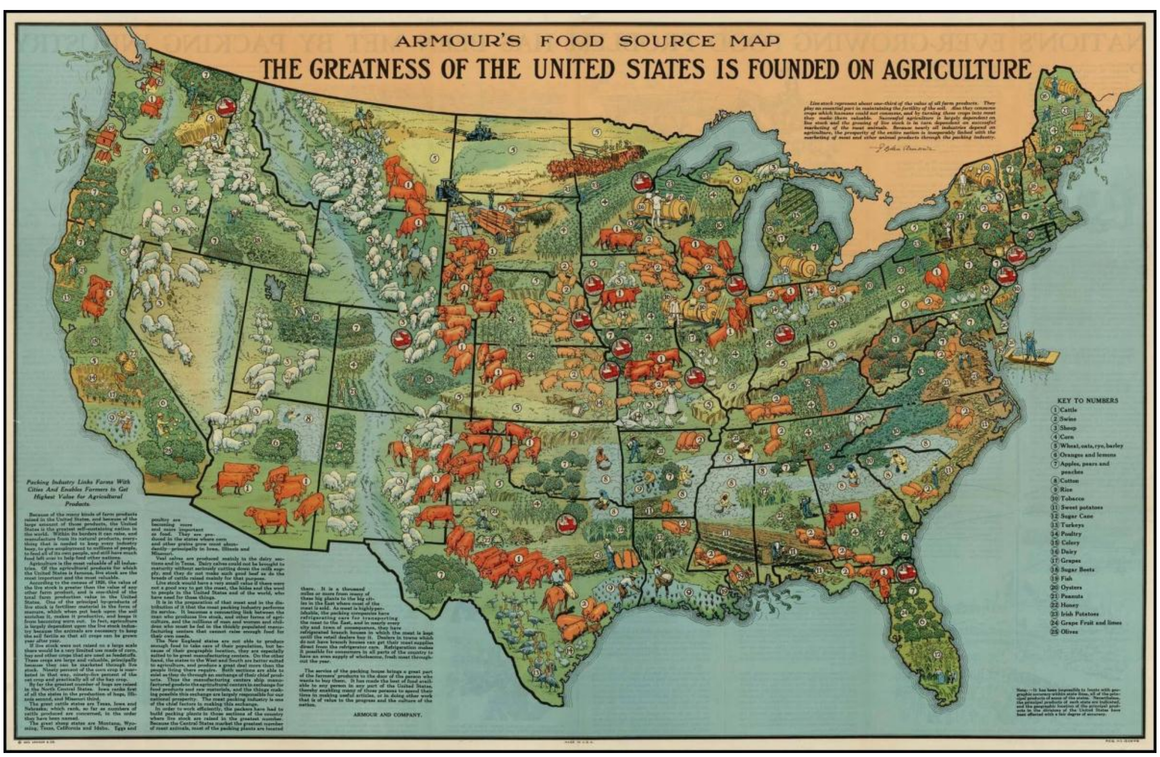
Using fruits and vegetables as a case study, determine whether production and supply of food is sufficient to meet current and growing population needs according to nutritional recommendations, globally and in individual countries.

I next examined, at the *global* level, whether supply/availability of fruits and vegetables is sufficient to meet population needs according to nutritional recommendations. I chose to investigate fruits and vegetables because (1) their production does not receive large amounts of agricultural subsidy dollars (in the US nor globally) but (2) they are recommended for prevention of cardiometabolic disease. For this analysis, I used data on food production and supply from the FAO and population estimates and projections from the United Nations. The specific methods and findings from this aim are presented in **Chapter 6**, which my co-authors and I published in *PLoS One* in 2014 [13].

A summary of the research findings, as well as a discussion of the limitations and strengths of the work and a reflection of the public health implications, is located in **Chapter 7**. There, I also propose suggestions for future research.

Chapter 2 - Background

The importance of food and agricultural policy for human wealth and health has been acknowledged across the ages. In his famous "An Essay on the Principle of Populations", Malthus, the 18th century political economist and demographer, lamented that expansion in food production, growing only in arithmetic proportion, could not keep up with the demand for food from the growth in human population, which was happening in geometric proportions [14]. A century later in 1826, the French epicurean Jean Anthelme Brillat-Savarain wrote, "The future of the nations will depend on the manner of how they feed themselves" [15]. And the map below, published by the meatpacking firm Armour and Company in 1922, boasts the strength of the United States (US) for agricultural greatness and its ability to be the most self-sustaining nation in the world [16].



Each instance above is focused on under nutrition and the need for – and ability of – nations to produce sufficient calories for populations, which was the predominant food-related issue at the time. Since then, technological advances spurred by the Green Revolution have helped to increase production and subsequent supply of total calories, primarily in the form of carbohydrates and grains to meet – even exceed – global population needs.

Still, the sentiments of Malthus, Brillat-Savarain, and Armour and Company remain applicable today. Modern food problems are not related to a lack of *quantity* of food, but rather an overall lack of *quality* of calories and unequal distribution of calories. In general, high-income countries like the US have far greater supply of calories than is needed to feed Americans [17], whereas low-income countries tend to have far less supply of calories than is needed to feed their populations. Both of these problems contribute to poor health – namely, malnutrition in the form of under nutrition and over nutrition and diseases associated with each condition. This dissertation focuses on the latter problem, that of over nutrition and resulting health problems: overweight and obesity, diabetes, and high blood pressure and cholesterol (hereafter referred to as "cardiometabolic diseases").

The Global Burden of Cardiometabolic Disease

The global burdens of obesity and associated cardiometabolic diseases (diabetes and cardiovascular diseases) are large and rising. From 1980 to 2013, the number of overweight and obese individuals worldwide rose from 857 million to 2.1 billion, or approximately one third of the global population [1]. Obesity is a major global public health concern because it affects nearly every organ in the body and has been linked to disabling conditions (diabetes, heart disease, osteoporosis, depression) and early mortality [18-20]. In 2013, an estimated 382 million adults aged 20-79 years had diabetes globally [2]. Cardiovascular diseases (coronary heart disease, stroke, peripheral vascular disease) are the leading causes of death and disability worldwide, accounting for 30% of global mortality, or over 15.6 million deaths in 2010 [3]. These cardiometabolic diseases are associated with major costs, particularly health care costs and reduced productivity due to absenteeism and premature mortality. Affected individuals spend 2-3 times more on health care and miss more days of work over their lifetime than unaffected individuals [21-23].

Individual-level Risk Factors

Cardiometabolic diseases are often linked together because they share common modifiable risk factors (dietary patterns and physical inactivity) and non-modifiable risk factors (age, sex, and genetics). These risk factors act across the life-course to increase or decrease disease risk [24, 25]. Although physical inactivity also plays an important role in disease development, this dissertation focuses on unhealthy diet alone, which was estimated to contribute to approximately 16.0 million disability-adjusted life years and 1.7 million deaths worldwide annually [26] and was *the* leading risk factor in the US, accounting for 26% of all deaths and 14% of all disability [12].

What do we mean by “unhealthy diet”? Specifically, when considering cardiometabolic disease, an unhealthy diet is one high in calories, saturated fats, sugars, and salt; and low in fruits and vegetables [27-34]. Red and processed meat consumption is also associated with diabetes and common co-morbidities such as cardiovascular events [35-37].

Nutrition experts have started to rethink dietary guidelines for cardiometabolic disease, with a focus on foods and dietary patterns rather than single key micro- or macro-nutrients [38]. For example, fruits, vegetables, whole grains, and nuts are consistently associated with lower disease risk (and fish with reduced cardiac mortality), while processed meats, packaged and fast foods, and sugar-sweetened beverages increase cardiometabolic risk [38]. Overall, healthy eating patterns tend to consist of whole or minimally processed foods and minimal sugary beverages; they tend to be naturally lower in salt, *trans* fat, saturated fat, refined carbohydrates, and added sugars while higher in unsaturated fats, fiber, antioxidants, minerals, and phytochemicals; and be more satiating [38, 39].

Diet quality is also strongly associated with diabetes and obesity. Results from a systematic review and meta-analysis indicate that dietary patterns (rather than specific foods) consisting of healthy foods and/or nutrient choices and with higher energy contributions from whole grain products, fruits, and vegetables may decrease the risk of type 2 diabetes. By contrast, dietary patterns represented by unhealthy food choices and higher energy contributions from foods such as red or processed meats, high-fat dairy, refined grains, and sweets may increase the risk of developing type 2 diabetes [40]. A prospective analysis of three separate cohorts found specific dietary (higher consumption of potato chips, potatoes, sugar-sweetened beverages, unprocessed red meats and processed meats; lower consumption of whole grains, fruits, vegetables, nuts, and yogurt) and lifestyle (physical inactivity, alcohol use, smoking, decreased sleep, and increased television watching) factors to be independently associated with long-term weight gain – and with a substantial synergistic effect [41].

Societal-level Risk Factors

As the famous epidemiologist Geoffrey Rose noted in 1985, "The efforts of individuals are only likely to be effective when they are working with the societal trends." Said another way, societal factors can influence and modify population exposure to individual-level risk factors. For example, economic growth and development improve access to modern conveniences, increasing caloric intake and reducing energy expenditure [42-44]. Labor market changes also lead to rising incomes and more women in the labor force. Economic growth has been accompanied by increased urbanization (more than half of the global population lived in urban environments in 2005, compared to 13% in 1900) [45]. Urbanization promotes exposure to mass media (marketing) and access to highly processed foods, further contributing to unhealthy eating habits [46, 47]. Moreover, global agriculture and food trade policies may further contribute to worsening dietary and activity patterns [48].

A growing body of literature provides evidence that societal factors contribute to the global burden of cardiometabolic diseases [49]. Associations have been reported between cardiometabolic disease mortality and processes of economic growth, market integration and foreign direct investment (exposure to unhealthy, processed foods), and urbanization (exposure to concentrated risk) [43]. Researchers have explored relationships between societal factors and various cardiometabolic diseases and risk factors, reporting single associations between obesity and societal indicators of diet (available animal fat and fruits and vegetables), physical inactivity (urbanization, passenger cars, and motorways), and macro-economic and policy variables (real domestic product and governance indicators) [50]. A cross-sectional modeling analysis investigated associations between national diabetes prevalence and availability of high-fructose corn sweetener (HFCS) [51]. Findings indicate that diabetes prevalence was 20% higher in countries with higher availability of HFCS compared to countries with low availability, after adjusting for body mass index (BMI), population, and gross-domestic product. In **Chapter 3**, I investigate these issues more in depth.

These studies underline the importance of the environment in which people live and work, helping to move the discussion from one that focuses on the role of the individual in determining cardiometabolic risk to one that considers the whole of society. Experts have begun to acknowledge this in the case of cardiometabolic disease. For example, in 2007 a Delphi process led to 20 policy and research priorities ("Grand Challenges on Non-Communicable Diseases") – included were priorities such as "develop and implement local, national and international policies and trade agreements, including regulatory restraints, to discourage the consumption of … unhealthy foods" and "increase the availability and consumption of healthy food" [52]. At the societal level, behavioral changes could potentially be achieved by a wide variety of policy responses. One powerful example comes from the US, where nutritional recommendations and food and agricultural policies are in opposition – or at least not well aligned.

Food and Agricultural Policy in the US: An Historical Perspective

Since a healthy diet can help to prevent obesity and cardiometabolic disease, the US Department of Agriculture (USDA) – the organization responsible for creating evidence-based nutritional recommendations and overseeing agricultural policy – recommends that Americans consume less than 17 grams of saturated fats and at least 4-5 servings of fruits and vegetables daily.

However, agricultural production policies, set by Congress and overseen by the USDA, are in opposition to these recommendations. One report found that less than 10% of USDA commodity subsidy dollars were allocated to fruits and vegetables in 2008-09, while more than 65% of subsidy dollars went to meat and dairy [53]. From 1995 to 2010, 83% of the $194 billion in government agricultural subsidies went to five commodity crops through Title I of the Farm Bill – corn ($77.1 billion), soybeans ($24.3 billion), wheat ($32.0 billion), rice ($12.9 billion), and sorghum ($6.1 billion), or $160.9 billion in total. In the same period, the USDA spent an additional $4.9 billion and $3.6 billion on Dairy and Livestock Programs, respectively [54]. A large proportion of these commodities become feed for livestock or ingredients in processed food.

Why do we subsidize food commodities at all? Broadly, food commodity subsidies serve as a tool of production at the farmer's level. They help to ensure a continuous supply of non-perishable food as well as to bolster farmers' livelihoods during adverse growing conditions or market conditions.

Today's farm policy can be traced to food-security decisions made in 1972, when President Nixon's grain deal with the Soviet Union fell through just as the farm belt experienced a bad growing season. Supermarket prices for staple foods tied to the cost of grain (meat, milk, bread) rose, and Nixon ordered his agricultural secretary, Earl (Rusty) Butz, to lower prices, however possible [55]. Butz acquiesced, dismantling farm policy that discouraged overproduction and urged American farmers to plant "fence row to fence row" while allowing them to dump their harvests on the market and receive payment, at any price and regardless of surplus. Since then, subsidies for key commodities (cotton, wheat, corn, soybeans, rice, sorghum) have kept prices low and production high by financially incentivizing farmers to grow these crops [55]. Present-day farm bills have expanded, and the lion's share (74%) of the dollars go to a small number of large-scale producers (4% of US farmers) [56], but the same commodity list remains. Every 5-7 years, the farm bill is renewed and political pressures make change difficult [57].

Food and Agricultural Policies and Health – What Is Known?

Mixed conclusions have been drawn regarding whether farm policies matter for health. Recent economic evaluations posit that agricultural policies play no role in determining consumption patterns and in turn, health [58-61]. The main arguments against farm policies playing a role are: (1) subsidies have a mixed effect on the prices and production outputs of various food items [59, 60, 62], (2) the impacts on commodity prices offer savings to the food industry, but have little effect on food costs at retail and even less on those prices passed on to consumers [61], (3) food consumption is relatively unresponsive to changes in market prices and so the very small food price changes induced by farm subsidies could not have had large effects on food consumption patterns [60], and (4) food consumption has not previously changed markedly in response to policy-induced adjustments in relative prices [58].

However, ecological studies suggest that farm policies do matter for health [63-67]. Since the 1970s when Butz took charge, food supply - the amount of calories (kcal) available to the population - has increased from 2,169 kcal/person/day in 1970 to 2,594 kcal/person/day in 2009 [7], with the largest increase seen in refined grains (187 kcal) and added fats and oils (168 kcal). At the same time, the US does not produce enough healthy foods (whole grains, fruits and vegetables) to meet the nutritional needs of the population in accordance with federal recommendations [8]. Since the agricultural sector of the US economy produces roughly 80% of the foods that Americans eat [67] – for example, only 8% of vegetables and 23% of fruits consumed in the US are imported [68] – domestic production is important. Less than 4% of US cropland was planted with fruits and vegetables in 2004 [69], and a report by the American Farmland Trust estimated that in order to produce enough to provide Americans with the 5 recommended servings of fruits and vegetables per day, approximately 13 million more acres of farmland devoted to growing these crops is needed [70]. Additionally, recent ecological studies highlight associations between concurrent changes in the US food supply and obesity and diabetes [6], high levels of processed foods [71], as well as the relatively high cost of healthy food compared to unhealthier foods (due to cheap grains) and the role of this in consumption patterns [9, 72]. Dietary choice is partially based on economic decision-making, such that subsidized commodities likely impact cardiometabolic health outcomes through unhealthy dietary choices.

To date, researchers have explored ecological associations between agricultural production practices and food consumption [53]. However, no study has empirically examined the influence of food and agricultural policy on cardiometabolic health at the *individual* level. The primary obstacle to better understanding the role of subsidies in cardiometabolic health is the lack of available methods to estimate how much an individual’s diet is comprised of subsidized food. Using the rich individual-level data available for the US Population, we have the opportunity to explore this gap. The goals of my dissertation are to build upon existing ecological evidence, fill the methodological gap in methods for estimating individual-level consumption of subsidized foods, and determine, in light of agricultural policies that encourage production of unhealthy crops, whether we are producing sufficient healthy crops as well.

Chapter 3 - Societal Correlates of Diabetes Prevalence: a Cross-Country Analysis of 94 Countries

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Structured Abstract

Aims: To quantify relationships between societal-level factors and diabetes prevalence and identify potential policy responses.

Methods: Using data from International Diabetes Federation, World Health Organization, World Bank, and Food and Agricultural Organization, we extracted recent estimates for country-level variables: total caloric availability; sugar, animal fat, fruit and vegetable availability; physical inactivity markers (vehicles per capita and value-added from service sector); gross domestic product per capita (GDP); imports; and age-adjusted mortality rate. We used generalized linear models to investigate relationships between these factors and diabetes prevalence.

Results: Median global diabetes prevalence was 6.4% in 2010. Every additional percentage point of calories from sugar/sweeteners and from animal fats were associated with 5% (OR: 1.05, 95% CI 1.02 – 1.07) and 3% (OR: 1.03, 95% CI 0.99 - 1.06) higher diabetes prevalence, respectively, while each additional unit in fruit and vegetable availability was associated with 3% lower diabetes prevalence (OR: 0.97, 95% CI 0.93 - 0.99). One percent higher GDP from the service industry was associated with a 1% higher diabetes prevalence (OR: 1.01, 95% CI 0.99 - 1.02).

Conclusion: Macro-level societal factors are associated with diabetes prevalence. Investigating how these factors affect individual-level diabetes risk may offer further insight into policy-level interventions.

Introduction

In 2009, 285 million individuals aged 20-79 years were estimated to have diabetes, and this number is projected to increase by 54% (to 439 million) by 2030.[73] Several countries, especially low- and middle-income countries (LMICs) where the epidemic is spreading rapidly, lack accurate and up-to-date data on diabetes prevalence, and therefore, the true global prevalence may be even greater.[74]

Diabetes is strongly associated with individual lifestyle factors, including physical inactivity and quantity and quality of dietary choices.[75-77] Socio-economic factors can influence and modify population exposure to these individual-level risk factors. For example, economic growth and development improve access to modern conveniences, increasing caloric intake and reducing energy expenditure.[42, 78, 79] Economic growth has been accompanied by increased urbanization (more than half of the global population lived in urban environments in 2005, compared to 13% in 1900).[45] Urbanization promotes sedentary occupations, mechanized transportation, exposure to mass media (marketing), and access to highly processed foods, further contributing to sedentary lifestyles and unhealthy eating habits.[46, 47] Moreover, global agriculture and food trade policies may further contribute to worsening dietary and activity patterns.[48, 80]

A quantitative understanding of the associations between societal-level factors and diabetes prevalence will be valuable in understanding underlying forces in the emergence and growth of diabetes at the population level, and may offer insights for potential macro-economic and social policy responses. We analyzed publicly available data to investigate the relationship(s) between macro-level societal factors and the variation in diabetes prevalence across 94 countries.

Materials and Methods

Data sources and variable selection

We identified country-level variables that reflect individual-level diabetes risk factors – obesity, high-calorie diets, consumption of sugar-sweetened beverages, saturated fat intake, low consumption of fiber (fruits and vegetables), and physical inactivity. Four sources of country-level data were used: the International Diabetes Federation (IDF) Diabetes Atlas,[73] the World Health Organization's (WHO) Infobase and Global Health Indicators,[81, 82] the World Bank World Development Indicators (WB WDI),[83] and the Food and Agricultural Organization (FAO) Statistical Yearbook.[84] Table 3.1 provides the list of variables and sources utilized.

Diabetes prevalence (among individuals aged 20-79 years) for each country for the year 2010 was obtained from IDF's Diabetes Atlas, 4th edition. These IDF estimates were obtained by applying age- and sex-specific diabetes prevalence data from regional surveys to national population distributions in 2010.[74] We estimated country-level obesity prevalence using sex-specific estimates from the WHO for 2003.[82] For each country, we weighted the sex-specific estimates by the proportion in each sex category in 2003 using data from the World Bank.[83] Indicators of food availability (as determined by food production, imports, and exports) included total energy and calories from animal (saturated) fat per capita, and calories from sugar and sweeteners, and from fruits and vegetables. Such availability data is increasingly used in global health research to demonstrate the links between the levels of agricultural production and health. [48, 79, 80]

Comparable physical inactivity data were only available for 50 countries from the WHO's World Health Survey (WHS) 2003. Therefore, we explored proxy variables for physical inactivity that were available in most countries. These included: value added by the service sector (reflecting the proportion of office-based jobs in a society), televisions per 1,000, internet users per 100, and total motor vehicles per 1,000 (reflecting leisure-time and community physical inactivity patterns). We correlated each proxy with physical inactivity data from 50 countries that participated in the WHS and thus had comparable data on physical inactivity prevalence data. Value added by the service sector and total vehicles were most highly correlated with physical inactivity (correlation coefficients of 0.15 and 0.08, respectively) and were thus included in the analysis.

We included additional country-level variables associated with the development of diabetes. These included gross domestic product (GDP) per capita (reflecting income per capita), value of imports as a percentage (%) of GDP (reflecting integration into the global marketplace and exposure to mass-produced processed/packaged foods), % of the population living in urban areas (reflecting country's level of urbanization), and age-adjusted mortality rate. Mortality rate was included to account for differences in the quality of medical care across countries, since this could affect diabetes prevalence (countries with less access to care may have individuals with undiagnosed diabetes who never reach a clinic and who are likely to die of complications more quickly).

Statistical analysis

We first performed an exploratory data analysis using bivariable regressions. Specifically, we used generalized linear models (GLMs) with binomial errors for our analysis. We opted for this model for a number of reasons. First, prevalence is a proportion and thus varies between 0 and 1. Second, these proportions in large countries are likely to be based on large samples while the opposite is likely in small countries; hence, a linear regression model with homogeneous errors is not appropriate. A GLM with binomial errors, on the other hand, takes this into account by giving low weight to proportions with small denominators. Our response vector therefore included the population size and the prevalence count. GLMs also estimate a flexible variance structure from the data, leading to efficient estimation and allowing for different heteroskedastic specifications. This model treats diabetes prevalence as a probability and considered it as proxy of the risk of diabetes at the "country-level", and estimates the odds of having diabetes in each country as derived from diabetes prevalence in the country. The model therefore estimates the diabetes prevalence odds ratio for a unit change in each of the variables included in the model.

We analyzed the residuals to check for the validity of the assumptions. The distribution of the logit of the proportions was approximately normal. To check for specifications errors in functional forms, we conducted an error analysis and found no evidence of misspecification.

Analyses were conducted using Stata version 11.1 (College Station, Texas). All data are available on request from the authors.

Results

Summary Statistics

Table 3.2 shows descriptive statistics for each variable, overall and by quartile of diabetes prevalence. Median global diabetes prevalence among individuals aged 20-79 years was 6.4% (range: 1.6% - 30.9%), with the highest prevalence in Nauru (30.9%) and the lowest in Iceland, Mongolia, and Rwanda (1.6%). Median adult mortality rate was 175.0 per 1,000 individuals, with the lowest rate (53.0 per 1,000) in San Marino and the highest (772.0 per 1,000) in Zimbabwe.

Variables for food availability and physical activity showed considerable inter-country variation. The median total energy availability was 2,752 kilocalories per person per day (range: 1,500 [Democratic Republic of the Congo] to 3,826 [United States] kilocalories per person per day). The median percentage of energy from sugar and sweeteners was 10.5%, and ranged from 0.84% in Rwanda to over 20.0% in many Caribbean countries. The median fruit and vegetable availability as a percentage of total energy was 5.3%, with a low of 0.42% in Eritrea and a high of 18.5% in Rwanda. The median availability of animal fat was 1.5%, ranging from less than 0.1% in Sierra Leone to approximately

12.0% in Denmark, Hungary, and Belgium. The median value added by the service industry (as a percentage of GDP) was 57.3%, ranging from 2.3% in Equatorial Guinea to 83.7% in Luxembourg. The median number of vehicles per 1,000 individuals was 116.5, with the lowest number (less than 5) in African countries like Liberia and Rwanda and the highest (over 800) in highly developed countries like the United States.

Societal correlates of diabetes prevalence

Results from the multivariable regression model, which includes 94 countries with complete data for all variables, are shown in Table 3.3. The final model included total available calories, sugar, fruits and vegetables, animal (saturated) fat, vehicles, value added from the service industry, GDP per capita, foreign direct investment (imports as a % of GDP), and mortality rate. Sugar availability was most strongly associated with diabetes prevalence, followed by fruit and vegetable and animal fat availability, and value added from the service industry; GDP, imports, and mortality rate were also controlled for in the final model (Table 3.3). Obesity and urbanization were neither significantly associated with the outcome nor improved model fit, and were removed.

Interpretation

To facilitate interpretation, we calculated the effect of higher or lower percentages of each exposure variable on diabetes prevalence (Figure 3.1). A 5%, 10%, and 20% higher availability of sugar (expressed as a percentage of total energy) was associated with 27.1%, 61.5%, and 160.9% higher relative diabetes prevalence, respectively. Every 5%, 10%, and 20% lower availability of fruits and vegetables (expressed as a percentage of total energy) was associated with a 16.7%, 30.6%, and 51.9% higher relative diabetes prevalence, respectively. Every 5%, 10%, and 20% higher availability of calories from animal fats was associated with a 13.6%, 29.0%, and 66.5% higher relative diabetes prevalence, while each additional 100 available calories/person/day was associated with a 1.01% relatively higher diabetes prevalence and each 500 additional calories was associated with 5.17% relatively higher prevalence. Every additional 5%, 10%, or 20% GDP contributions from the service industry was associated with a 4.9%, 10.0%, and 20.9% higher relative diabetes prevalence. Total number of vehicles was inversely associated with diabetes prevalence as could be expected, although not significantly.

Discussion

Our results indicate significant associations between multiple upstream societal-level indicators and diabetes prevalence. This finding adds to the growing body of data suggesting that the growth of diabetes may be influenced by powerful underlying socio-environmental factors and that variation in the availability of some foods may influence diabetes prevalence in populations.[78, 85, 86] While we cannot infer causality, we estimated that 10% lower availability of calories from sugar is associated with a 61.5% lower diabetes prevalence. Similarly, 10% lower availability of calories from animal fat is associated with a 29.0% lower diabetes prevalence, although non-significantly; meanwhile, 10% higher availability of calories from fruits and vegetables is associated with 30.6% lower diabetes prevalence. Unsurprisingly, 500 fewer available calories per person per day is associated with 5.2% lower diabetes prevalence. With a 10% higher contribution to a country's GDP from the service sector, diabetes prevalence would also be expected to be higher by a similar magnitude (10.0%).

Previous reports have explored relationships between societal factors and various chronic diseases and risk factors, reporting single associations between obesity and societal indicators of diet (available animal fat and fruits and vegetables), physical inactivity (urbanization, passenger cars and motorways), and macro-economic and policy variables (real domestic product and governance indicators), and between NCD mortality and processes of economic growth, market integration, foreign direct investment, and urbanization.[50, 78] These results corroborate our findings, and our data advance the field by quantifying the relationships between diabetes and *multiple* socio-economic variables, isolating effects independent of interactions with other societal-level influences. Nonetheless, our model inevitably has limitations.

First, the data used were derived from multiple published and public sources, and therefore data collection criteria and methods vary considerably.[87] However, collection of each exposure variable was executed using standardized methods across all countries, limiting the impact of this drawback, since cross-country uniformity of each exposure variable is most important for our purposes. Second, the analysis is prone to ecological fallacy. Our analyses are based on an underlying assumption that relationships between country-level proxy determinants and diabetes at the population level mirror individual-level exposure-outcome relationships. While there is reason to believe that societal change may impact diet and physical activity patterns,[42, 48, 78] caution is warranted before inferring causal connections or translating population-level associations to individual-level interventions, as biological heterogeneity may exist or the variables measured may simply be markers of other causal pathways.

Third, acknowledging that occurrence of diabetes within populations is highly complex and driven by a broad set of societal and individual (behavioral and familial) factors, we caution that our results are not to be interpreted as: 1) a comprehensive representation of the only variables associated with diabetes, nor 2) that the associations are causal. For example, neither obesity nor urbanization were included in the final model (due to the inclusion of proximal causes of obesity in the model, such as the FAO food availability data and proxies of physical inactivity). Moreover, it may be argued that the proxy measures of diet and physical inactivity are a subjective sub-sample of all potential lifestyle indicators. While FAO dietary data may not precisely measure population consumption,[88] these data are a reliable reflection of existing food and agricultural policies, which (at least in part) underlies food intake patterns. Similarly, estimating physical inactivity is also a difficult task; the variables we used may not precisely measure the exact quantities in which they are used, but they implicitly measure variables that contribute to physical inactivity within a society. For example, machine operators in manufacturing may be as physically inactive as office workers and, at least on a regional level, car ownership may be a reflection of the efficiency of public transport rather than use of a car. However, the purpose of our analysis was to gain insights into whether an association exists between diabetes and societal-level factors. Our study adds value by underlining the importance of the environment in which people live and work, helping to move the discussion from one that focuses on the role of the individual in determining diabetes risk to one that considers the whole of society. Further analysis could delve into these associations, exploring interactions between additional variables and heterogeneity within countries and regions. However, this requires more elaborate and standardized data collection in a study with both societal and individual-level variables across countries. Such data collection would be extremely costly and challenging. The Prospective Urban Rural Epidemiology (PURE) study, a large-scale epidemiological study of approximately 140,000 individuals in 17 diverse countries around the world, may provide such data to begin elucidating these issues, as it includes individual data and information with respect to the built environment, nutrition and associated food policy, psychosocial/socioeconomic factors, and the tobacco environment.[89] Additionally, the Community Interventions Pilot Study in China, India, and Mexico has collected similar individual-level and community-level data on food, physical activity, and tobacco environments in these countries, which could provide insight into regional variations in diabetes risk.[90, 91]

A fourth limitation of our study is that these data are cross-sectional, thus limiting any notions of causality. However, the goal of the analysis was to quantify the association between societal drivers and diabetes prevalence, and to use these associations to identify potential underlying factors that may be further investigated for insights into macro-economic and social policy responses to the diabetes pandemic. The model may also serve as a tool to assist policy-makers in identifying gaps in data for making evidence-based decisions.[92] Specifically, the model could allow policy-makers not only to regularly update estimates, project burdens and consider appropriate responsive resource allocation, but to apply various scenarios (permutations of different intervention combinations) to the data to project outcomes (risks and benefits), while exploring a variety of preventive policy strategies that fit within their resource constraints.

To put the findings into the context of individuals in a population, without implying causal connections or assuming reversibility of effect, for a 2,000 kcal/day diet for the average adult individual, our model suggests that shifting daily energy from sugar by 5% would equate to consuming 100 fewer kcal of sugar a day – for instance, drinking one less can of regular soda per day or eating half a chocolate bar less – and may be associated with a 27% lower diabetes prevalence in the population. Shifting daily energy from animal fat by 5% would equate to consuming 100 fewer kcal of animal fat a day, or refraining from eating one quarter pound hamburger per day, and may be associated with a 15% lower population diabetes prevalence. In light of the increasing diabetes burden in LMIC regions, policies to limit the unfettered availability of sugar, animal fat, and total calories may be worthy of further careful investigation, within a holistic nutrition strategy.[93, 94] On the other hand, increasing fruit and vegetable consumption by 5% could be accomplished by increasing the availability of fruits and vegetables by one or two servings per person per day, and, according to our model, would be associated with a 17% lower diabetes prevalence in the population.

At the societal level, behavioral changes could be achieved by a wide variety of policy responses. For example, policy action to decrease sugar or animal fat availability and subsequent consumption, or to increase fruit and vegetable consumption, could examine trade policies (imports and exports) to ensure that these economic policies also consider the availability and pricing of healthy versus unhealthy foods to the population. Policy action to increase fruit and vegetable consumption would also need to consider the barriers to adequate consumption, including distribution (fruit and vegetables are highly prone to spoiling before they reach their market destination, particularly in warm climates like India or Africa),[95] cost,[96] subsidies, and encouraging consumption at the individual level.[97] In each case, policy responses would need to be tailored to the country-specific context, considering needs as well as resources available.

One additional consideration is that we live in a world of limited resources[98] and where evidence for the long-term benefits of structured lifestyle interventions in reducing diabetes incidence comes mainly from robust trials targeting high-risk groups.[99] Recommendations to date involve intensive lifestyle interventions aimed at high-risk populations, since broader policy interventions to whole populations regardless of their diabetes risk is more difficult to justify, in monetary terms, especially since most “population-shifting” interventions are of unproven or limited efficacy.[87] Preliminary data on broad-based policy interventions suggest that they may assist changes in behaviors at the individual and population level, as complementary or synergistic to other interventions that improve awareness and empower.[100] Moreover, changing some of the powerful societal forces that drive increases in diabetes prevalence at the population level may potentially strengthen the effects of high-risk approaches.

The recent United Nations High-Level Meeting on NCDs signifies an opportunity to highlight NCD burdens, where governments and donors will convene to consider investment and prioritization of diabetes and NCDs in countries, regions, and globally. In the wake of this UN meeting, one major goal is to encourage policy-makers to tailor country-level socioeconomic development through policies and resource allocation that improve standards of living and macroeconomic indicators, but also minimize the negative consequences of development (emerging NCDs), respond adequately to current NCD burdens, and promote future population health and well-being. It is hoped that the preliminary model presented here may provide value through offering a quantitative understanding of the influence of upstream precipitants of diabetes, and guide conversations and future investigations to consider appropriate economic and social policy responses.

Table 3.1: Descriptions of dependent and independent variables included in the analysis

Indicator	Year of Data	Number of Countries	Unit	Description	Source
Demographic, Social, and Economic Indicators					
Gross Domestic Product (GDP)	2008	173	Current international dollars	GDP per capita at Purchasing Power Parity (PPP)	World Bank World Development Indicators
Urbanization	2008	189	% of population	Percentage of the population residing in urban areas	World Bank World Development Indicators
Foreign Direct Investment (market integration)	2008	158	% of GDP	Value of all imports as a percentage of gross domestic product	World Bank World Development Indicators
Health Indicators					
Diabetes Prevalence	2010	191	% of total population	Comparative diabetes prevalence (adjusted to the age profile of the world population) estimate for the year 2010 according to IDF. Rates for each country have not been age-standardized, but are presented as the crude rates for the specific country and region according to the number of persons aged 20-79 years for that national or geographical entity.	International Diabetes Federation Diabetes Atlas, 4th edition (2009)
Mortality Rate	2008	189	Deaths per 1,000 population	Adult mortality rate (probability of dying between 15 and 60 years per 1000 population, age-standardized)	World Health Organization Global Health Indicators
Obesity prevalence	2002	190	% of total population	Adults aged 15 years and above prevalence of obesity (defined as >=30kg/m^2)	World Health Organization Non-Communicable Disease (NCD) InfoBase
Food Indicators					
Total Energy Consumption	2003-2005	166	Kcal/person/day	Calories per person per day	Food and Agricultural Organization Statistical Yearbook 2009
Calories from Animal Fats	2003-2005	164	% of total energy intake	Share of animal fats in dietary energy consumption	Food and Agricultural Organization Statistical Yearbook 2009
Calories from Sugar and Sweeteners	2003-2005	164	% of total energy intake	Share of sugar and sweeteners in dietary energy consumption	Food and Agricultural Organization Statistical Yearbook 2009
Calories from	2003-	164	% of total	Share of fruits (excluding wine) and vegetables in	Food and Agricultural

Fruits and Vegetables	2005		energy intake	dietary energy consumption	Organization Statistical Yearbook 2009
Physical Activity Indicators					
Value added by Service Industry, % of GDP	2008	133	% of GDP	Services correspond to International Standard Industrial Classification (ISIC) divisions 50-99 and they include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services. Also included are imputed bank service charges, import duties, and any statistical discrepancies noted by national compilers as well as discrepancies arising from rescaling. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources.	World Health Organization World Health Survey
Total motor vehicles	2007	142	Per 1,000 population	Motor vehicles include cars, buses, and freight vehicles but do not include two-wheelers. Population refers to midyear population in the year for which data are available.	World Bank World Development Indicators
Total televisions	2006	159	Per 1,000 population	Televisions per 1,000 individuals	World Bank World Development Indicators
Total internet users	2008	184	Per 100 population	Internet users are people with access to the worldwide network.	International Telecommunication Union, World Telecommunication Development Report and Database

Note: Total prevalence for obesity was calculated from gender-specific rates by the authors, weighting each gender according to the proportions of each in the population in 2008.

Table 3.2: Summary statistics for potential predictor variables, overall and by quartile of diabetes prevalence

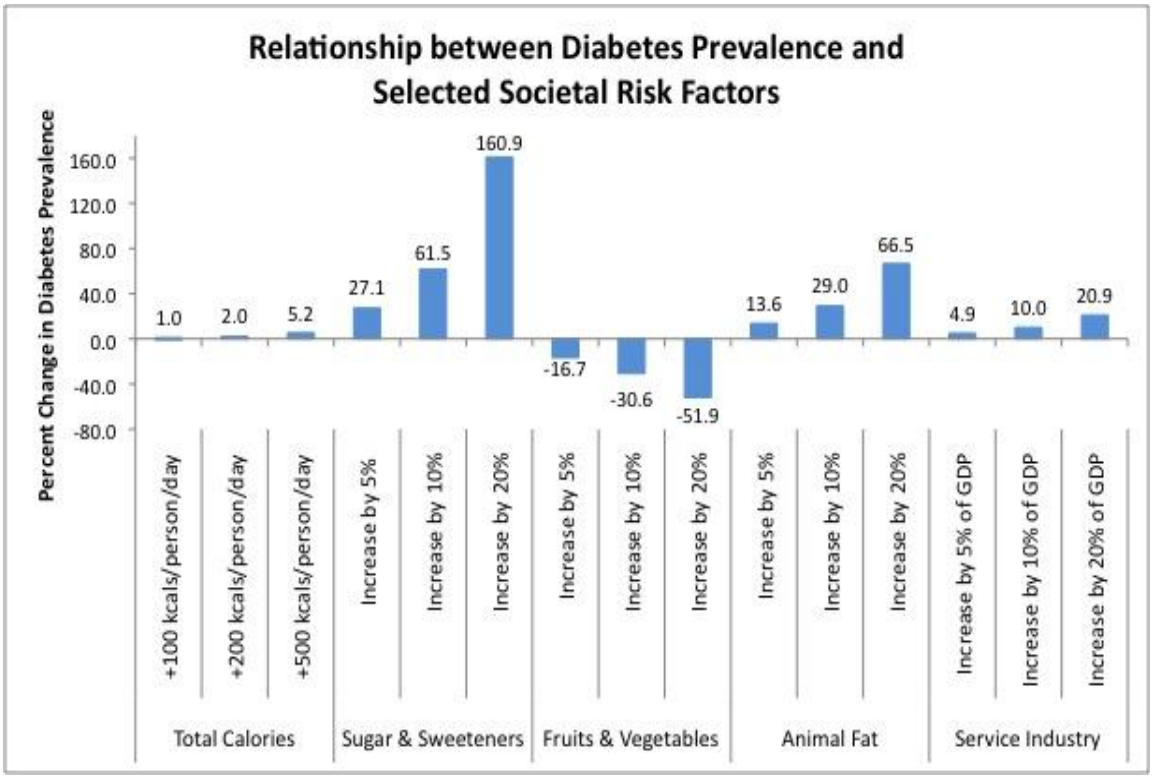
Indicator	Indicators Overall (Median (Range))	Diabetes Prevalence*			
		1st Quartile	2nd Quartile	3rd Quartile	4th Quartile
Diabetes prevalence	6·4 (1·6 – 30·9)	3·5 (1·6 – 4·6)	5·4 (4·7 – 6·4)	7·5 (6·5 – 8·9)	11·6 (9·0 – 30·9)
Demographic, Social, and Economic Indicators					
Gross Domestic Product (PPP), in millions of $US	7,293·0 (185·0 – 78,922·0)	1,360	10,304	12,035	10,534
Urbanization, % of popn	56·8 (10·0 – 100·0)	33·3	61·3	64·9	69·5
Foreign Direct Investment, % of GDP	46·1 (13·6 – 202·6)	40·2	41·9	47·8	61·5
Health Indicators					
Mortality Rate, per 1,000	175·0 (53·0 – 772·0)	329·5	165·0	153·0	159·0
Obesity, % of popn	11·0 (0·1 – 67·7)	2·4	10·4	15·2	17·3
Food Indicators					
Total Energy Consumption, kcal/person/day	2,752·2 (1,500·0 – 3,826·3)	2,162	2,784	2,990	2,826
Calories from Animal Fats, % of total	1·5 (0·1 – 12·7)	0·5	1·8	2·3	1·5
Calories from Sugar and Sweeteners, % of total	10·5 (0·8 – 20·8)	4·6	10·2	10·8	13·9
Calories from Fruits and Vegetables, % of total	5·3 (0·4 – 18·5)	3·6	5·3	6·2	5·7
Physical Activity Indicators					
Value added by Service Industry, % of GDP	57·3 (2·3 – 83·7)	42·4	57·9	62·6	59·3
Total motor vehicles, per 1,000 popn	116·5 (0·0 – 900·0)	18·0	138·5	263·5	173·0

Notes: Abbreviations: PPP, purchasing power parity; GDP, gross domestic product; %, percentage.

Table 3.3: Parameter Estimates Final Adjusted Model (n=94 countries)

Covariate	**Prevalence Odds ratio**	**95% Confidence Interval**	**P-value**
Total Calories, kcal per person per day	1·00	0·99 – 1·00	0.81
Calories from Sugar and Sweeteners, % of total	1·05	1·02 - 1·07	<0·0001
Calories from Fruits and Vegetables, % of total	0·97	0·93 – 0·99	0·03
Calories from Animal Fats, % of total	1·03	0·99 - 1·06	0·16
Value added by the service industry, % of GDP	1·01	0·99 – 1·02	0·08
Total motor vehicles per 1,000 population	0·99	0·99 – 1·00	0·31
Gross Domestic Product per capita (GDP-PPP)	1·00	0·99 – 1·00	0·28
Imports, % of GDP	1·00	0·99 – 1·00	0·69
Mortality Rate per 1,000	1·00	1·00 – 1·00	0·001

Figure 3.1: Associations between Diabetes Prevalence and Selected Societal Risk Factors



Note: Adjusted for Gross Domestic Product per capita (Purchasing Power Parity), mortality rate (age-adjusted), and foreign direct investment (FDI). Total calories is total kilocalories available per person per day. Sugar & Sweeteners, Fruits &Vegetables, and Animal Fat are the percentage of each nutrient as a percentage of total energy intake (total kilocalories per person per day). Service industry is the value added from the service industry as a percentage of Gross Domestic Product (GDP).

Chapter 4 - The Contribution of Subsidized Food Commodities to Total Energy Intake among Adults in the United States

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SubjectDietary intake, Subsidized food commodities, Obesity, Diabetes, National Health and Nutrition Examination Surveys

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Abstract (300 words)

Background: Increases in US obesity and diabetes prevalence coincide with 4 decades of agricultural subsidies for food commodity production. The contribution of subsidized commodities to total food consumption is unknown.

Objective: To estimate the proportion of individual daily caloric intake from subsidized food commodities that from 1995–2010 received the largest subsidies (corn, soybeans, wheat, rice, sorghum, dairy, livestock).

Design: We analyzed 24-h dietary recall data from 2001–2006 National Health and Nutrition Examination Surveys (11 811 participants, aged 18–64 y). To estimate consumption of subsidized food commodities, we integrated information from 3 federal sources: My Pyramid Equivalents, Food Intakes Converted to Retail Commodities, and What We Eat in America. We computed a Subsidy Consumption Score (SCS) representing the percentage of total caloric intake from agriculturally-subsidized commodities, and examined the score's distribution, and the probability of having a "high" (≥ 70th percentile) versus "low" (≤ 30th percentile) SCS, for the adult population and across age, sex, race, education, and income.

Results: SCS was near-normally distributed. Median SCS was 56.7% (interquartile range: 47.2– 65.4%) and varied across subgroups, with younger, less educated, poorer, and Mexican Americans having relatively higher SCS. After controlling for all covariates, age, education, and income remained independently associated with SCS:

compared with individuals aged 55–64 y, individuals aged 18–24 y had a 50% higher probability of having a high SCS ($P < 0.0001$). Individuals reporting less than high school education had 21% higher probability of having a high SCS than individuals reporting college completion or higher ($P = 0.003$) and individuals in the lowest poverty income ratio category had 11% higher probability of having a high SCS as compared with individuals in the highest tertile ($P = 0.02$).

Conclusions: Over 50% of calories in US diets are derived from federally-subsidized commodities.

Introduction

In the United States, 26% and 14% of mortality and disability-adjusted life years, respectively, are related to our dietary patterns [12]. Diets high in total calories, refined carbohydrates, and red and processed meats have been implicated in the development of obesity, diabetes, and common co-morbidities, particularly cardiovascular diseases [35, 36, 101], while diets high in fruit and vegetables are associated with reduced risks [28, 102]. Currently, more than one-third (36%) of American adults are obese [103], 12% have diabetes [104], and heart disease is the leading cause of death [105].

Finding suitable policy interventions that positively influence the nation's diet and resulting cardiometabolic health has been challenging. The US Department of Agriculture (USDA) and Health and Human Services (HHS) set nutritional recommendations that encourage consumption of diets high in fruits and vegetables and lower in calories, sugar, salt, and saturated fat, but a recent report suggests that Americans have a long way to go to meet these dietary guidelines [106]. Moreover, current US agricultural policies promote the production of refined grains, dairy, and meat products. From 1995 to 2010, 83% of the $194 billion total in government agricultural subsidies went to 5 commodity crops – corn, soybeans, wheat, rice, and sorghum. In the same period, the USDA spent an additional $5 and $4 billion on dairy and livestock commodities, respectively [54].

Ecological data suggest that US agricultural policies influence food consumption and thereby, cardiometabolic health [64, 65], but we lack direct evidence on the impact of agricultural price policies on nutrition [66]. To date, no study has empirically and systematically quantified individual-level consumption of foods derived from subsidized commodities. In this report, we describe a method to estimate the proportion of total daily dietary caloric intake that comes from the 7 commodities (corn, soybeans, wheat, rice, sorghum, dairy, livestock) that from 1995 to 2010 received the most federal subsidy dollars overall in an individual's diet.

Although many forms of food subsidies exist, we focus on commodity programs in Title I of the US Farm Bill [107]. The majority (80–90%) of food subsidy dollars are spent on only 7 key food commodities (corn, soybeans, wheat, rice, sorghum, dairy, livestock; Supplemental data 4.1). However, these commodities are abundant throughout our food system. For this reason, in estimating consumption of subsidized food commodities, it is important to include not only the raw commodities, but also their numerous end-products and byproducts. For example, a large proportion of commodities becomes feed for livestock and farm-raised fish or ingredients in highly processed foods. Of the corn grown in the US, approximately 5% is consumed as sweet corn, corn meal, or corn starch; the majority is incorporated into processed foods and made into high-fructose corn syrup or is used as feed for livestock, which is then turned into dairy and meat products [108]. As another example, approximately 1% of the sorghum grown in the US is turned into molasses; the rest is grain sorghum, which is used as feed for livestock. To trace these food commodities through the food system, we used several federal databases, each of which provided key pieces of information.

Study population and methods

Data sources

National Health and Nutrition Examination Survey (NHANES) [109]: We used information from NHANES to determine the actual intake of specific foods. The National Center for Health Statistics at the Centers for Disease Control and Prevention conducts continuous, cross-sectional surveys of the US population in 2-y cycles. NHANES uses stratified multistage probability cluster sampling to ensure adequate representation of the nation's non-institutionalized civilian population. We pooled NHANES dietary data from 2001 to 2006, recent years in which the sampling and dietary measurement methods were similar across the 2-y cycles. Dietary intake data were collected through 24-h dietary recall (1 d in the 2001–2002 cycle; 2 d in 2003–2004 and 2 d in 2005–2006); to ensure methodological consistency, we used data from only the first survey day of each survey cycle. Nutrient content of foods reported in NHANES included total intakes in calories and grams as determined by standardized food-composition databases [110, 111]. With the NHANES database restricted to individuals aged 18–64 y, a total of 11 811 non-elderly adults from 2001–2006 surveys completed the first day of 24-h recalls and examination.

MyPyramid Equivalency Database (MPED) [112]: MPED provides the number of MyPyramid equivalents (standard serving sizes of grams, cups, ounces, or teaspoons) of major food categories (grains, meat, dairy, fruit, vegetables, and beans as well as for added sugars and discretionary fat) that each NHANES participant reports consuming daily. We used MPED version 1.0 for NHANES data collected in 2001–2002, and version 2.0 for data in 2003– 2006.[1]

Food Intakes Converted to Retail Commodities Database (FICRCD) [113]: Similar to the MPED, this database provides the number of grams of 65 commodities in each 100 g of food, including food commodities of interest: dairy, fats and oils, fruit, grain, meat, poultry, fish and eggs, nuts, caloric sweeteners, and vegetables. This conversion database was developed for the foods reported in various national surveys, including NHANES 2001–2002.[2]

What We Eat In America Food Commodity Intake Database (WWEIA) [114]: This database, produced by the Environmental Protection Agency, provides information about the gram weights of certain food commodities, including farm-raised fish, soybean oil, and sorghum syrup, present in foods reported in NHANES 2001/2002–2007/2008.[3]

Tracing food commodities throughout the food system

Our objective was to identify, for each individual, the number of grams consumed from the 7 subsidized commodities and those consumed from all other sources. We used data from NHANES to identify the quantity consumed and which food items (e.g., hamburgers) were consumed. We used MPED to derive the daily amounts (in ounces or

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[1] These 2 versions of MPED are comparable and based on the same methodological principles; the MPED 1.0 was developed for use with NHANES surveys from 1994-2002, while the updated MPED 2.0 was developed for use with the NHANES What We Eat in America surveys for 2003-2004 and is updated with 70 additional food codes and 811 food modification codes. MPED can be accessed at: http://www.ars.usda.gov/Services/docs.htm?docid=17565.

[2] FICRCD can be accessed at: http://www.ars.usda.gov/Services/docs.htm?docid=21993.

[3] WWEIA can be accessed at: http://fcid.foodrisk.org/.

teaspoons) of soy products and added sweeteners in each food. To identify corn sweeteners specifically from the added sweetener category, we used the Glinsmann Method [115, 116], which uses data on availability of natural and added sugars, including high fructose corn syrup, sucrose, and other corn sweeteners to create category-wide estimates of the proportion of added sweetener that is derived from corn for various industry sectors: dairy products; bakery and cereal products; canned, bottled, and frozen foods; confectionary and related products; beverages; all other foods [115, 116]. We applied this to the individual diet by multiplying each individual's added sugar consumption by these category-wide estimates for the proportion of added sweetener that is derived from corn. We converted the amounts of soy and corn sweeteners from ounces/tsp into grams using conversion factors of 28.3495 g per ounce and 16 g per tsp [117].

We used FICRCD to estimate the amount (in g) of whole corn, corn flour/corn starch, soybean meal (feed), grain sorghum (feed), wheat, rice, dairy (milk, yogurt, cheese, butter), and meat (beef, pork, chicken) per 100 g of each reported food item in NHANES. We used WWEIA for soybean oil, farm-raised fish, and sorghum syrup. To convert these values into the amounts of commodities (in g) consumed, we multiplied the percentages by the total amount (in g) of the food consumed as reported in NHANES.

From these 4 sources, we estimated the grams of food commodities of interest consumed by each NHANES participant. To account for imported foods (which do not receive US subsidies), we divided each commodity category (meats, dairy, grains) by the appropriate number according to the percentage of that category imported in 2002, 2004, and 2006, as reported by the USDA [68] (Supplemental data 4.2).

Subsidy consumption score

We multiplied the total amount of foods (in g) by the energy (in kilocalories, or kcal, per g) to obtain the total energy consumed from each commodity. We obtained energy per gram from the USDA's National Nutrient Database for Standard Reference [117]. For commodity categories with a range of calories per gram (such as cheese, for example), we calculated the median value across the category and used that for our calculations (Supplemental data 4.3). We used the median rather than the mean value due to the skewed nature of these food categories. We also performed sensitivity analyses using the 25th and 75th percentile values across each category.

We computed the Subsidy Consumption Score (SCS) as the proportion of total energy derived from subsidized commodities. Specifically, we divided the total energy from subsidized commodities by the total energy intake (in kcal/day), using the formula:

$$SCS = \frac{\left(\sum_{i=1}^{n} MPED_i * Kcal_i\right) + \left(\sum_{j=1}^{n} FICRCD_j * \frac{Grams_j}{100} * Kcal_j\right) + \left(\sum_{k=1}^{n} WWEIA_k * Kcal_k\right)}{TotalDailyKcal}$$

where $MPED_i$ is the grams consumed daily of each subsidized commodity from MPED (soy products and corn sweeteners), $FICRCD_j$ is the grams per 100g of food item of each of the commodities from FICRCD (corn flour/starch, corn/soybean meal/sorghum used as feed, wheat, rice, dairy, and meat); $WWEIA_k$ is the grams of each of the commodities from WWEIA (soybean oil, farm-raised fish, sorghum consumed by humans). Grams is the number of grams of the food item consumed (provided by NHANES); Kcal is the amount of energy (in kcal) per gram of food item; and TotalDailyKcal is the total daily energy intake (in kcal).

As initially computed, 0.46% of SCSs exceeded 1.0 (max value: 1.27). We truncated these scores at a theoretical maximum of 1.0. Thus, the SCS ranges from 0.0 to 1.0, where 0.0 indicates zero percentage of total energy from commodities, and 1.0 indicates 100% of total energy from commodities.

Statistics

We used Statistical Analysis Software version 9.2 (SAS Institute Inc., Cary, North Carolina) for calculations and analyses, and SAS-callable SUDAAN (version 10.0; RTI International, Research Triangle Park, North Carolina) to adjust for the complex sample design used in NHANES. To ensure results are representative of the US population ages 18-64y, we applied sample weights for the 6 years of data that reflected the probability of selection and non-response.

We calculated weighted medians and interquartile ranges (IQR) for the SCS. To check whether the SCS performs as we would expect, with individuals with low versus high SCS consuming relatively small and large amounts of subsidized commodities, respectively, we split our sample population into deciles of SCS and calculated the mean amount (in grams) of commodities consumed in each decile. Additionally, we randomly selected 2 individuals each from the 10^{th}, 50^{th}, and 90^{th} percentile of the SCS to compare the actual foods consumed by individuals with a low, median, and high SCS.

We also calculated medians and IQRs, as well as means and 95% confidence intervals (CIs) of the SCS, by key demographic subgroups that differ in their food consumption patterns and risk for cardiometabolic disease, specifically: age (categorized into 10-year intervals), sex (male/female), self-reported race/ethnicity (non-Hispanic white [NHW], non-Hispanic black [NHB], Mexican American [MA], other [OTH]), educational attainment (less than high school, high school, some college, college graduate or above), and socioeconomic status (determined using tertiles of poverty income ratio, or PIR). PIR is an index of income in relation to family need, derived from household income and federally established poverty thresholds based on family size and cost of living as reported by the Consumer Price Index [119]. We categorized PIR according to eligibility for food assistance programs: <130% of poverty level (eligible for Supplemental Nutrition Assistance Program [SNAP] and free school meals), ≥130% but <185% of poverty level (eligible for the Women, Infants, and Children program [WIC]), ≥185% of poverty level (high income). We used F tests to compare SCS means across groups; all P-values were 2-sided; $P < 0.05$ was considered statistically significant.

We also performed multivariate logistic regression (categorizing SCS as “high” [in the highest 30^{th} percentile, >0.6362] or “low” [in the lowest 30^{th} percentile, <0.4935]) to investigate associations between various demographic subgroups and odds of having a high versus low SCS. Prevalence ratios (PR) and 95% CIs derived from predicted marginal probabilities are reported and *P*-values were calculated using the Wald *F* test.

Validation

Since the construction of our main score, the SCS, is novel, we performed an internal validation to test its reliability. To do this, we used a split-sample comparison by dividing our 2001-2006 NHANES sample into two even random samples and comparing the mean (95% CI), median (IQR), and distribution of the SCS for each sample.

Findings

The SCS estimated for the adult, non-elderly population was near-normally distributed. Among US adults aged 18–64 y, the median SCS was 56.7% (IQR: 47.2–65.4%) and the mean SCS was 56.1% (95% CI: 55.7–56.6%) (**Figure 4.1** and **Table 4.1**). Random selection of individuals in the 10th, 50th, and 90th percentile of the SCS shows a range of diets, whereby an individual with a lower SCS consumed a diet relatively higher in foods derived from non-subsidized commodities (peanut butter, fruit, vegetables, chocolate, coffee, wine) and an individual with a higher SCS consumes a diet higher in foods derived from subsidized commodities (whole milk, meat, and grains like pasta and rice) (**Table 4.2**).

The SCS varied by demographic subgroups. Individuals aged 18–24 y had higher mean SCS (59.5%, 95% CI: 58.5–60.4%) as compared with adults aged 55–64 y (53.9%: 53.2–54.6%). Compared with non-Hispanic whites (55.8%: 55.2–56.4%) and non-Hispanic blacks (55.7%: 54.5–56.9%), Mexican Americans had higher mean SCS (59.1%: 58.2–60.1%). SCS varied across levels of educational attainment, with higher SCS among individuals reporting less than a high school education compared with college or higher-educated individuals (58.0%: 57.1–58.8% vs 54.4: 53.8–55.1%). Those in the lowest category of PIR (poorest individuals) had higher SCS, compared with those in the highest category (richest individuals) (58.4: 57.6–59.2% vs 55.3: 54.8–55.9%). SCS did not vary by sex (P = 0.15) (Table 4.1).

In models adjusted for age, sex, race/ethnicity, education, and income, we noted that age, education, and income remained independently associated with high SCS. Compared with individuals aged 55–64 y, higher proportions of those aged 18–24 y (PR: 1.50, 95% CI: 1.34–1.68%), those aged 25–34 y group (PR: 1.40, 95% CI: 1.24–1.57%), and those aged 35–44 y (PR: 1.21, 95% CI: 1.07–1.36%) consumed high SCS diets. Compared with non-Hispanic whites, 20% more Mexican Americans had high SCS (PR: 1.20, 95% CI: 1.07 – 1.35). Compared with college-educated individuals, 21% more of those with less than a high school education (PR: 1.21, 95% CI: 1.08–1.36%) and 18% more of those with a high school education alone (PR: 1.18, 95% CI: 1.07–1.30%) consumed high SCS diets. Compared with individuals in the highest PIR category (representing higher socioeconomic status), 11% more of those in the lowest PIR category [lowest socioeconomic status] (PR: 1.11, 95% CI: 1.03–1.20%). Controlling for covariates, high SCS consumption did not vary significantly by sex nor across race-ethnicity (**Table 4.3**).

Sensitivity analysis

As described in the methods section, we performed a sensitivity analyses in which we calculated the SCS using the 25th and 75th percentile values for the amount of energy (calories) per gram of commodity categories from the USDA's National Nutrient Database for Standard Reference [117]. In this sensitivity analysis, the SCS also had a relatively normal distribution and respective means of 50.2% and 64.2% (Supplemental data 4.4).

Validation

Results from the split-sample validation of the SCS suggests strong reliability – sample 1 (n=5,905) had a median SCS of 56.7% (IQR: 47.3 – 65.4%) and mean of 56.1% (95% CI: 55.5 – 56.6), while sample 1 (n=5,906) had a median SCS of 56.7% (IQR: 47.0 – 65.4) and a mean of 56.2% (95% CI: 55.5 – 56.8).

Discussion

Overall, US non-elderly adults (aged 18–64 y) consume more than half (56.7%) their total daily energy intake in the form of foods derived from seven subsidized commodities – corn, soybeans, wheat, rice, sorghum, dairy, and livestock. Among younger individuals, Mexican Americans, lower-educated, and lower-income individuals have a larger percentage of their diets comprised of foods derived from these subsidized commodities. Adjusted for common sociodemographic factors, younger, lower-educated, and lower-income individuals were significantly more likely to have a high versus low SCS diet.

Our study has several important strengths. We used nationally representative, high quality data and, to our knowledge, this is the first study to estimate the proportion of foods derived from subsidized commodities that are consumed by average US adults. We have presented a method to describe the contribution of subsidized commodities to the diet of US adults. The SCS has a relatively normal distribution and varies across meaningful demographic subgroups. The large sample size and detailed description of dietary intakes facilitated comparison of the proportion of energy derived from subsidized commodities among various demographic subgroups. However, there are some limitations to our analysis.

First, approximately 0.46% of computed SCS values exceeded 1.0, suggesting inconsistencies and limitations across the databases used in its derivation. This could be due to over-estimation of the amount of commodities in various foods in the databases used. Another reason may be that, across some commodity categories, we averaged the calories per gram. The use of these averages may have led to overestimation of calories from commodities as a percentage of total calories. For example, it was not possible to directly estimate the amount of high-fructose corn syrup in foods due to incomplete nutritional and ingredient information for foods reported in NHANES. Additionally, there are some byproducts of subsidized commodities (such as soy lecithin, for example) that have not been captured by our analysis, since these byproducts are not traced through the food system. However, the amount of these byproducts in foods is negligible and their exclusion is unlikely to significantly affect results.

Second, we are limited in our ability to precisely estimate consumption of imported foods (~11% of total US food supply), which do not receive federal subsidies. However, we used category-specific estimates of the shares of imported foods, as reported by the USDA, which attenuate this limitation.

Third, a single 24-hour dietary recall was used to assess diet; this may not represent the usual diet of respondents (which varies by week or weekend days), and may serve to decrease between-group differences we see in Table 3. However, a single 24-hour recall is appropriate to assess mean group intakes [120], and provides greater detail on the specific types and amounts of food eaten than does a food-frequency questionnaire. Fourth, underreporting of certain foods high in sugar, fat, salt, or calories may occur more frequently among certain subgroups.

To date, opinions—and ecological evidence—on the role of farm policies, food consumption, and health have been mixed. From the international perspective, ecological data suggest that global food availability can influence food consumption patterns and in turn, health [11, 121]. Availability depends in part on local subsidy mechanisms, but a major obstacle to understanding the role of food subsidies in diet has been the lack of methods to estimate how much an *individual*'s diet is comprised of subsidized foods. Using national-level dietary intake data, our study fills this gap. Our analysis suggests that US agricultural policy may play a role in the population's diet, with more than half of all calories consumed coming from foods derived from subsidized commodities—many of which are processed/packaged foods that are high in sugar, salt, and potentially hazardous fats. In contrast, healthier foods in the US have become relatively more expensive, with an adverse effect on consumption patterns [122-124]. Future research is needed that examines how agricultural policies, including major subsidies, are associated with key markers of cardiometabolic health at the individual level.

Acknowledgements

The authors' responsibilities were as follows– KRS, KMB, MKA, HSK, GI: designed the research; KRS and KMB: compiled the dataset and analyzed the data; ADS, HSK, NKM, AWG, KMVN, GI: provided advice and consultation; KRS: drafted the manuscript. All authors contributed to the revision of the manuscript, and reviewed and approved the final manuscript. None of the authors had any personal or financial conflicts of interest.

Table 4.1: Percentage of dietary calories from subsidized food commodities, overall and by age, sex, race/ethnicity, educational attainment, and socioeconomic status for US adults aged 18-64 y, NHANES 2001-2006 (n=11,811)

	Sample N	Median (IQR)	Mean (95% CI)	*P* -value
Overall	11 811	56.7 (47.2 – 65.4)	56.1 (55.7 – 56.6)	
Sex				0.15
Men	5580	56.7 (46.9 – 65.3)	55.9 (55.4 – 56.4)	
Women	6231	56.7 (47.4 – 65.5)	56.3 (55.8 – 56.9)	
Age, y				< 0.0001
18 – 24	2998	60.3 (51.0 – 68.6)	59.5 (58.5 – 60.4)	
25 – 34	2505	58.2 (49.1 – 67.3)	58.0 (57.0 – 59.0)	
35 – 44	2327	56.7 (47.0 – 65.0)	56.0 (55.2 – 56.9)	
45 – 54	2174	54.5 (44.6 – 63.0)	53.7 (52.7 – 54.7)	
55 – 64	1807	54.0 (45.0 – 63.2)	53.9 (53.2 – 54.6)	
Ethnicity/Race				<0 .0001
NHW	5356	56.1 (46.6 – 65.2)	55.8 (55.2 – 56.4)	
NHB	2805	56.4 (47.1 – 64.9)	55.7 (54.5 – 56.9)	
MA	2753	60.0 (51.3 – 67.8)	59.1 (58.2 – 60.1)	
Other	897	58.3 (48.0 – 65.9)	56.6 (55.4 – 57.8)	
Educational Attainment				< 0.0001
Less than High School	3287	58.9 (49.6 – 67.5)	58.0 (57.1 – 58.8)	
High School	2960	57.5 (47.7 – 66.4)	56.9 (56.2 – 57.6)	
Some college	3399	56.3 (46.9 – 65.3)	55.9 (55.2 – 56.6)	
College graduate or more	2160	54.7 (45.6 – 63.5)	54.4 (53.8 – 55.1)	
Poverty-Income Ratio				< 0.0001
≤130% of PL	3356	59.4 (50.0 – 67.0)	58.4 (57.6 – 59.2)	
131-185% of PL	1307	58.5 (49.3 – 67.1)	57.6 (56.3 – 58.8)	
>185% of PL	6533	55.7 (46.3 – 64.9)	55.3 (54.8 – 55.9)	

Notes: Data on 5 individuals was missing for Educational Status; data on 615 individuals was missing for Poverty-Income Ratio. NHANES=National Health and Nutrition Examination Surveys, IQR=Interquartile Range, CI=Confidence Interval, NHW=Non-Hispanic White, NHB=Non-Hispanic Black, MA=Mexican American, PL = poverty level.

Table 4.2: Dietary patterns (by amount) by Subsidy Consumption Score (SCS) decile

Dietary	SCS Decile [mean (SE)]									
component	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**
n	1077	1035	1082	1041	1074	1125	1115	1106	1128	1137
Total calories	2305 (48)	2370 (43)	2453 (56)	2321 (38)	2304 (49)	2395 (42)	2394 (48)	2296 (54)	2235 (44)	2005 (40)
Total milk	111.5 (7.0)	186.7 (14.2)	201.7 (10.3)	214.8 (12.5)	223.1 (17.4)	219.6 (11.3)	225.0 (11.3)	283.1 (19.0)	291.4 (19.5)	316.7 (21.9)
Whole milk	33.6 (3.1)	59.0 (5.9)	51.9 (5.2)	58.2 (5.0)	69.8 (6.1)	68.2 (4.9)	63.4 (5.0)	95.1 (12.1)	90.0 (8.5)	121.7 (14.2)
2% milk	29.6 (3.9)	40.6 (7.9)	51.4 (6.0)	60.7 (5.9)	61.5 (7.3)	69.9 (7.1)	75.1 (5.9)	96.0 (9.5)	92.1 (11.5)	95.7 (8.3)
1% milk	8.9 (1.9)	15.8 (2.8)	19.6 (3.4)	22.1 (3.9)	20.2 (3.8)	23.2 (6.3)	27.4 (5.9)	25.4 (3.4)	41.5 (7.2)	52.1 (13.9)
Skim milk	39.4 (4.4)	71.3 (9.3)	78.9 (7.3)	73.7 (9.8)	71.6 (10.1)	58.2 (5.2)	59.2 (10.5)	66.7 (10.2)	67.8 (11.7)	47.3 (9.1)
Butter	1.4 (0.3)	1.5 (0.2)	2.2 (0.3)	1.6 (0.2)	2.4 (0.3)	2.1 (0.3)	2.0 (0.3)	2.3 (0.3)	1.7 (0.2)	2.0 (0.3)
Cheese	15.6 (1.2)	23.9 (1.6)	27.9 (2.2)	33.4 (2.4)	32.9 (2.0)	36.6 (1.8)	38.6 (1.8)	43.3 (2.2)	42.9 (2.0)	54.4 (4.1)
Yogurt	5.3 (1.0)	7.8 (1.5)	11.1 (2.0)	11.3 (2.0)	10.4 (1.8)	10.4 (2.7)	9.0 (1.5)	8.1 (1.8)	10.3 (2.4)	13.5 (2.8)
Eggs	19.9 (1.4)	21.1 (1.4)	26.2 (2.0)	25.2 (1.7)	28.7 (1.9)	26.5 (1.9)	30.3 (1.9)	27.1 (1.7)	27.6 (2.0)	23.9 (1.8)
Corn flour	7.9 (0.6)	10.4 (0.7)	12.1 (0.9)	10.4 (1.1)	13.1 (0.9)	14.8 (1.0)	16.8 (1.2)	14.1 (1.3)	15.5 (1.2)	14.1 (1.0)
Sweet corn	9.0 (2.5)	12.3 (2.7)	14.3 (2.9)	13.4 (1.8)	21.2 (3.3)	12.8 (2.4)	21.0 (4.3)	24.0 (4.3)	31.9 (5.3)	69.5 (9.3)
Rice	6.7 (0.9)	10.0 (1.2)	10.9 (1.1)	11.2 (1.0)	10.3 (1.3)	11.2 (1.1)	12.3 (1.4)	13.5 (1.8)	17.7 (2.2)	15.3 (1.4)
Wheat flour	60.9 (2.2)	80.0 (2.4)	94.5 (3.7)	95.0 (3.5)	95.4 (2.7)	108.9 (2.4)	109.8 (3.2)	115.0 (4.6)	109.0 (3.7)	96.2 (4.3)
Total meat	88.8 (4.2)	125.1 (4.5)	144.3 (4.3)	157.1 (5.1)	163.0 (5.8)	179.7 (5.6)	197.6 (8.3)	179.2 (6.1)	205.5 (7.6)	217.5 (7.6)
Beef	32.1 (2.3)	44.4 (2.6)	59.0 (4.4)	57.2 (3.0)	65.7 (4.4)	72.8 (3.7)	85.1 (5.3)	74.3 (4.6)	85.4 (5.3)	82.6 (5.3)
Pork	20.6 (1.8)	27.9 (2.2)	28.9 (1.7)	37.4 (4.2)	38.3 (3.4)	38.1 (3.1)	37.3 (3.5)	35.7 (3.3)	36.8 (3.1)	35.7 (3.5)
Chicken	31.8 (3.1)	46.7 (3.7)	50.7 (4.7)	54.6 (2.9)	51.4 (3.3)	61.0 (3.6)	67.7 (4.1)	61.7 (3.6)	73.0 (3.9)	86.8 (6.1)
Turkey	4.3 (0.9)	6.2 (1.1)	5.8 (0.8)	7.9 (1.4)	7.5 (1.1)	7.9 (1.3)	7.6 (1.7)	7.5 (1.0)	10.3 (2.3)	12.0 (2.6)
Soy	2.4 (0.4)	2.5 (0.7)	1.5 (0.4)	1.8 (0.4)	2.5 (0.6)	2.1 (0.6)	1.1 (0.2)	1.8 (0.6)	0.9 (0.2)	3.9 (1.0)
Vegetables	381.8 (13.0)	388.1 (16.7)	403.9 (16.2)	388.1 (15.3)	385.5 (16.8)	367.0 (10.8)	359.4 (11.9)	338.6 (13.5)	308.0 (11.3)	242.5 (9.0)
Fruit	492.3 (24.2)	401.1 (25.7)	449.1 (45.4)	349.9 (18.7)	298.5 (15.5)	296.0 (23.1)	250.8 (16.2)	213.1 (13.4)	157.4 (10.3)	117.4 (9.1)

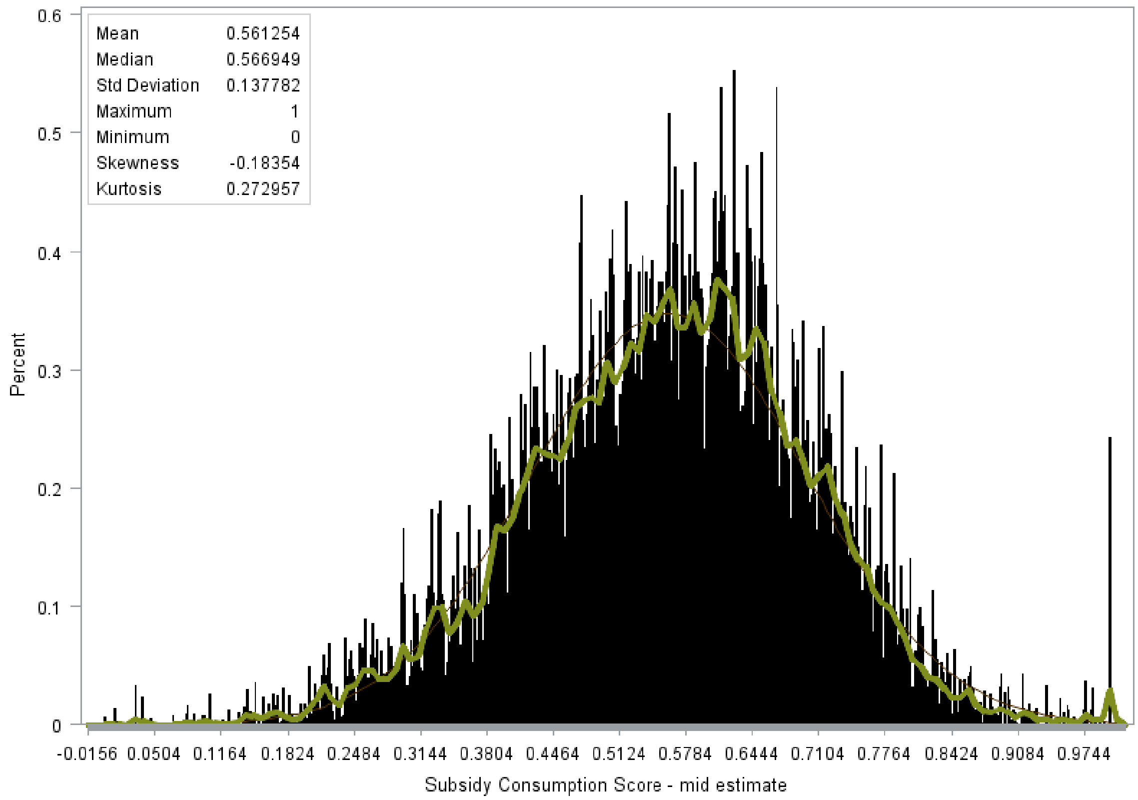
Note: Total calories are reported in kilocalories. All dietary components are in grams. “Vegetables” category excludes sweet corn. SCS Deciles are broken down as follows: 1st (<=0.3868); 2nd (0.3868 – 0.4465); 3rd (0.4465 – 0.4935); 4th (0.4935 – 0.5327); 5th (0.5327 – 0.5669); 6th (0.5669 – 0.6024); 7th (0.6024 – 0.6362); 8th (0.6362 – 0.6755); 9th (0.6755 – 0.7310); 10th (>0.7310).

Table 4.3: Multivariate logistic regression to predict the probability of having a high versus low Subsidy Consumption Score (SCS)

	Predicted marginal probability (SE)	Prevalence Ratio (95% CI)	*P*-value
Sex			0.05
Men	48.8% (0.011)	0.95 (0.90 – 1.00)	
Women	51.6% (0.015)	1.00 (ref)	
Age, y			<0.0001
18 – 24	62.2% (0.022)	1.50 (1.34 – 1.68)	
25 – 34	58.0% (0.023)	1.40 (1.24 – 1.57)	
35 – 44	50.1% (0.020)	1.21 (1.07 – 1.36)	
45 – 54	40.8% (0.021)	0.98 (0.88 – 1.10)	
55 – 64	41.6% (0.017)	1.00 (ref)	
Ethnicity/race			0.02
NHW	46.7% (0.027)	1.00 (ref)	
NHB	59.6% (0.031)	0.94 (0.83 – 1.07)	
MA	49.7% (0.032)	1.20 (1.07– 1.35)	
Other	49.8% (0.014)	1.00 (0.87 – 1.15)	
Educational attainment			0.003
Less than high school	54.8% (0.019)	1.21 (1.08 – 1.36)	
High school	53.4% (0.016)	1.18 (1.07 – 1.30)	
Some college	49.4% (0.018)	1.09 (0.99 – 1.20)	
College graduate or more	45.2% (0.019)	1.00 (ref)	
Poverty-income ratio			0.02
Tertile 1	54.1% (0.017)	1.11 (1.03 – 1.20)	
Tertile 2	53.4% (0.027)	1.10 (0.99 – 1.21)	
Tertile 3	48.7% (0.012)	1.00 (ref)	

Notes: The dependent variable was defined as SCS values in the lowest 30th percentile (< 0.4935) vs values in the highest 30th percentile (> 0.6362). The reference category was low SCS (i.e., < 0.4935). Wald *F* tests were used to determine *P*-values. SE=Standard Error, CI=Confidence Interval, NHW=Non-Hispanic white, NHB=Non-Hispanic black, MA=Mexican American.

Figure 4.1: Distribution of the Subsidy Consumption Score (SCS)



Supplemental data 4.1: Agricultural Subsidy Program Recipients, 1999-2005

Program	**Subsidy total (US $, in millions)**		
	(Sept 1999 – Aug 2001)	(Sept 2001 – Aug 2003)	(Sept 2003– Aug 2005)
Corn subsidies	15 626	8481	8749
Wheat subsidies	7736	3945	3225
Soybean subsidies	5944	5557	2943
Rice subsidies	2677	2568	2148
Sorghum subsidies	1368	738	637
Livestock subsidies[1]	630	1320	294
Dairy program subsidies[1]	785	1754	223

[1]The livestock and dairy subsidies cycle is from Jan – Dec (2000 – 2001, 2002 – 2003, 2004 – 2005).

Source: Environmental Working Group (EWG)

Supplemental data 4.2: Import shares of US food consumption (by volume)*

	2002	2004	2006	Average 2002 – 2006[4]
	Percent			
Total agriculture[1]	14.3	15.2	17.0	15.5
Animal products[2]	6.4	6.6	6.4	6.47
Red meat	9.4	10.4	9.0	9.6
Poultry and eggs	0.1	0.1	0.2	0.13
Dairy products	3.0	3.0	2.7	2.9
Fish and shellfish	77.5	84.3	86.0	82.6
Plant products[3]	20.1	21.5	25.1	22.2
Grains	14.2	12.6	14.8	13.9
Fruits and nuts	29.7	32.3	36.9	33.0
Vegetables	13.8	14.8	16.4	15.0
Sweeteners	15.0	17.0	25.0	19.0

*To estimate the import share of US food consumption based on volume, analysts divide the physical weight of imports for each food group or their aggregate by the physical weight of the corresponding food group or aggregate consumed in the United States. [1]All other foods except eggs, tree nuts, fresh fruits and vegetables. [2]Includes added animal fats (butter, lard, and edible tallow). [3]Includes added vegetable oils and fats. [4] 2003 and 2005 are assumed to be linearly interpolated.

Source: USDA

Supplemental data 4.3: Calories per Gram of Commodities

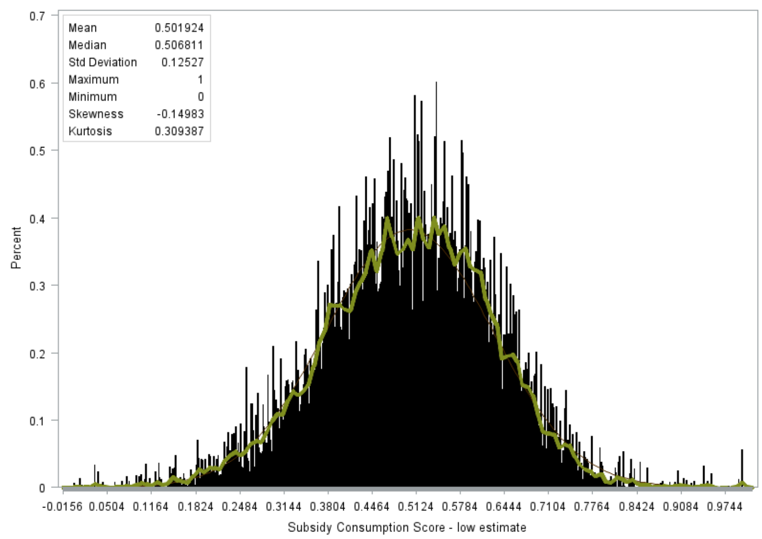
Commodity	Minimum	Maximum	Mean	Standard Error	25th percentile	50th percentile (median)	75th percentile
Fluid Whole Milk	0.61	0.83	0.72	0.16	0.61	0.72	0.83
Fluid 2% Milk	0.50	0.76	0.61	0.14	0.50	0.56	0.76
Fluid 1% Milk	0.42	0.76	0.58	0.17	0.42	0.56	0.76
Fluid Skim Milk	0.34	0.41	0.37	0.03	0.35	0.37	0.40
Butter	7.17	7.17	7.17	0.00	7.17	7.17	7.17
Cheese	0.67	4.66	2.92	1.01	2.40	3.10	3.71
Yogurt	0.43	1.12	0.86	0.23	0.62	0.96	1.04
Eggs, without shell	0.52	3.22	1.72	1.37	0.52	1.43	3.22
Corn Flour and Meal	0.72	3.81	3.38	0.85	3.52	3.62	3.70
Sweet Corn	0.86	0.86	0.86	-	0.86	0.86	0.86
Rice (Dry)	3.57	3.74	3.65	0.06	3.62	3.65	3.70
Wheat Flour	1.98	4.05	3.45	0.41	3.40	3.57	3.64
Beef	0.85	8.54	2.18	0.73	1.72	2.06	2.50
Pork	0.85	8.98	2.13	1.22	1.37	1.82	2.34
Chicken	0.94	2.58	1.61	0.53	1.19	1.48	2.13
Turkey	1.12	1.97	1.53	0.38	1.14	1.51	1.96
Soy	1.66	5.40	3.63	1.10	3.21	3.53	3.84
Total Caloric Sweeteners	2.68	3.99	3.22	0.49	2.86	2.97	3.80

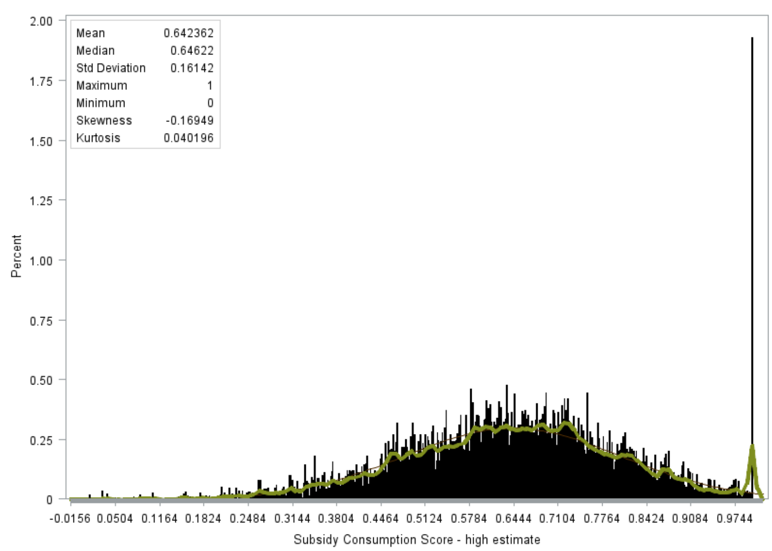
Source: USDA's National Nutrient Database for Standard Reference [117]

Supplemental data 4.4: Sensitivity Analysis for Percentage of Dietary Calories from Subsidized Food Commodities

	n	Mean (95% CI)
SCS, low estimate	11 811	50.2 (49.7 – 50.6)
SCS, high estimate	11 811	64.2 (63.7 – 64.7)

SCS, low estimate was calculated using the 25th percentile estimates for calories per gram of each commodity category (see Table 3). SCS, high estimate was calculated using the 75th percentile estimates for calories per gram of each commodity category.





Chapter 5 - Consumption of Subsidized Foods and Cardiometabolic Risk in the United States

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Subject Keywords Dietary intake, Subsidized food commodities, Cardiometabolic Risk, National Health and Nutrition Examination Surveys

Abstract

Importance: Understanding whether subsidized food consumption (corn, soybeans, wheat, rice, sorghum, dairy, meat) is associated with cardiometabolic risk is critical for informing agricultural policy in the United States.

Objective: Determine whether consumption of subsidized food commodities is associated with higher cardiometabolic risk.

Design: Cross-sectional analyses using 24-hour dietary recall in National Health and Nutrition Examination Survey 2001-2006. We used four federal databases (My Pyramid Equivalents Database, Food Intakes Converted to Retail Commodities Database, What We Eat In America, and National Nutrient Database of Standard Reference) to estimate amounts of subsidized commodities in food items consumed, and created a scoring algorithm to calculate a Subsidy Consumption Score (SCS), defined as the proportion of an individual's total daily caloric intake from subsidized foods. We also created individual SCS for subsidized foods consumed in the form of meats; grains; dairy; and oils or corn sweeteners. Each score was categorized into quartiles.

Participants: Nationally representative sample of 10,920 non-pregnant adults aged 18-64 years.

Main Outcome Measures: Overweight was defined as body mass index [BMI] 25.0 to 29.9 kg/m^2, obesity as BMI ≥30 kg/m^2. Abdominal adiposity was defined as: normal, waist-to-height ratio<0.50; moderately enlarged, 0.50 to 0.64; very enlarged, ≥0.65. We categorized blood pressure [BP] and nonHDL-cholesterol [nonHDL-c] as: normal (no self-reported diagnosis [SR] and BP<120/80 mmHg – or nonHDL-c<130 mg/dL); pre-hypertension or pre-hyperlipidemia (no SR and BP 120/80 to <140/90 mmHg – or nonHDL-c 130 to <160 mg/dL); undiagnosed (no SR and BP≥140/90 mmHg – or nonHDL-c≥160 mg/dL); self-reported hypertension or hyperlipidemia. Dysglycemia was defined as no SR and HbA1C≥5.7%; diagnosed diabetes as SR. Individuals without SR and HbA1C<5.7% were considered normal. We used the Framingham score to calculate 10-year coronary heart disease risk.

Results: Overall, 56.1% of calories consumed are from subsidized food commodities. Controlling for covariates, individuals in the highest quartile of SCS vs the lowest had increased probability of obesity (prevalence ratio [PR]: 1.33 [95% confidence interval, 1.21 – 1.47]), abdominal adiposity (PR: 1.35 [1.18 – 1.54]), hyperlipidemia (PR: 1.11 [1.03 – 1.20]), and dysglycemia (PR: 1.26 [1.03 – 1.53]), and 10-14% higher 10-year CHD risk in individuals aged 45-64 years.

Conclusions and Relevance: Consuming a larger proportion of subsidized food commodities is associated with higher cardiometabolic risk.

Introduction

Suboptimal diet quality is a leading factor associated with death and disability in the United States (US) [12] and globally [26]. Specifically, diets high in calories, saturated fats, salt [30], and sugars but low in fruits and vegetables have been implicated in the development of cardiometabolic conditions (obesity, elevated blood pressure, elevated lipids, and diabetes). Red and processed meat consumption is also associated with diabetes and common co-morbidities, particularly cardiovascular events [35-37], while diets high in fruit and vegetables are associated with reduced risks [125]. In the US, burden of these cardiometabolic diseases is large and rising. Currently, more than one-third (36%) of American adults are obese [103], 12% have diabetes [104], and heart disease is the leading cause of death [105].

As a result, the United States Department of Agriculture (USDA) takes the prevention and control of cardiometabolic diseases into consideration in their federal nutritional guidelines. These guidelines emphasize consumption of fruits, vegetables, grains, protein, and moderate amounts of dairy while recommending limited consumption of saturated fats, sugars, and salt [126]. However, current federal food commodity subsidies – set by Congress and implemented by the USDA – promote the production of refined grains, dairy, and meat products. Under Title I (Commodity Programs) of the Farm Bill, the commodity crops that receive the largest subsidies from 1995 to 2010 were corn, soybeans, wheat, rice, sorghum, dairy, and livestock [54].

There is utility in examining the impact of these commodities' subsidies on health – since commodity subsidies are federally funded, taxpayers pay for these subsidized commodities as well as downstream health expenditures and indirect economic costs from future lost work productivity attributable to obesity, type 2 diabetes, and cardiovascular disease [127]. To date, commentators have called attention to the ecological associations between food and agricultural policy and rising obesity and cardiometabolic diseases [64, 65]. However, no study has examined associations between consumption of subsidized foods and cardiometabolic health at the *individual* level. Using a previously calculated scoring system to estimate an individual's consumption of subsidized foods and their derivatives (**Chapter 4**), this paper aims to fill this gap.

Methods

Data Sources and Participant Selection

We used participants in the National Health and Examination Surveys (NHANES) 2001-2006, a continuous, cross-sectional study of the US population with data released in 2-year cycles. A description of NHANES sampling methods is provided elsewhere [128]. We restricted our sample to non-pregnant individuals aged 18-64 years who provided reliable dietary information (ie, complete dietary data as determined by NHANES, n=10,920).

Exposure Variables

Our main exposure variable was a Subsidy Consumption Score (SCS), the details and methods for which have been described previously (**Chapter 4**). Using NHANES dietary recall data and several federally-sponsored linked databases (My Pyramid Equivalents, Food Intakes Converted to Retail Commodities, What We Eat In America, and National

Nutrient Database for Standard Reference), the SCS measures the proportion of an individual's diet that is derived from subsidized food commodities receiving the most US dollars (corn, soybeans, wheat, rice, sorghum, dairy, and livestock) and foods derived from those commodities. For example, corn as a food commodity may be present in a person's diet as whole corn or corn flour / starch, but it can also end up in the food system as high-fructose corn syrup or in the form of a hamburger since more than 95% of US-produced meat during the period of study (2001-2006) came from animals that were corn-fed. As a continuous measure, the variable ranges from 0.0 (indicating a low percentage of energy from subsidized food commodities) to 1.0 (indicating a high percentage of energy from subsidized commodities). We also categorized the SCS into quartiles in order to assess differences across larger increments. Quartile definitions are in Table 1.

In order to assess which foods in particular may be driving cardiometabolic risk, we also created individual SCS for food commodities consumed in the form of meat, grains, dairy, and oils/corn sweeteners separately. These scores were also categorized into quartiles, as described in Table 5.1.

Outcome Measures

We used five cardiometabolic risk factors for our outcome measures: overweight/obesity, abdominal adiposity, elevated blood pressure, elevated lipids, and dysglycemia. Overweight/obesity were defined using body mass index (BMI), calculated from standardized height and weight measurements. Overweight was defined as 25 kg/m^2

≤BMI <30 kg/m^2, and obesity as BMI ≥30 kg/m^2. Abdominal adiposity was determined using waist-to-height ratio (WHtR) from measured waist circumference and height, and categorized as follows: normal, <0.50; moderately enlarged, ≥0.50 but <0.65; very enlarged, ≥0.65.

We categorized elevated blood pressure as: normal (no self-reported diagnosis and systolic blood pressure [sBP]<120 and diastolic blood pressure [dBP]<80 mmHg); pre-hypertension (no self-reported diagnosis and sBP 120 to <140 or dBP 80 to <90); undiagnosed (no self-reported diagnosis and sBP≥140 or dBP≥90 mmHg); diagnosed controlled (SR and sBP<120 and dBP<80 mmHg); diagnosed uncontrolled (self-reported diagnosis and sBP≥140 or dBP≥90 mmHg). Hyperlipidemia (nonHDL-c) was categorized similarly: normal (no self-reported diagnosis and nonHDL-c <130 mg/dL); pre-hyperlipidemia (no self-reported diagnosis and nonHDL-c 130 to <160 mg/dL); undiagnosed: no self-reported diagnosis and nonHDL-c≥160 mg/dL); diagnosed controlled: self-reported diagnosis and nonHDL-c<130 mg/dL); and diagnosed uncontrolled (self-reported diagnosis and nonHDL-c≥130 mg/dL). Dysglycemia was defined as no self-reported diagnosis and glycated hemoglobin (HbA1C)≥5.7%; diagnosed diabetes was defined as self-reported diagnosis. Individuals with no self-reported diagnosis and HbA1C<5.7% were categorized as normal.

We also created dichotomous variables for each of the five outcome measures to indicate the presence or absence of the risk factor – obesity (BMI≥30 kg/m^2) versus no obesity; abdominal adiposity (WHtR≥0.65) versus no abdominal adiposity; elevated blood pressure (sBP≥120 mmHg or dBP≥80 mmHg) versus normal blood pressure; elevated lipids (non-HDL cholesterol≥130 mg/dL) versus normal lipids; and dysglycemia (HbA1C≥5.7%) versus normal blood glucose.

Lastly, we used the Framingham Risk Score to calculate 10-year coronary heart disease (CHD) risk [129]. The score uses six risk variables (sex, age, blood pressure, total cholesterol, diabetes status, and smoking status) to determine a CHD risk score, which can then be translated into 10-year CHD risk, expressed as a percentage.

Covariates

Demographic information included each participant's age in years, sex, self-reported race/ethnicity, educational attainment, and poverty-income ratio (PIR). We categorized age into five intervals: 18-24, 25-34, 35-44, 45-54, 55-64 years. Race/ethnicity was categorized as non-Hispanic white, non-Hispanic black, Mexican American, and other. Educational attainment was categorized as less than high school (HS), HS, some college, college graduate or more. We categorized PIR according to eligibility for food assistance programs: <130% of poverty level (eligible for Supplemental Nutrition Assistance Program [SNAP] and free school meals), ≥130% but <185% of poverty level (eligible for the Women, Infants, and Children program [WIC]), ≥185% of poverty level (high income).

We also incorporated self-reported variables to measure SNAP usage (current use; past use; never used) and overall food security status (food secure; marginally food insecure without hunger; marginally food insecure with hunger; food insecure), as well as smoking status (current; past; never) and leisure-time moderate or vigorous physical activity over the past 30 days (yes; no).

Statistical Analysis

Statistical analysis software (SAS version 9.3; SAS Institute) and SAS-callable SUDAAN (version 10.0; RTI International, Research Triangle Park, North Carolina) were used for all analyses and specific procedures that allowed for analysis of a complex survey were employed. We used crosstabs procedures to examine population characteristics overall and across SCS quartile. To assess the mean (95% confidence interval) SCS across cardiometabolic risk factor status, we used bivariate regression. To determine the prevalence of cardiometabolic risk factors at various quartiles of SCS, controlling for covariates such as demographics, physical activity, and smoking status, we used multivariable logistic regression. To investigate the association between SCS and 10-year CHD risk, we used crosstabs procedures, adding in an interaction term for age and SCS. Chi-square tests were used to determine all p-values ($p<0.05$ was significant).

Results

Table 5.2 shows characteristics of the study population, overall and by SCS quartiles. Overall, 49.5% of our study population was female, and this did not vary significantly across quartiles of SCS ($p=0.69$). The breakdown of our population by age, race/ethnicity, educational attainment, poverty-income ratio, and food security status varied across SCS quartiles. The mean age of individuals in Quartile 1 (Q1) was 42.4 years vs 37.3 years in Quartile 4 (Q4), and Q4 had a higher proportion of younger individuals aged 18-24 years as compared to Q1 (21.5% vs 11.8%, $p<0.0001$). Q4 also contained a higher proportion of Mexican American individuals (10.5% vs 5.6%) and a lower proportion of non-Hispanic whites and non-Hispanic blacks (86.3% vs 80.4%) as compared to Q1 ($p = 0.0004$). As compared to Q1, Q4 contained a higher proportion of individuals with a high school education or less (47.4% vs 37.2%, $p<0.0001$), a higher proportion of individuals in the lowest poverty-income ratio category (23.9% vs 16.0%, $p<0.0001$), and a smaller proportion of fully food secure individuals (78.5% vs 85.5%, $p<0.0001$). SNAP usage did not vary significantly across SCS quartile ($p=0.61$).

Smoking status and leisure-time physical activity also varied across SCS quartile, with a higher proportion of current smokers in Q4 as compared to Q1 (31.2% vs 29.7%, $p=0.0004$) and a smaller proportion of individuals reporting moderate or vigorous leisure-time physical activity in Q4 as compared to Q1 (66.8% vs 73.2%, $p=0.003$).

Table 5.3 shows unadjusted mean Subsidy Consumption Scores and 95% confidence intervals across categories of obesity, abdominal adiposity, elevated blood pressure, elevated lipids, and dysglycemia. We found significant positive associations between SCS and obesity and abdominal adiposity. We found no statistically significant association between SCS and hypertension or hyperlipidemia. Similarly, we found no statistically significant association between SCS and dysglycemia status, with the exception of a positive association between the meat-only SCS and dysglycemia and a negative association between oil/corn sweeteners-only SCS and dysglycemia.

The main adjusted results, illustrating the probability of each cardiometabolic risk factor in each SCS quartile as well as corresponding prevalence ratios (Q1 is the referent group), are in Table 5.4. All models were adjusted for age, sex, race/ethnicity, educational attainment, poverty income ratio, smoking status, and moderate/vigorous leisure-time physical activity. Individuals in SCS Q4 had 33% higher probability of obesity as compared to individuals in Q1 (PR: 1.33 [1.21 – 1.47]), and this association remained significant for meat-only SCS, with those in Q4 having a 32% higher probability of obesity (PR: 1.32 [1.16 – 1.50]). In terms of abdominal adiposity, individuals in Q4 had a 35% higher probability of being abdominally adipose as compared to those in Q1 (PR: 1.35 [1.18 – 1.54]). Similar to obesity, the association remained significant for meat-only SCS, with those in Q4 having 21% higher probability as compared to those in Q1 (PR: 1.21 [1.03 – 1.42]). We also found that individuals in Q4 had a 26% higher probability of having dysglycemia as compared to those in Q1 (PR: 1.26 [1.03 – 1.53]). Those in Q4 of the meat-only, grains-only, and oil/corn sweeteners scores had higher probability of dysglycemia as compared to those in Q1, although the differences were not statistically significant. Lastly, individuals in Q4 had 11% higher probability of hyperlipidemia (PR: 1.11 [1.03 – 1.20]), and this positive association held for the meat-only score, with individuals in Q4 having 13% higher probability than those in Q1 (PR: 1.13 [1.05 – 1.22]). We found no statistically significant associations between hypertension and SCS. Tables 5.5 and 5.6 show the unadjusted and partially adjusted results; no major differences in the unadjusted versus adjusted models are seen, with the exception of the association with dysglycemia.

Figure 5.1 shows the association between the SCS and 10-year CHD risk, by age group ($p<0.0001$ for age*SCS interaction term). We found that the association between SCS and 10-year CHD risk remains relatively flat at 2% for individuals aged 18 to 34 years. Among individuals aged 35 to 44 years, 10-year CHD risk increased slightly to around 3%. A statistically significant association between SCS and 10-year CHD risk appeared in individuals aged 45 to 54 and 55 to 64 years, with individuals in SCS Q3 and Q4 having higher risk than individuals in Q1 and Q2 (and the population's average risk) at each age group – 6.6% and 6.7% vs 5.9% and 5.4% in individuals aged 45-54 years, 10.5% and 10% vs 9.1% in individuals aged 55-64 years.

Discussion

More than half (56.1%) of all calories consumed in the US are from subsidized food commodities. Moreover, we found that consumption of subsidized food commodities is associated with increased prevalence of obesity, abdominal adiposity, hyperlipidemia, and dysglycemia, although not with increased prevalence of hypertension. Subsidized food commodities in the form of meat (the livestock subsidy itself, as well as grains that have been fed to cattle and livestock) appear to be the main driver of this association with cardiometabolic risk, although subsidized food commodities in the form of grains and corn sweeteners also may contribute. We also found a significant association with consumption of subsidized food commodities and increased 10-year CHD risk in individuals aged 45-64 years, with individuals aged 45-54 years in Q4 having about 14%

higher 10-year CHD risk as compared to individuals in Q1, and individuals aged 55-64 years in Q4 having almost 10% higher 10-year CHD risk as compared to individuals in Q1.

The main contribution of our research is a broad understanding of how consumption of foods derived from subsidized food commodities is distributed across the population and how this consumption impacts cardiometabolic health at the *individual* level. The analyses we performed have several important strengths. First, we used nationally representative, high quality data that yielded a large sample size and detailed description of dietary intakes, as well as a large number of covariates. Second, to our knowledge, this is the first study to estimate the proportion of foods derived from subsidized commodities that are consumed by average US adults at the *individual* – rather than population – level. Although the SCS is an estimation, the scores broken down into foods consumed (meat, grains, dairy, oil/corn sweeteners) allowed us to disentangle in which end-product from the food subsidies are driving adverse health.

There are also some limitations. First, a single day of 24-hour dietary recall was used to assess diet and create our exposure variable (SCS); this may not represent the usual diet of respondents (which may vary by week or different days of the week) and may serve to decrease between-group differences. However, a single 24-hour recall is appropriate to assess mean group intakes [120] and provides greater detail on the specific types and amounts of food eaten than does a food-frequency questionnaire. Second, the SCS can only be viewed as an estimation. For example, it was not possible to directly estimate the amount of high-fructose corn syrup in foods due to incomplete nutritional and ingredient information for foods reported in NHANES. Additionally, there are some byproducts of subsidized commodities (such as soy lecithin, for example) that have not been captured by our analysis, since these byproducts are not traced through the food system. However, the amount of these byproducts in foods is negligible and their exclusion is unlikely to significantly affect results. Third, our analysis is cross-sectional and therefore can only be used to find associations; we cannot assess temporality or causality.

Nonetheless, our analysis may help to clarify the ongoing debate – and ecological evidence – on the role of farm policies, food consumption, and health. For example, some industry professionals deny that federal farm subsidies contribute to cardiometabolic health, citing less physical activity, less home-cooked meals due to demanding work schedules, time- and energy-saving technological innovations, and advertising as more important factors in influencing poor cardiometabolic health [130]. Other industry professionals argue that consumer demand, rather than farm policies, determine what crops farmers grow [130] and that agricultural research and development, rather than farm policies, contribute to declining commodity prices [58]. Most recently, economic analyses suggest that the share of the cost of commodities in the retail price of food products is relatively small (i.e., the retail cost of food products without subsidies would not be very different), such that cheap commodities do not meaningfully contribute to reduced retail prices (the cost of high-fructose corn syrup in a can of a typical soft drink represents 1% or less of the retail price, for example) [131] and that food consumption patterns do not tend to change significantly in response to small price changes [132, 133].

On other hand, health professionals argue, dietary choice is partially based on economic decision-making, such that subsidized commodities very likely impact cardiometabolic health outcomes through unhealthy dietary choices [9, 122, 134]. Moreover, subsidies encourage overproduction (the more a farm produces, the larger the support payment), raising production levels above demand and depressing commodity prices; by keeping commodity prices artificially low, price supports also encourage the use of commodities in processed foods and as animal feed [131]. While these commodity crops are not inherently unhealthy, a large proportion of the crops produced are used as ingredients for processed and packaged foods that are high in calories, saturated fats, sugars, and salt. For example, of the corn grown in the US, approximately 5% is consumed as sweet corn, corn meal, or corn starch; the majority is incorporated into processed foods and made into high-fructose corn syrup or is used as feed for livestock, which is then turned into dairy and meat products [108].

It is important to note that our findings that diets with a higher proportion of calories from subsidized food commodities are associated with adverse cardiometabolic health outcomes does not prove that subsidies are causing these adverse health outcomes (due to the cross-sectional nature of this study) nor that it is the agricultural subsidies themselves that are responsible for escalating cardiometabolic health problems in the US. What the findings do suggest, however, is that if we want to invest in health and better align our agricultural and nutritional policies, we may need to think long and hard about re-organizing our current food production system. Our analysis shows that, holding calories constant, individuals consuming a diet comprised of more subsidized foods have worse health outcomes as compared to those individuals consuming a diet comprised of fewer subsidized foods. Returning to the rationale for the analysis that we underlined in the introduction – that since commodity subsidies are federally funded, taxpayers pay for these subsidized commodities as well as downstream health expenditures – this is a particularly important finding.

The finding that younger, poorer, less educated, and less food-secure individuals consume disproportionately higher proportions of subsidized food commodities highlights the impact that agricultural subsidies may be having on health disparities in the US. Previous research has described the impact of socio-economic status and educational attainment on cardiometabolic health in the US, with poorer and less educated individuals more likely to suffer from poor cardiometabolic health [135, 136]. One reason for this may be the relatively low cost per calorie of unhealthier food, and the higher cost per calorie of healthier food [137]. This has implications for food security, since these groups may also be restricted by the amount of money they have to spend on their daily 2,000 kilocalories requirements. For example, higher prices of healthy foods have been found to be associated with increased blood sugar among people with type 2 diabetes – and this association is especially pronounced among low-income individuals with diabetes [138]. One potential policy lever for addressing this may be shifting agricultural subsidies toward the production of healthier crops, such as fruits and vegetables, unrefined grains, and lower-fat dairy – rather than meat products high in calories and saturated fat. Although we found that younger individuals, particularly those aged 18-34, had no increased 10-year CHD risk with higher subsidy consumption, this may simply be due to insufficient time to develop the risk. However, a question that remains to be answered is how a higher SCS early in life might impact 10-year CHD risk later in life – this could be addressed using longitudinal data.

This paper presents results that provide an initial, broad understanding of how consumption of foods derived from subsidized commodities impacts cardiometabolic health at the *individual* level. Follow-up analyses could further examine how SCS is associated with disease at levels of food security. Future research is needed to investigate temporal ordering using existing longitudinal cohorts with dietary intake data: the Harvard cohorts (Nurses' Health Study, Nurses' Health Study II, and the Health Professionals Follow-up Study), CARDIA to explore effects in specific age groups, and the MESA (Multi-ethnic Study of Atherosclerosis) and ARIC (Atherosclerosis Risk in Communities) studies to explore effects in ethnic subgroups. Additionally, modeling analyses are need to investigate how various changes to the current subsidy structures would impact consumption of various foods, and resulting health outcomes.

Table 5.1: Exposure Variables (Subsidy Consumption Score, SCS) as Continuous and Categorical Measures

Score	How Categorized	Range	
SCS	Continuous	0.0 (low % of total energy from commodities) to 1.0 (high % of total energy from commodities)	
	High / low	High (in highest 30th perctile): >0.6362 Low (in lowest 30th perctile): < 0.4935	
	Quartiles	Q1: 0 – 0.4717 Q2: 0.4718 – 0.5669	Q3: 0.5670 – 0.6541 Q4: 0.6542 – 1.0
SCS - meat	Quartiles	Q1: 0 – 0.052 Q2: 0.053 – 0.107	Q3: 0.108 – 0.171 Q4: 0.172 – 1.0
SCS - dairy	Quartiles	Q1: 0 – 0.054 Q2: 0.055 – 0.106	Q3: 0.107 – 0.174 Q4: 0.175 – 1.0
SCS - grains	Quartiles	Q1: 0 – 0.112 Q2: 0.113 – 0.165	Q3: 0.166 – 0.225 Q4: 0.226 – 1.0
SCS – oils/corn sweeteners	Quartiles	Q1: 0 – 0.067 Q2: 0.068 – 0.124	Q3: 0.125 – 0.194 Q4: 0.195 – 1.0

Table 5.2: Characteristics of the Adult Population Aged 18-64 years (% [SE]), Overall and by Quartiles of Subsidy Consumption Score (SCS Q1-4)

	n (*Total=10920*)	Total Population	SCS Q1	SCS Q2	SCS Q3	SCS Q4	p-value
Sex							0.69
Males	*5580*	50.5% (0.5)	50.9% (1.1)	49.7% (1.2)	51.7 % (1.4)	49.6% (1.1)	
Females	*5340*	49.5% (0.5)	49.1% (1.1)	50.3% (1.2)	48.3% (1.4)	50.4% (1.1)	
Age							<0.0001
18-24 yrs	*2663*	15.9 (0.7)	11.8 (0.9)	12.7 (1.0)	17.8 (1.1)	21.5 (1.4)	
25-34 yrs	*2033*	20.1 (0.8)	16.8 (1.2)	18.8 (1.3)	20.4 (1.2)	24.6 (1.3)	
35-44 yrs	*2243*	23.9 (0.8)	23.9 (1.2)	23.5 (1.2)	25.5 (1.6)	22.7 (1.4)	
45-54 yrs	*2174*	24.4 (0.7)	28.7 (1.4)	27.3 (1.5)	23.1 (1.0)	18.6 (1.2)	
55-64 yrs	*1807*	14.7 (0.6)	17.3 (1.1)	16.3 (0.8)	13.2 (1.1)	12.2 (0.7)	
Mean age (SE)		40.1 (0.3)	42.4 (0.4)	41.5 (0.4)	39.2 (0.4)	37.3 (0.4)	
Race/ethnicity							0.0004
NHW	*4938*	71.0 (1.8)	74.2 (1.5)	72.0 (2.0)	68.6 (2.5)	69.0 (2.2)	
NHB	*2661*	12.0 (1.1)	12.1 (1.3)	12.5 (1.2)	12.0 (1.5)	11.4 (1.3)	
MA	*2508*	8.3 (0.8)	5.6 (0.6)	7.3 (1.0)	9.9 (1.2)	10.5 (1.1)	
Other	*813*	8.8 (0.9)	8.2 (1.0)	8.2 (1.2)	9.5 (1.2)	9.1 (1.2)	
Educational Attainment							<0.0001
Less than HS	*3029*	16.6 (0.7)	13.6 (1.0)	14.5 (1.0)	18.9 (0.9)	19.6 (1.0)	
HS	*2766*	25.3 (0.7)	23.6 (1.1)	24.5 (1.3)	25.3 (1.2)	27.8 (1.1)	
Some college	*3164*	32.5 (0.7)	33.4 (1.2)	32.8 (1.3)	31.8 (1.1)	31.9 (1.2)	
College graduate or more	*1956*	25.6 (1.2)	29.4 (1.5)	28.2 (2.0)	23.9 (1.6)	20.8 (1.3)	
Poverty Income Ratio							<0.0001
≤130%	*3054*	20.5 (1.0)	16.0 (1.2)	18.6 (1.0)	23.8 (1.5)	23.9 (1.5)	
<130 to ≤185%	*1204*	8.8 (0.4)	8.1 (0.7)	8.2 (0.7)	8.7 (0.7)	10.0 (0.7)	
>185%	*6084*	70.7 (1.1)	75.9 (1.4)	73.2 (1.3)	67.5 (1.4)	66.1 (1.7)	
SNAP							0.61
Current	*592*	7.1 (0.5)	6.8 (0.9)	6.2 (0.7)	7.7 (0.9)	7.4 (0.8)	
Past	*126*	1.2 (0.2)	1.1 (0.3)	1.1 (0.3)	1.3 (0.3)	1.4 (0.3)	
Never	*6631*	91.7 (0.6)	92.1 (1.0)	92.7 (0.8)	91.1 (1.0)	91.2 (0.9)	
Food Security Status							<0.0001
Fully Food Secure	*7868*	82.5 (0.7)	85.5 (1.0)	85.0 (0.8)	81.0 (1.0)	78.5 (1.3)	
Marginally Food Secure	*1006*	6.7 (0.4)	4.7 (0.6)	5.8 (0.5)	7.5 (0.7)	8.7 (1.0)	
Food Insecure w/o hunger	*1026*	6.5 (0.4)	5.0 (0.6)	5.7 (0.5)	7.2 (0.7)	8.2 (0.6)	
Food Insecure w/ hunger	*589*	4.3 (0.4)	4.8 (0.7)	3.5 (0.5)	4.4 (0.7)	4.7 (0.5)	

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Smoking Status							0.0004
Current	*3163*	28.9 (0.8)	29.7 (1.5)	26.8 (1.2)	28.0 (1.2)	31.2 (1.3)	
Past	*2101*	21.2 (0.7)	24.4 (1.4)	21.9 (1.2)	20.8 (1.3)	17.8 (1.2)	
Never	*5563*	49.8 (0.9)	45.9 (1.5)	51.3 (1.5)	51.3 (1.6)	51.0 (1.4)	
Leisure-time Physical Activity							0.003
Yes	*7151*	70.0 (0.9)	73.2 (1.1)	71.9 (1.4)	68.2 (1.6)	66.8 (1.5)	
No	*3768*	30.0 (0.9)	26.8 (1.1)	28.2 (1.4)	31.8 (1.6)	33.2 (1.5)	

SE = Standard Error; NHW = Non-Hispanic White; NHB = Non-Hispanic Black; MA = Mexican American; HS = High school; SNAP = Supplemental Nutrition Assistance Program. Subsidy Consumption Score (SCS) quartiles were defined as follows: Q1: 0 – 0.4717; Q2: 0.4718 – 0.5669; Q3: 0.5670 – 0.6541; Q4: 0.6542 – 1.0. Poverty-income Ratio was defined as >185% of the poverty level (higher income); <130 to ≤185% (eligible for Women, Infants, and Children but not SNAP); <130% of the poverty level (eligible for SNAP and free school meals). Leisure-time physical activity includes moderate and vigorous activity. Chi-square tests were used to determine *P*-values.

Table 5.3: Unadjusted Mean Subsidy Consumption Scores (95% CI) and Cardiometabolic Health

	n	SCS (full)	SCS (meat only)	SCS (dairy only)	SCS (grains only)	SCS (oil/HFCS only)
Overall		56.1 (55.6 - 56.5)	12.2 (11.9 – 12.5)	12.4 (12.1 – 12.8)	17.5 (17.1 – 17.9)	13.9 (13.4 – 14.4)
BMI						
Normal weight	*3784*	55.2 (54.5 – 55.9)	11.0 (10.6 – 11.4)	12.8 (12.2 – 13.3)	17.8 (17.3 – 18.4)	13.6 (13.0 – 14.3)
Overweight	*3483*	55.6 (54.9 – 56.4)	12.5 (12.0 – 13.0)	12.2 (11.6 – 12.8)	17.3 (16.7 – 17.9)	13.7 (13.0 – 14.4)
Obese	*3478*	57.4 (56.8 – 58.0)	13.3 (12.7 – 13.9)	12.3 (11.7 – 12.9)	17.4 (16.8 – 17.9)	14.4 (13.9 – 15.0)
Abdominal adiposity (WHtR)						
<0.50	*2904*	54.8 (54.0 - 55.6)	11.0 (10.5 – 11.6)	12.6 (12.0 – 13.2)	17.7 (17.1 – 18.3)	13.4 (12.8 – 14.0)
0.50 – <0.65	*5843*	56.2 (55.6 - 56.7)	12.5 (12.1 – 12.9)	12.4 (12.0 – 12.9)	17.4 (16.9 – 17.9)	13.9 (13.3 – 14.6)
≥0.65	*2173*	57.5 (56.7 - 58.3)	13.1 (12.4 – 13.7)	12.3 (11.6 – 12.9)	17.7 (17.1 – 18.3)	14.4 (13.7 – 15.1)
Hypertension						
Normal	*5182*	56.9 (56.3 – 57.5)	11.8 (11.4 – 12.3)	12.9 (12.4 – 13.4)	18.0 (17.5 – 18.5)	14.3 (13.6 – 14.9)
Pre	*2708*	55.6 (55.0 – 56.3)	12.5 (12.0 – 13.0)	12.1 (11.6 – 12.6)	17.3 (16.7 – 17.9)	13.8 (13.2 – 14.4)
Undx	*629*	54.0 (52.6 – 55.4)	11.6 (10.7 – 12.4)	11.5 (10.5 – 12.6)	17.4 (16.5 – 18.4)	13.5 (12.5 – 14.5)
Dx - uncontrolled	*1727*	55.3 (54.4 – 56.1)	12.8 (12.2 – 13.4)	12.3 (11.6 – 13.1)	16.8 (16.2 – 17.4)	13.3 (12.5 – 14.2)
Dx - controlled	*674*	55.9 (54.3 – 57.5)	13.0 (12.1 – 13.8)	12.1 (10.8 – 13.4)	17.3 (16.2 – 18.5)	13.5 (12.4 – 14.6)
Hyperlipidemia						
Normal	*4370*	56.4 (55.7 – 57.1)	11.7 (11.3 – 12.1)	12.6 (12.1 – 13.2)	17.6 (17.1 – 18.2)	14.5 (13.9 – 15.1)
Pre	*2262*	55.7 (54.8 – 56.6)	12.1 (11.5 – 12.7)	12.2 (11.8 – 12.7)	17.5 (16.8 – 18.3)	13.9 (13.1 – 14.7)
Undx	*2063*	57.1 (56.3 – 58.0)	13.1 (12.3 – 13.9)	12.5 (11.8 – 13.1)	17.5 (16.8 – 18.2)	14.1 (13.3 – 14.9)
Dx - uncontrolled	*1727*	54.9 (54.0 – 55.9)	12.3 (11.7 – 13.0)	12.6 (12.0 – 13.3)	17.1 (16.5 – 17.8)	12.9 (12.2 – 13.5)
Dx - controlled	*498*	54.6 (53.2 – 56.0)	12.2 (11.2 – 13.2)	11.5 (10.6 – 12.5)	18.5 (17.3 – 19.8)	12.4 (11.4 – 13.3)
Diabetes (DM)						
Normal	*8381*	55.9 (55.4 - 56.4)	11.9 (11.6 – 12.3)	12.5 (12.2 – 12.9)	17.4 (17.0 – 17.8)	14.0 (13.5 – 14.6)
Dysglycemia	*1366*	56.3 (55.4 - 57.2)	13.1 (12.2 – 13.9)	11.6 (10.8 – 12.4)	17.7 (17.1 – 18.4)	14.0 (13.2 – 14.7)
Diagnosed DM	*721*	57.0 (55.5 - 56.5)	14.1 (12.8 – 15.3)	12.9 (11.7 – 14.2)	19.2 (17.4 – 21.1)	10.8 (9.8 – 11.8)

SCS = Subsidy Consumption Score; BMI = Body Mass Index; WHtR = Waist-to-height ratio; undx/dx = undiagnosed/diagnosed; DM = diabetes. BMI status was defined as normal (BMI <25 kg/m^2); overweight (25 kg/m^2 < BMI < 30 kg/m^2); obese (BMI ≥30 kg/m^2). Hypertension status was defined as normal (no self-reported diagnosis and systolic <120 and diastolic <80 mmHg); pre-hypertension (no self-reported diagnosis and 120 ≤systolic <140 or 80 ≤diastolic <90 mmHg); undiagnosed (no self-reported diagnosis but systolic >140 or diastolic >90 mmHg); diagnosed/uncontrolled (self-reported diagnosis and systolic ≥120 or diastolic ≥80 mmHg); diagnosed/controlled (self-reported diagnosis and systolic <120 and diastolic <80 mmHg). Hyperlipidemia status was defined as normal (no self-reported diagnosis and <130 mg/dL); pre-Hyperlipidemia (no self-reported diagnosis and 130 ≤chol <160 mg/dL); undiagnosed (no self-reported diagnosis but chol ≥160 mg/dL); diagnosed/uncontrolled (self-reported diagnosis and chol ≥130 mg/dL); diagnosed/controlled (self-reported diagnosis and chol <130 mg/dL). Diabetes status was defined as normal (no self-reported diagnosis and Hemoglobin A1C [HbA1C] <5.7%); dysglycemia (no self-reported diagnosis and 5.7 ≤ HbA1C <6.5%); diagnosed diabetes (self-reported diagnosis and HbA1C≥6.5%).

Table 5.4: Prevalence of Cardiometabolic Risk Factors by SCS Quartiles

		Obesity (BMI ≥30 kg/m^2)		WHtR ≥0.65		Dysglycemia (HbA1C ≥5.7)*	
		% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio
SCS - full							
	Q1	27.6 (0.012)	1.00 (ref)	16.5 (0.010)	1.00 (ref)	10.5 (0.008)	1.00 (ref)
	Q2	29.7 (0.014)	1.08 (0.98 – 1.19)	17.1 (0.011)	1.04 (0.91 – 1.18)	10.2 (0.009)	0.97 (0.77 – 1.22)
	Q3	34.5 (0.016)	1.25 (1.12 – 1.40)	20.2 (0.011	1.23 (1.05 – 1.43)	12.8 (0.009)	1.22 (1.03 – 1.44)
	Q4	36.7 (0.014)	1.33 (1.21 – 1.47)	22.2 (0.012)	1.35 (1.18 – 1.54)	13.2 (0.008)	1.26 (1.03 – 1.53)
SCS - meat							
	Q1	27.2 (0.013)	1.00 (ref)	17.1 (0.011)	1.00 (ref)	11.0 (0.008)	1.00 (ref)
	Q2	30.9 (0.015)	1.14 (1.03 – 1.26)	18.2 (0.011)	1.06 (0.90 – 1.25)	12.0 (0.009)	1.09 (0.91 – 1.31)
	Q3	34.4 (0.017)	1.27 (1.12 – 1.44)	19.9 (0.012)	1.16 (0.98 – 1.38)	11.1 (0.007)	1.01 (0.84 – 1.23)
	Q4	35.9 (0.017)	1.32 (1.16 – 1.50)	20.8 (0.011)	1.21 (1.03 – 1.42)	12.1 (0.009)	1.11 (0.88 – 1.38)
SCS - dairy							
	Q1	33.0 (0.015)	1.00 (ref)	19.3 (0.010)	1.00 (ref)	12.1 (0.008)	1.00 (ref)
	Q2	31.6 (0.014)	0.96 (0.85 – 1.07)	18.8 (0.012)	0.98 (0.86 – 1.12)	11.0 (0.008)	0.91 (0.78 – 1.07)
	Q3	32.5 (0.018)	0.98 (0.87 – 1.11)	19.2 (0.015)	1.00 (0.84 – 1.19)	11.8 (0.008)	0.98 (0.82 – 1.17)
	Q4	31.2 (0.012)	0.95 (0.84 – 1.07)	18.7 (0.010)	0.97 (0.83 – 1.13)	11.2 (0.010)	0.93 (0.77 – 1.12)
SCS - grains							
	Q1	30.9 (0.015)	1.00 (ref)	17.7 (0.009)		10.9 (0.008)	1.00 (ref)
	Q2	32.2 (0.015)	1.04 (0.93 – 1.17)	18.8 (0.011)	1.06 (0.91 – 1.23)	10.8 (0.009)	0.99 (0.81 – 1.22)
	Q3	31.9 (0.016)	1.03 (0.92 – 1.15)	19.1 (0.011)	1.08 (0.96 – 1.21)	12.2 (0.009)	1.12 (0.90 – 1.39)
	Q4	33.3 (0.018)	1.08 (0.94 – 1.23)	20.4 (0.013)	1.15 (0.96 – 1.37)	12.4 (0.009)	1.14 (0.94 – 1.39)
SCS – oil/HFCS							
	Q1	32.0 (0.020)	1.00 (ref)	17.8 (0.014)	1.00 (ref)	10.9 (0.008)	1.00 (ref)
	Q2	28.6 (0.016)	0.90 (0.77 – 1.05)	17.7 (0.014)	0.99 (0.80 – 1.24)	10.5 (0.009)	0.96 (0.77 – 1.19)
	Q3	31.7 (0.014)	0.99 (0.85 – 1.15)	19.6 (0.012)	1.10 (0.89 – 1.35)	13.2 (0.009)	1.20 (0.97 – 1.49)
	Q4	36.0 (0.014)	1.13 (0.98 – 1.30)	20.9 (0.012)	1.17 (0.96 – 1.43)	11.6 (0.007)	1.06 (0.87 – 1.30)

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Table 5.4. Prevalence of Cardiometabolic Risk Factors by SCS Quartiles (continued)

	Hypertension (BP ≥120)*		Hyperlipidemia (chol ≥130 mg/dL)*	
	% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio
SCS - full				
Q1	42.2 (0.016)	1.00 (ref)	51.3 (0.014)	1.00 (ref)
Q2	41.7 (0.016)	0.99 (0.91 – 1.08)	53.7 (0.018)	1.05 (0.96 – 1.14)
Q3	39.4 (0.018)	0.93 (0.85 – 1.03)	56.0 (0.016)	1.09 (1.01 – 1.18)
Q4	42.5 (0.019)	1.01 (0.91 – 1.12)	57.1 (0.013)	1.11 (1.03 – 1.20)
SCS - meat				
Q1	39.2 (0.015)	1.00 (ref)	50.2 (0.016)	1.00 (ref)
Q2	42.3 (0.017)	1.08 (0.98 – 1.19)	55.8 (0.016)	1.11 (1.02 – 1.21)
Q3	41.4 (0.019)	1.06 (0.96 – 1.17)	55.9 (0.015)	1.11 (1.03 – 1.21)
Q4	43.0 (0.018)	1.10 (1.00 – 1.21)	56.8 (0.012)	1.13 (1.05 – 1.22)
SCS - dairy				
Q1	41.4 (0.019)	1.00 (ref)	54.3 (0.014)	1.00 (ref)
Q2	42.7 (0.015)	1.03 (0.93 – 1.14)	56.1 (0.017)	1.03 (0.95 – 1.12)
Q3	41.3 (0.016)	1.00 (0.89 – 1.12)	54.6 (0.015)	1.01 (0.93 – 1.09)
Q4	40.4 (0.17)	0.98 (0.89 – 1.07)	53.4 (0.017)	0.98 (0.90 – 1.07)
SCS - grains				
Q1	42.1 (0.017)	1.00 (ref)	53.1 (0.018)	1.00 (ref)
Q2	42.8 (0.016)	1.02 (0.93 – 1.11)	56.2 (0.013)	1.06 (0.98 – 1.14)
Q3	39.5 (0.018)	0.94 (0.84 – 1.05)	54.2 (0.013)	1.02 (0.94 – 1.10)
Q4	41.5 (0.018)	0.99 (0.88 – 1.11)	55.0 (0.014)	1.04 (0.95 – 1.13)
SCS – oil/HFCS				
Q1	42.4 (0.017)	1.00 (ref)	54.7 (0.014)	1.00 (ref)
Q2	40.5 (0.017)	0.96 (0.86 – 1.06)	55.1 (0.015)	1.01 (0.94 – 1.08)
Q3	41.0 (0.016)	0.97 (0.88 – 1.07)	52.8 (0.013)	0.97 (0.89 – 1.05)
Q4	42.0 (0.015)	0.99 (0.91 – 1.08)	55.8 (0.018)	1.02 (0.93 – 1.12)

SCS = Subsidy Consumption Score; BMI = Body Mass Index; WHtR = waist-to-height ratio; HbA1C = Hemoglobin A1C; SE = Standard Error; Q1-4 = Quartile 1-4; BP = blood pressure. SCS quartiles were defined as: Q1: 0 – 0.4717; Q2: 0.4718 – 0.5669; Q3: 0.5670 – 0.6541; Q4: 0.6542 – 1.0. SCS – meat quartiles were defined as: Q1: 0 – 0.052; Q2:

0.053 – 0.107; Q3: 0.108 – 0.171; Q4: 0.172 – 1.0. SCS – dairy quartiles were defined as: Q1: 0 – 0.054; Q2: 0.055 – 0.106; Q3: 0.107 – 0.174; Q4: 0.175 – 1.0. SCS – grains quartiles were defined as: Q1: 0 – 0.112; Q2: 0.113 – 0.165; Q3: 0.166 – 0.225; Q4: 0.226 – 1.0. SCS – oils/sweets: Q1: 0 – 0.067; Q2: 0.068 – 0.124; Q3: 0.125 – 0.194; Q4: 0.195 – 1.0.
All models adjusted for age, sex, race/ethnicity, educational attainment, poverty income ratio, smoking status, moderate/vigorous leisure-time physical activity.
* Denotes that the category excludes self-reported diagnosed disease (dysglycemia, hypertension, or hyperlipidemia).

Table 5.5: Prevalence of Cardiometabolic Risk Factors by SCS Quartiles - UNADJUSTED

	Obesity (BMI ≥30 kg/m^2)		WHtR ≥0.65		Dysglycemia (HbA1C ≥5.7)*	
	% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio
SCS - full						
Q1	27.7 (0.013)	1.00 (ref)	16.7 (0.011)	1.00 (ref)	11.4 (0.008)	1.00 (ref)
Q2	30.5 (0.014)	1.10 (1.00 – 1.22)	18.0 (0.010)	1.08 (0.95 – 1.22)	10.9 (0.009)	0.95 (0.77 – 1.17)
Q3	34.2 (0.016)	1.24 (1.11 – 1.37)	20.2 (0.010)	1.21 (1.03 – 1.41)	12.6 (0.009)	1.11 (0.94 – 1.31)
Q4	36.1 (0.014)	1.30 (1.18 – 1.45)	21.8 (0.011)	1.31 (1.14 – 1.49)	11.6 (0.007)	1.01 (0.87 – 1.19)
SCS - meat						
Q1	26.9 (0.013)	1.00 (ref)	17.5 (0.011)	1.00 (ref)	10.3 (0.009)	1.00 (ref)
Q2	30.9 (0.014)	1.15 (1.05 – 1.27)	18.4 (0.011)	1.05 (0.91 – 1.21)	11.7 (0.008)	1.13 (0.92 – 1.39)
Q3	34.2 (0.017)	1.27 (1.12 – 1.45)	19.7 (0.012)	1.12 (0.94 – 1.34)	11.2 (0.007)	1.09 (0.89 – 1.33)
Q4	36.3 (0.016)	1.35 (1.20 – 1.53)	21.0 (0.011)	1.20 (1.03 – 1.40)	13.4 (0.009)	1.30 (1.03 – 1.64)
SCS - dairy						
Q1	33.4 (0.015)	1.00 (ref)	19.9 (0.010)	1.00 (ref)	13.6 (0.008)	1.00 (ref)
Q2	31.6 (0.015)	0.95 (0.85 – 1.06)	19.0 (0.012)	0.95 (0.83 – 1.10)	11.7 (0.009)	0.86 (0.73 – 1.01)
Q3	32.7 (0.018)	0.98 (0.87 – 1.10)	19.3 (0.014)	0.97 (0.81 – 1.16)	11.3 (0.009)	0.83 (0.68 – 1.01)
Q4	30.6 (0.013)	0.92 (0.81 – 1.03)	18.5 (0.011)	0.93 (0.79 – 1.09)	9.9 (0.009)	0.73 (0.60 – 0.89)
SCS - grains						
Q1	31.6 (0.014)	1.00 (ref)	18.3 (0.009)	1.00 (ref)	11.8 (0.008)	1.00 (ref)
Q2	32.4 (0.014)	1.03 (0.93 – 1.14)	18.6 (0.010)	1.02 (0.90 – 1.16)	10.8 (0.008)	0.92 (0.76 – 1.11)
Q3	31.8 (0.015)	1.01 (0.91 – 1.12)	19.1 (0.012)	1.05 (0.93 – 1.18)	11.8 (0.009)	1.00 (0.81 – 1.24)
Q4	32.6 (0.017)	1.03 (0.91 – 1.18)	20.6 (0.013)	1.13 (0.97 – 1.31)	12.2 (0.009)	1.03 (0.85 – 1.25)
SCS – oil/HFCS						
Q1	32.3 (0.020)	1.00 (ref)	18.7 (0.015)	1.00 (ref)	11.6 (0.009)	1.00 (ref)
Q2	28.3 (0.016)	0.88 (0.75 – 1.02)	17.2 (0.013)	0.92 (0.75 – 1.14)	10.8 (0.009)	0.93 (0.75 – 1.15)
Q3	31.4 (0.014)	0.97 (0.84 – 1.12)	19.4 (0.012)	1.04 (0.84 – 1.28)	13.0 (0.009)	1.12 (0.91 – 1.38)
Q4	36.2 (0.013)	1.12 (0.98 – 1.29)	21.3 (0.012)	1.14 (0.93 – 1.39)	11.1 (0.006)	0.96 (0.80 – 1.15)

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Table 5.5: Prevalence of Cardiometabolic Risk Factors by SCS Quartiles - UNADJUSTED (continued)

		Hypertension (BP ≥120)*		Hyperlipidemia (chol ≥130 mg/dL)*	
		% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio
SCS - full					
	Q1	44.8 (0.017)	1.00 (ref)	52.8 (0.014)	1.00 (ref)
	Q2	42.7 (0.016)	0.95 (0.88 – 1.03)	54.8 (0.018)	1.04 (0.95 – 1.13)
	Q3	38.9 (0.017)	0.87 (0.79 – 0.95)	54.9 (0.015)	1.04 (0.96 – 1.13)
	Q4	39.3 (0.017)	0.88 (0.79 – 0.97)	53.7 (0.014)	1.02 (0.94 – 1.10)
SCS - meat					
	Q1	37.5 (0.015)	1.00 (ref)	49.8 (0.016)	1.00 (ref)
	Q2	42.2 (0.016)	1.12 (1.03 – 1.23)	54.5 (0.015)	1.10 (1.01 – 1.19)
	Q3	41.9 (0.019)	1.12 (1.01 – 1.24)	55.5 (0.013)	1.12 (1.03 – 1.20)
	Q4	44.2 (0.018)	1.18 (1.07 – 1.29)	56.5 (0.012)	1.14 (1.05 – 1.23)
SCS - dairy					
	Q1	42.4 (0.019)	1.00 (ref)	53.7 (0.014)	1.00 (ref)
	Q2	44.2 (0.015)	1.04 (0.95 – 1.14)	56.7 (0.016)	1.06 (0.98 – 1.14)
	Q3	40.5 (0.016)	0.95 (0.85 – 1.07)	53.3 (0.013)	0.99 (0.92 – 1.07)
	Q4	38.4 (0.016)	0.91 (0.82 – 0.99)	52.5 (0.017)	0.98 (0.89 – 1.07)
SCS - grains					
	Q1	43.8 (0.018)	1.00 (ref)	53.9 (0.017)	1.00 (ref)
	Q2	43.1 (0.016)	0.98 (0.90 – 1.08)	56.1 (0.013)	1.04 (0.96 – 1.12)
	Q3	38.9 (0.019)	0.89 (0.79 – 1.01)	52.6 (0.013)	0.98 (0.90 – 1.05)
	Q4	39.9 (0.017)	0.91 (0.81 – 1.02)	53.4 (0.016)	0.99 (0.91 – 1.08)
SCS – oil/HFCS					
	Q1	43.8 (0.019)	1.00 (ref)	56.9 (0.014)	1.00 (ref)
	Q2	41.4 (0.018)	0.95 (0.85 – 1.06)	55.5 (0.017)	0.98 (0.90 – 1.05)
	Q3	40.7 (0.017)	0.93 (0.83 – 1.04)	51.6 (0.013)	0.91 (0.84 – 0.98)
	Q4	39.8 (0.013)	0.91 (0.83 – 0.99)	52.5 (0.016)	0.92 (0.85 – 1.01)

SCS = Subsidy Consumption Score; BMI = Body Mass Index; WHtR = waist-to-height ratio; HbA1C = Hemoglobin A1C; SE = Standard Error; Q1-4 = Quartile 1-4; BP = blood pressure. SCS quartiles were defined as: Q1: 0 – 0.4717; Q2: 0.4718 – 0.5669; Q3: 0.5670 – 0.6541; Q4: 0.6542 – 1.0. SCS – meat quartiles were defined as: Q1: 0 – 0.052; Q2: 0.053 – 0.107; Q3: 0.108 – 0.171; Q4: 0.172 – 1.0. SCS – dairy quartiles were defined as: Q1: 0 – 0.054; Q2: 0.055 – 0.106; Q3: 0.107 – 0.174; Q4: 0.175 – 1.0. SCS – grains quartiles were defined as: Q1: 0 – 0.112; Q2: 0.113 – 0.165; Q3: 0.166 – 0.225; Q4: 0.226 – 1.0. SCS – oils/sweets: Q1: 0 – 0.067; Q2: 0.068 – 0.124; Q3: 0.125 – 0.194; Q4: 0.195 – 1.0.
* Denotes that the category excludes self-reported diagnosed disease (dysglycemia, hypertension, or hyperlipidemia).

Table 5.6: Prevalence of Cardiometabolic Risk Factors by SCS Quartiles - ADJUSTED FOR AGE, SEX, RACE, SES

		Obesity (BMI ≥30 kg/m^2)		WHtR ≥0.65		Dysglycemia (HbA1C ≥5.7)*	
		% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio
SCS - full							
	Q1	27.2 (0.012)	1.00 (ref)	16.4 (0.010)	1.00 (ref)	10.4 (0.008)	1.00 (ref)
	Q2	29.7 (0.014)	1.09 (0.99 – 1.20)	17.1 (0.010)	1.04 (0.92 – 1.18)	10.2 (0.009)	0.97 (0.77 – 1.22)
	Q3	34.7 (0.016)	1.28 (1.14 – 1.43)	20.3 (0.011)	1.24 (1.06 – 1.45)	12.8 (0.009)	1.22 (1.03 – 1.45)
	Q4	36.8 (0.015)	1.35 (1.22 – 1.50)	22.3 (0.012)	1.36 (1.19 – 1.56)	13.2 (0.008)	1.27 (1.04 – 1.54)
SCS - meat							
	Q1	27.2 (0.013)	1.00 (ref)	17.1 (0.011)	1.00 (ref)	10.9 (0.008)	1.00 (ref)
	Q2	30.8 (0.015)	1.13 (1.02 – 1.26)	18.2 (0.011)	1.06 (0.91 – 1.25)	11.9 (0.009)	1.09 (0.91 – 1.31)
	Q3	34.1 (0.017)	1.26 (1.11 – 1.42)	19.8 (0.012)	1.15 (0.97 – 1.37)	11.1 (0.007)	1.02 (0.84 – 1.23)
	Q4	36.0 (0.017)	1.32 (1.17 – 1.50)	20.9 (0.011)	1.22 (1.04 – 1.43)	12.2 (0.009)	1.11 (0.89 – 1.39)
SCS - dairy							
	Q1	32.7 (0.015)	1.00 (ref)	19.2 (0.010)	1.00 (ref)	12.1 (0.008)	1.00 (ref)
	Q2	31.5 (0.014)	0.95 (0.84 – 1.08)	18.8 (0.012)	0.98 (0.86 – 1.13)	11.0 (0.008)	0.90 (0.77 – 1.06)
	Q3	32.7 (0.018)	1.00 (0.89 – 1.12)	19.3 (0.015)	1.01 (0.84 – 1.20)	11.7 (0.008)	0.97 (0.80 – 1.16)
	Q4	31.1 (0.012)	0.95 (0.84 – 1.08)	18.7 (0.010)	0.97 (0.84 – 1.14)	11.2 (0.010)	0.93 (0.77 – 1.12)
SCS - grains							
	Q1	30.3 (0.015)	1.00 (ref)	17.6 (0.009)	1.00 (ref)	10.9 (0.008)	1.00 (ref)
	Q2	32.2 (0.015)	1.06 (0.95 – 1.19)	18.8 (0.011)	1.07 (0.92 – 1.25)	10.8 (0.009)	0.99 (0.81 – 1.22)
	Q3	32.0 (0.016)	1.06 (0.94 – 1.18)	19.2 (0.011)	1.09 (0.97 – 1.23)	12.1 (0.009)	1.11 (0.90 – 1.38)
	Q4	33.7 (0.018)	1.11 (0.97 – 1.28)	20.5 (0.013)	1.17 (0.98 – 1.40)	12.4 (0.009)	1.14 (0.94 – 1.39)
SCS – oil/HFCS							
	Q1	32.1 (0.020)	1.00 (ref)	18.0 (0.014)	1.00 (ref)	10.9 (0.008)	1.00 (ref)
	Q2	28.6 (0.016)	0.89 (0.76 – 1.04)	17.7 (0.014)	0.99 (0.79 – 1.23)	10.5 (0.009)	0.96 (0.77 – 1.20)
	Q3	31.5 (0.014)	0.98 (0.84 – 1.14)	19.5 (0.012)	1.08 (0.88 – 1.33)	13.2 (0.009)	1.21 (0.98 – 1.50)
	Q4	35.8 (0.014)	1.11 (0.96 – 1.29)	20.8 (0.012)	1.16 (0.95 – 1.41)	11.7 (0.007)	1.07 (0.88 – 1.30)

Cont’d

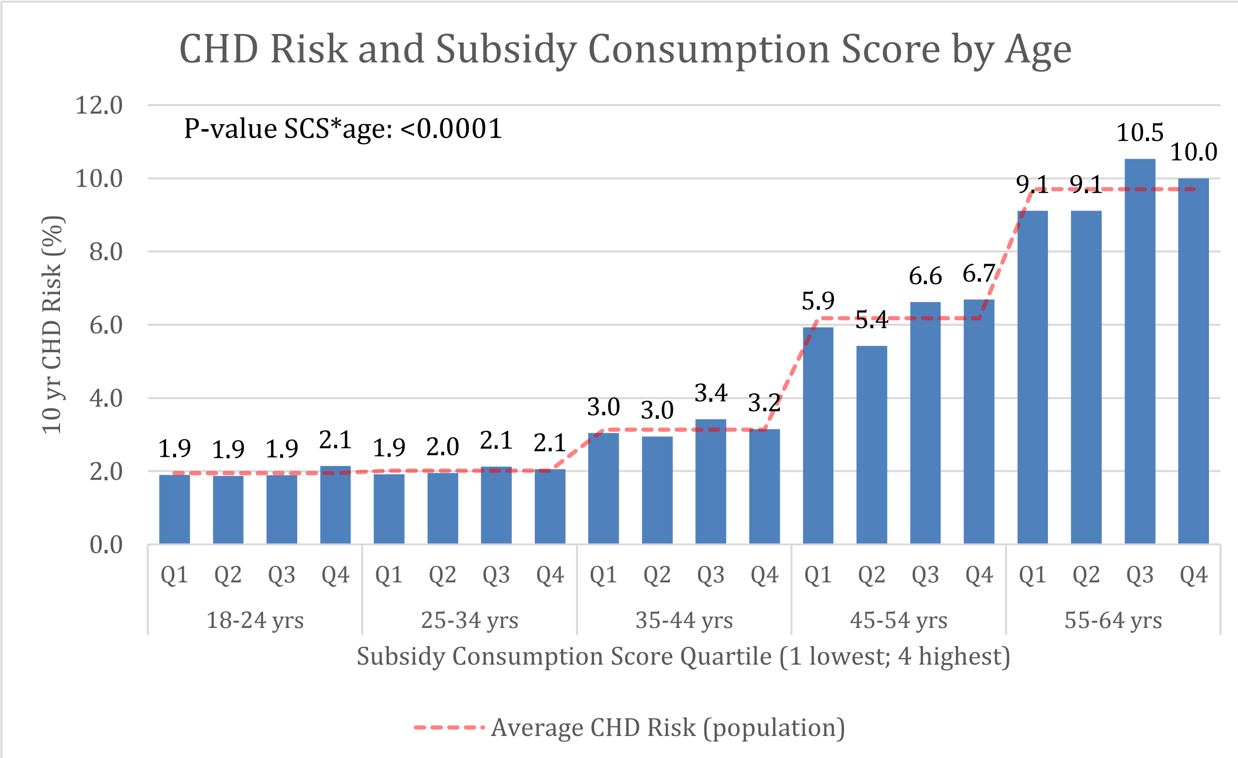
Table 5.6: Prevalence of Cardiometabolic Risk Factors by SCS Quartiles - ADJUSTED FOR AGE, SEX, RACE, SES (continued)

	Hypertension (BP ≥120)*		Hyperlipidemia (chol ≥130 mg/dL)*	
	% (SE)	Prevalence Ratio	% (SE)	Prevalence Ratio
SCS - full				
Q1	42.0 (0.016)	1.00 (ref)	51.1 (0.013)	1.00 (ref)
Q2	41.6 (0.016)	0.99 (0.91 – 1.08)	53.6 (0.018)	1.05 (0.96 – 1.14)
Q3	39.4 (0.018)	0.94 (0.85 – 1.03)	56.0 (0.016)	1.10 (1.01 – 1.19)
Q4	42.6 (0.019)	1.01 (0.92 – 1.12)	57.1 (0.013)	1.12 (1.04 – 1.20)
SCS - meat				
Q1	39.2 (0.016)	1.00 (ref)	50.1 (0.016)	1.00 (ref)
Q2	42.2 (0.017)	1.08 (0.97 – 1.19)	55.7 (0.016)	1.11 (1.02 – 1.21)
Q3	41.3 (0.019)	1.05 (0.95 – 1.17)	55.7 (0.015)	1.11 (1.03 – 1.21)
Q4	43.0 (0.018)	1.10 (1.00 – 1.21)	56.7 (0.012)	1.13 (1.05 – 1.22)
SCS - dairy				
Q1	41.3 (0.019)	1.00 (ref)	54.2 (0.014)	1.00 (ref)
Q2	42.5 (0.015)	1.03 (0.93 – 1.14)	56.0 (0.017)	1.03 (0.95 – 1.12)
Q3	41.3 (0.016)	1.00 (0.89 – 1.12)	54.5 (0.015)	1.01 (0.93 – 1.08)
Q4	40.4 (0.017)	0.98 (0.89 – 1.08)	53.3 (0.016)	0.98 (0.90 – 1.07)
SCS - grains				
Q1	41.8 (0.017)	1.00 (ref)	52.8 (0.017)	1.00 (ref)
Q2	42.6 (0.016)	1.02 (0.93 – 1.12)	56.2 (0.012)	1.06 (0.98 – 1.15)
Q3	39.5 (0.018)	0.95 (0.85 – 1.06)	54.0 (0.012)	1.02 (0.95 – 1.11)
Q4	41.5 (0.018)	0.99 (0.89 – 1.11)	55.0 (0.014)	1.04 (0.95 – 1.14)
SCS – oil/HFCS				
Q1	42.3 (0.017)	1.00 (ref)	54.6 (0.014)	1.00 (ref)
Q2	40.4 (0.017)	0.96 (0.86 – 1.06)	54.9 (0.015)	1.01 (0.94 – 1.08)
Q3	41.0 (0.016)	0.97 (0.88 – 1.07)	52.8 (0.013)	0.97 (0.90 – 1.05)
Q4	41.9 (0.015)	0.99 (0.91 – 1.08)	55.7 (0.018)	1.02 (0.93 – 1.12)

SCS = Subsidy Consumption Score; BMI = Body Mass Index; WHtR = waist-to-height ratio; HbA1C = Hemoglobin A1C; SE = Standard Error; Q1-4 = Quartile 1-4; BP = blood pressure. SCS quartiles were defined as: Q1: 0 – 0.4717; Q2: 0.4718 – 0.5669; Q3: 0.5670 – 0.6541; Q4: 0.6542 – 1.0. SCS – meat quartiles were defined as: Q1: 0 – 0.052; Q2: 0.053 – 0.107; Q3: 0.108 – 0.171; Q4: 0.172 – 1.0. SCS – dairy quartiles were defined as: Q1: 0 – 0.054; Q2: 0.055 – 0.106; Q3: 0.107 – 0.174; Q4: 0.175 – 1.0. SCS – grains quartiles were defined as: Q1: 0 – 0.112; Q2: 0.113 – 0.165; Q3: 0.166 – 0.225; Q4: 0.226 – 1.0. SCS – oils/sweets: Q1: 0 – 0.067; Q2: 0.068 – 0.124; Q3: 0.125 – 0.194; Q4: 0.195 – 1.0.

* Denotes that the category excludes self-reported diagnosed disease (dysglycemia, hypertension, or hyperlipidemia)

Figure 5.1: Consumption of Subsidized Foods and 10-year CHD Risk



CHD = Coronary Heart Disease. 10 yr CHD Risk was calculated using the Framingham Risk Score (Wilson et al 1998). Subsidy Consumption Score (SCS) quartiles were defined as follows: Q1: 0 – 0.4717; Q2: 0.4718 – 0.5669; Q3: 0.5670 – 0.6541; Q4: 0.6542 – 1.0.

Chapter 6 - Do We Produce Enough Fruits and Vegetables to Meet Global Health Need?

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Abstract

Background: Low fruit and vegetable (FV) intake is a leading risk factor for chronic disease globally, but much of the world's population does not consume the recommended servings of FV daily. It remains unknown whether global supply of FV is sufficient to meet current and growing population needs. We sought to determine whether supply of FV is sufficient to meet current and growing population needs, globally and in individual countries.

Methods and Findings: We used global data on agricultural production and population size to compare supply of FV in 2009 with population need, globally and in individual countries. We found that the global supply of FV falls, on average, 22% short of population need according to nutrition recommendations (supply:need ratio: 0.78 [Range: 0.05 - 2.01]). This ratio varies widely by country income level, with a median supply:need ratio of 0.42 and 1.02 in low-income and high-income countries, respectively. A sensitivity analysis accounting for need-side food wastage showed similar insufficiency, to a slightly greater extent (global supply:need ratio: 0.66, varying from 0.37 [low-income countries] to 0.77 [high-income countries]). Using agricultural production and population projections, we also estimated supply and need for FV for 2025 and 2050. Assuming medium fertility and projected growth in agricultural production, the global supply:need ratio for FV increases slightly to 0.81 by 2025 and to 0.88 by 2050, with similar patterns seen across country income levels. In a sensitivity analysis assuming no change from current levels of FV production, the global supply:need ratio for FV decreases to 0.66 by 2025 and to 0.57 by 2050.

Conclusion: The global nutrition and agricultural communities need to find innovative ways to increase FV production and consumption to meet population health needs, particularly in low-income countries.

Introduction

Low fruit and vegetable (FV) intake is a leading risk factor for death and disability globally, estimated to contribute to approximately 16.0 million disability-adjusted life years and 1.7 million deaths worldwide annually [139]. According to a World Health Organization report, current global dietary guidelines recommend that individuals consume at least 5 servings of FV daily [140]. Recent cross-country evidence supports this recommendation, showing a strong dose-response relationship between higher FV consumption and lower all-cause mortality [141] as well as lower risk of major chronic diseases such as cardiovascular disease, diabetes, and certain cancers, which impact every region of the world [142-144].

Much of the world's population, however, does not consume the recommended five servings of FV daily. Data from 52 mainly low- and middle-income countries participating in the 2002-2003 World Health Survey reported that, overall, 77.6% of men and 78.4% of women surveyed consumed less than the recommended five daily servings of FV. The survey also showed that FV consumption patterns vary around the world, but lower-than-recommended reported consumption is common in high, middle, and low-income countries. For example, in a recent report, poor dietary habits, which includes low FV consumption, was *the* leading risk factor in the United States (U.S.), accounting for 26% of all deaths and 14% of all disability [12], and increasing individual FV consumption to up to 600 grams per day (slightly more than 5 servings per day) could reduce the total worldwide burden of disease by 1.8%, and reduce the burden of ischemic heart disease and ischemic stroke by 31% and 19% respectively [140].

Despite a wealth of research on behavioral determinants of FV, it remains unknown whether global production and supply of FV is actually sufficient to meet population needs. We used global population and agriculture databases to compare the global supply of ("supply") with recommended dietary intake (implied "demand", hereafter referred to as "need") globally and in individual countries. Using agricultural production and population projections data, we also project supply and need for FV for 2025 and 2050.

Methods

Data Sources

We used three main data sources for our analysis: (1) Food and Agricultural Organization (FAO) 2009 Food Balance Sheets[145], (2) age-specific FV intake recommendations for individuals [140], and (3) the United Nations (UN) World Population Prospects: The 2012 Revision [146].

The FAO 2009 Food Balance Sheets (the most recent year for which these data were available) report FV (excluding wine) supply by individual country for over 175 countries. These data are calculated by taking into account production, imports and exports, and food losses (through storage, transport, and processing; feed to livestock; or use as seeds and non-dietary purposes). The data reflect "formal" food production, and do not capture FV production from subsistence farming and production, which may not enter formal economies. For the FAO Food Balance Sheets, this estimated national food supply is divided by population size estimates to derive the reported per capita supply of FV (in kg/person/year).

For FV recommendations, we used a World Health Organization (WHO) report on the quantitative comparison of different health risks worldwide [140]. The report cited previously calculated and validated estimates for the average annual weight of the 5 recommended servings of FV per day: 330 grams per day for individuals aged 0-4 years, 480 grams per day for individuals aged 5-14 years, and 600 grams per day for all individuals aged 15 years and older. We converted these data into kilograms.

The UN World Population Prospects: 2012 Revision (the most recent version) provides country-level population estimates, in terms of the total population size as well as the proportion of each country's population by age. Calculations are done yearly using data classified by broad age groups (0-14 years, 15+ years) and for five-year periods (the latest years being 2005 and 2010) using data classified by more specific age groups, including 0-4 years, 5-14 years, and 15 years and older. To align our population estimates with age-specific FV recommendations, we used population estimates from 2010. This data source also provides population projections based on different scenarios for changing fertility levels for the period 2010-2100 for individual countries and globally.

Data Analysis

To calculate "supply" (in kg/year), we multiplied the FAO per-capita estimates by total population estimates for each country from the UN. The equation for supply is:

$$Supply = \frac{FV(kg)}{person} * population$$

To calculate "need" (assuming all individuals are able to meet their daily recommended intake of FV – "perfect need"), we multiplied the UN's age-specific population estimates by recommendations for FV servings per day for the same age-specific groups. Total country-specific population need (in kg/year) was then calculated by summing the recommended FV weights for all three age categories. The equation for "need" is:

$$Need = \left[popn(0-4yrs)\frac{0.33kg}{persons0-4yrs})\right] + \left[popn(5-14yrs)\frac{0.48kg}{persons5-14yrs})\right] + \left[popn(15+yrs)\frac{0.60kg}{persons15+yrs})\right]$$

Finally, we calculated a supply:need ratio by dividing supply by need, both expressed in kg/year, where a value greater than 1.0 signifies surplus, a value of 1.0 implies balance, and less than 1.0 signifies deficit. Supply, need, and supply:need ratios were calculated for each individual country and globally. We also calculated averages of these supply, need, and supply:need ratio indicators across varying country income levels, defined according to World Bank categories: low-income economies (per capita Gross Domestic Product [GDP] of $1,025 or less), lower-middle-income economies (per capita GDP of $1,026 to $4,035), upper-middle-income economies (per capita GDP of $4,036 to $12,475), and high-income economies (per capita GDP of $12,476 or more).

For the projections for 2025 and 2050, we calculated changes in production ("supply") using agricultural production growth rates to 2030 (1.6% for developing and 0.7% for developed countries) and 2050 (0.9% for developing and 0.3% for developed countries) as estimated by the FAO[147]. Similar to our calculations for current need, we calculated projected need by multiplying age-specific population projections for 2025 and 2050 by recommendations for FV servings per day for the same age-specific groups and summing across all three groups. For this projections analysis, we assumed a medium variant fertility scenario (2-3 children per woman).

All calculations were performed in Excel and data analysis was performed using Statistical Analysis Software (SAS) version 9.3.

Sensitivity Analyses

To account for need-side food wastage at the household/individual level, we performed a sensitivity analysis to adjust these estimates to account for wastage of 33% in high-income regions/countries and 15% in low- to middle-income regions/countries [148]. For the projections, we also performed a sensitivity analysis in order to account for “best-case” (low fertility, or <2.1 children per woman) and “worst-case” (high fertility, or >5 children per woman) scenarios [146]. In addition to the main projections analysis, we also performed a sensitivity analysis assuming current levels of agricultural production.

Results

Table 6.1 shows descriptive statistics, overall and by country income level, for all countries for which all data were available (n=170). Overall, the global supply (not including subsistence production that may not enter formal economies) of available FV falls 22% short of population’s need according to nutritional recommendations, and as much as 95% short in some countries (overall supply:need ratio: 0.78 [range: 0.05 – 2.01]). This ratio varies widely by country income level, with a median supply:need ratio of 0.42 in low-income countries and a median supply:need ratio of 1.02 in high-income countries (Table 6.1). In a sensitivity analysis in which we accounted for need-side food wastage, similarly insufficient FV supplies were noted, to a slightly greater extent. The global supply:need ratio was 0.66 when need-side wastage was accounted for, and this varied from 0.37 (low-income countries) to 0.77 (high-income countries) (see Supplemental data 6.1 for results by country and Supplemental data 6.2 for results across country income level).

The supply:need ratio also varies widely by geographical region. The highest ratios of greater than 1.0 (indicating more than sufficient supply to meet the population's needs) are seen in the Mediterranean/North African countries of Montenegro (supply:need ratio 2.01), Greece (1.86), Turkey (1.78), Egypt (1.72), Libya (1.67), Tunisia (1.52), Italy (1.50), and Portugal (1.48); Middle Eastern countries of Iran (1.78), Israel (1.56), and Lebanon (1.46); Caribbean countries of Bahamas (1.61) and Belize (1.50); Albania (1.59); and China (1.86). The countries with the greatest shortage, where need is far greater than supply, are primarily African countries such as Eritrea (0.05), Chad (0.09), Burkina Faso (0.10), Mozambique (0.12), Ethiopia (0.12).

Table 6.2 shows projected supply, need and supply:need ratios overall and by country income level, for all countries for which all data was available (n=169). Assuming medium fertility (2-3 children per woman) and projected agricultural production growth rates, the global supply:need ratio for FV increases slightly to 0.81 by 2025 and to 0.88 by 2050. As with current, the projected supply:need ratio in 2025 and 2050 varies by country income level. The lowest ratio is seen in low-income countries, where it dips to 0.30 in 2050, assuming medium fertility. The projected supply:need ratio is higher in high income countries, where it ranges from an estimated 0.98 to 1.21. In a sensitivity analysis using current levels of FV production (ie, assuming no increase in production), the global supply:need ratio for FV decreases to 0.66 by 2025 and to 0.57 by 2050 assuming medium fertility (2-3 children per woman). As with current, the projected supply:need ratio in 2025 and 2050 varies by country income level, with the lowest ratio of 0.18 in low-income countries by 2050 and the highest ratio of 0.99 in high income countries.

Figure 6.1 illustrates current and projected supply:need ratios, highlighting the growing gap between supply and need in low-income countries over time.

Discussion

Within the formal agricultural sector, there is an estimated 22% supply gap in meeting current need for FV (34% when considering food wastage at the household/individual level), and this varies from 58% to 13% across low- and upper-middle income countries. High income countries appear to have sufficient supply (supply:need ratio is 1.02). Furthermore, these gaps between high/middle-income and low-income countries will worsen with time. Assuming medium fertility and projected increases in production of FV, the global supply:need ratio for FV increases slightly to 0.81 by 2025 and to 0.88 by 2050, but divergence occurs whereby we estimated a supply gap of 70% and 65% in low-income countries by 2025 and 2050, respectively, while middle- and high-income countries approach a supply:need of 1.0, implying balance of supply and need. Without the projected increase in FV production, however, the global supply:need ratio could decrease to 0.66 by 2025 and to 0.57 by 2050, dipping as low as 0.18 in low-income countries.

There may be several reasons for these findings. Supply-side factors include subsidies and distribution systems for supply, and international trade for addressing imbalances in supply:need ratios across countries and country-income levels [149]. Many countries provide producer-end subsidies for grain crops and meat/dairy, incentivizing farmers to grow these items while dis-incentivizing FV production. In the U.S., the commodity crops receiving the largest amount of agricultural subsidies are grains, livestock, and dairy and under current agricultural policy, farmers are penalized for growing “specialty crops” (FV) if they have received federal farm payments to grow other crops [8, 63]. As a result, grains, meat, and dairy are abundant [55], the supply of FV, at least in the US, is insufficient to meet population needs [70]. In low-income countries, where we found FV need to be greatest, the lack of adequate distribution systems may lead to supply-side wastage and disincentives for their production. This is an issue particularly in warm climates like India and Africa, where FV are prone to spoiling before reaching their market destinations [95].

In particular, international trade (and climates ideal for growing FV) could help explain the differences in findings across country-income groups and geographical regions.

International trade in FV, which since the 1980s has expanded more rapidly than other agricultural commodities and was 17% of total agricultural trade in 2001, is also an important consideration for increasing supply of FV, particularly in countries where production may be high but supply low due to exports [150]. Climates ideal for growing FV is also a very important supply-side factor when considering FV production. As noted in the results section, there appear to be varying levels of agronomical potentials of countries located in different geographical regions, as highlighted by the large geographical variations in the supply:need ratio, with high ratios seen in many Mediterranean countries. For example, it is known that Mediterranean countries are great producers of fruits for the fresh market due to climatic conditions – drip irrigation combined with dry summers is a perfect scenario for producing high quality crops (although a substantial proportion of this production is exported to other countries).

On the need side of the equation, population size – and relatively large projected increases, particularly in certain low-income countries – helps to explain the large and growing gaps between supply and need in these countries. The projections data show that, assuming an estimated increase in FV production, the supply:need ratio narrows on a global scale, but that it widens to a considerable extent in low-income countries, primarily as a reflection of higher fertility in these countries and agricultural production growth rates that cannot keep up with population growth. The ability to produce enough FV to meet the needs of large and growing populations, coupled with the supply-side limitations mentioned above, are of particular concern for these countries. In the 18th century, Malthus projected that human population growth would outpace expansion in food production. Since then, with the help of technological advances spurred by the Green Revolution, production and subsequent supply of carbohydrates and grains has increased to meet global population needs. Our projections analysis suggests that high-income countries may be making strides towards increasing production and subsequent supply of FV to meet their population's needs, but that the same cannot be said for the low-income countries, at least within the formal agricultural economy, where the gap in supply not taking subsistence farming into account could widen to 65% by 2050 if not addressed. Of greater concern, if projected increases in agricultural production of FV do not manifest, by 2025 and 2050 high- and low-income countries alike may not able to meet their population's needs for FV.

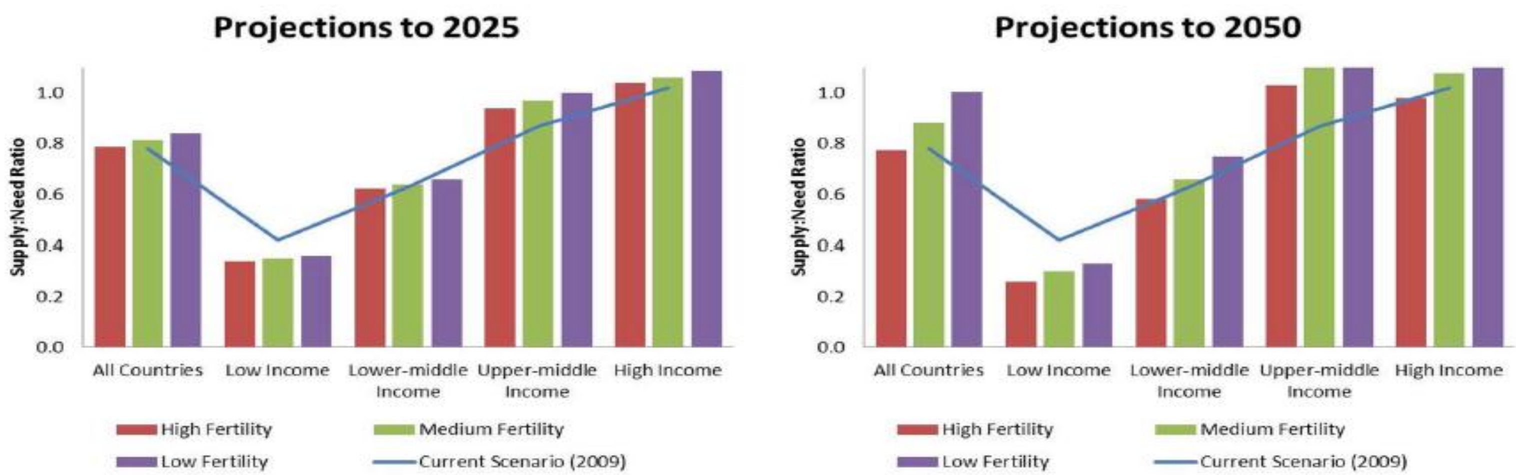
While ecological data suggests that food availability can influence food consumption patterns and in turn, cardiometabolic health outcomes like diabetes [11, 121], to date there has been a relatively limited focus on production and supply of FV. Researchers at America's Farmland Trust investigated supply of FV in the United States (U.S.) alone; they concluded that an estimated 13 million more acres of farmland would be needed to produce a sufficient supply for the U.S. population [151]. Our analysis builds upon these results. The first study to incorporate empirical country-level data and age-specific recommendations for FV consumption to examine global and country-specific FV supply (in the formal sector) as it compares to need, our study highlights inadequate supply of FV as it compares to the population's nutritional needs, from the perspective of preventing chronic diseases, which currently place enormous burdens on countries around the world and are largely preventable through healthy diet and higher FV consumption [12, 140].

These findings must be contextualized by limitations to our analysis. First, the data used were macro-level indicators collected at the country-level and may be prone to either over- or under-estimation. The data do not account for how much people actually access FV in various countries nor the quality and diversity of FV consumption, including how these FV are consumed (raw, cooked, or processed FV have different nutrient bioavailability), nor how much *individuals* actually consume. For example, many Mediterranean and Caribbean countries, which were found to have high supply:need ratios, are great citrus producers, but in the latter fruits are processed (for juice) and not sold on the fresh market. Additionally, every fruit and vegetable does not have the same macro- and micro-nutrient content, and even the same fruit or vegetable grown in a different climate or soil may have differing amounts of macro- and micro-nutrients. Additionally, there may also be differences in the quality and validity of the data in high- versus low-income countries. However, the FAO Food Balance Sheets are the most commonly used source of food availability information at the national level, providing standardized estimates of the average amount of food available per person on a daily basis and a useful tool for international comparisons [152]. Second, our analysis is at the country level, and therefore does not take into account urban/rural differences in supply that may result from challenges in distribution (for example, transporting FV from the farm to urban areas. This may be a particular issue in resource-poor settings, where distributional infrastructure may be lacking. Further analyses could investigate these issues, analyzing potential heterogeneity of supply and need within countries and in urban versus rural settings.

A third limitation is that our analysis does not capture local food economies (ie, subsistence farming and food production) in individual countries. That is, it does not take into account the production of FV that may exist outside of the formal agricultural sector (i.e., home gardens), which may vary widely across countries. This may be an additional area of future research. For example, researchers could utilize the powerful technologies of Google Earth to look within countries, at the regional, city, district, or even household level, at the presence or absence of informal community or household gardens. Lastly, our analysis does not incorporate additional economic indicators such as the costs of production or the resulting prices of FV. Our results suggest that insufficient supply exists relative to population needs under current production conditions. We have not taken into account the potential for supply to increase due to technological improvements and supportive government policies. Both those factors could lower FV prices and increase consumption.

Our study adds unique value by underlining the importance of increasing supply of FV and sets the stage for further analyses to delve further into the policy levers for increasing production and supply. In particular, investigating the supply of FV resulting from subsistence farming could augment our analysis. At the same time, continuing efforts to improve demand for FV – for example, through public health education and health promotion programs, proposing taxes on foods of low nutritional value (e.g., soda, high-fat foods) or subsidies on foods of high nutrition value (e.g., FV), improved food labeling, and stricter controls on the marketing of foods [97, 153-156] – is equally important. Without an accompanying increase in supply, however, these efforts may have limited reach. It is hoped that our straightforward analysis, highlighting inadequate formal supply of FV in the context of perfect need (assuming all individuals are able to meet their daily recommended intake of FV), may provide value by offering an understanding of the current and future global disconnect between nutritional recommendations and supply of FV, and guide conversations and future investigations to consider appropriate policy responses. The triumph of grains production over the doom and gloom forecast of Malthus is a major testament to the technological and organizational success of food production and distribution worldwide that has accompanied industrialization and modern development. The current state of affairs presents a challenge to the global nutrition and agricultural communities to increase FV production in the same way, especially in low-income countries. Change is possible.

Figure 6.1: Projected Supply: Need Ratio, 2025 and 2050



Notes: Country Income Level defined according to World Bank categories: Low-income economies ($1,025 or less), Lower-middle-income economies ($1,026 to $4,035), Upper-middle-income economies ($4,036 to $12,475), High-income economies ($12,476 or more). Fertility is defined according to the United Nations World Population Prospects, 2012 Revision: high fertility (5 or more children per woman), medium fertility (2-3 children per woman), and low fertility (less than 2.1 children per woman).

Table 6.1: Descriptive Statistics of Fruit and Vegetable Supply, Need, and Supply:Need Ratio, Overall and by Country Income Level

	n	**Supply**	**Need**	**Supply:Need Ratio**
Full Sample, all countries	170	1.15 (0.01 – 524.25)	1.90 (0.02 – 282.50)	0.78 (0.05 – 2.01)
Low Income	34	0.97 (0.05 – 7.50)	2.36 (0.13 – 30.18)	0.42 (0.05 – 0.99)
Lower-middle Income	43	1.01 (0.01 – 142.51)	1.49 (0.02 – 241.62)	0.63 (0.19 – 1.72)
Upper-middle Income	50	1.52 (0.01 – 524.25)	1.71 (0.02 – 282.50)	0.87 (0.24 – 2.01)
High Income	43	1.60 (0.04 – 71.63)	1.64 (0.05 – 64.59)	1.02 (0.55 – 1.86)

Notes: All numbers provided as median (range). Supply and Need are reported in billions of kilograms of fruits and vegetables. Country Income Level defined according to World Bank categories: Low-income economies ($1,025 or less), Lower-middle-income economies ($1,026 to $4,035), Upper-middle-income economies ($4,036 to $12,475), High-income economies ($12,476 or more).

Table 6.2: Projected Need and Supply:Need Ratios, Overall and by Country Income Level

		2025			2050		
	n	**Supply**	**Need**	**Supply:Need Ratio**	**Supply**	**Need**	**Supply:Need Ratio**
Full Sample, all countries	169	1.45 (0.02 – 675.83)			1.79 (0.02 – 875.25)		
High fertility			2.21 (0.02 – 310.96)	0.79 (0.04 – 2.52)		2.74 (0.02 – 380.34)	0.78 (0.03 – 3.25)
Medium fertility			2.16 (0.02 – 302.40)	0.81 (0.04 – 2.59)		2.48 (0.02 – 335.52)	0.88 (0.03 – 3.69)
Low fertility			2.10 (0.02 – 293.83)	0.84 (0.04 – 2.67)		2.23 (0.02 – 293.93)	1.00 (0.03 – 4.21)
Low Income	34	1.20 (0.07 – 9.67)			1.55 (0.09 – 12.52)		
High fertility			3.65 (0.19 – 37.53)	0.34 (0.04 – 1.15)		5.89 (0.33 – 48.38)	0.26 (0.03 – 1.30)
Medium fertility			3.55 (0.19 – 36.28)	0.35 (0.04 – 1.18)		5.28 (0.30 – 42.11)	0.30 (0.03 – 1.47)
Low fertility			3.45 (0.18 – 35.03)	0.36 (0.04 – 1.22)		4.70 (0.27 – 36.43)	0.33 (0.03 – 1.68)
Lower-middle Income	42	1.32 (0.04 – 183.72)			1.71 (0.06 – 237.93)		
High fertility			2.35 (0.04 – 297.58)	0.62 (0.16 – 1.90)		3.49 (0.05 – 380.34)	0.58 (0.09 – 2.34)
Medium fertility			2.28 (0.04 – 288.77)	0.64 (0.16 – 1.95)		3.08 (0.05 – 335.52)	0.66 (0.10 – 2.65)
Low fertility			2.21 (0.04 – 279.95)	0.66 (0.17 – 2.02)		2.70 (0.04 – 293.93)	0.75 (0.11 – 3.01)
Upper-middle Income	50	1.96 (0.02 – 675.83)			2.54 (0.02 – 875.25)		
High fertility			1.85 (0.02 – 310.96)	0.94 (0.19 – 2.52)		1.86 (0.02 – 327.36)	1.03 (0.12 – 3.25)
Medium fertility			1.79 (0.02 – 302.40)	0.97 (0.19 – 2.59)		1.64 (0.02 – 290.93)	1.16 (0.14 – 3.69)
Low fertility			1.74 (0.02 – 293.83)	1.00 (0.20 – 2.67)		1.44 (0.02 – 257.35)	1.33 (0.15 – 4.21)
High Income	43	1.79 (0.04 – 80.09)			1.97 (0.04 – 88.05)		
High fertility			1.91 (0.06 – 74.60)	1.04 (0.59 – 2.04)		2.17 (0.07 – 92.40)	0.98 (0.52 – 2.15)
Medium fertility			1.86 (0.06 – 72.69)	1.06 (0.61 – 2.09)		1.96 (0.07 – 83.32)	1.08 (0.58 – 2.38)
Low fertility			1.81 (0.06 – 70.79)	1.09 (0.63 – 2.14)		1.76 (0.06 – 74.67)	1.21 (0.65 – 2.65)

Notes: All numbers provided as median (range). Need is reported in billions of kilograms of fruits and vegetables. Country Income Level defined according to World Bank categories: Low-income economies ($1,025 or less), Lower-middle-income economies ($1,026 to $4,035), Upper-middle-income economies ($4,036 to $12,475), High-income economies ($12,476 or more). Fertility is defined according to the United Nations World Population Prospects, 2012 Revision: high fertility (more than 5 children per woman), medium fertility (2-3 children per woman), and low fertility (less than 2.1 children per woman).

Supplemental data 6.1: List of Countries and Their Respective Supply, Need, and Supply:Need Ratios

Country	Supply	Not Accounting for Need-side Food Wastage		Accounting for Need-side Food Wastage	
		Need	Supply:Need Ratio	Need	Supply:Need Ratio
Albania	1.03	0.65	1.59	0.75	1.39
Algeria	7.59	7.46	1.02	8.58	0.88
Angola	0.87	3.67	0.24	4.22	0.21
Antigua and Barbuda	0.02	0.02	1.31	0.02	1.14
Argentina	5.66	8.22	0.69	9.46	0.60
Australia	4.39	4.64	0.95	6.18	0.71
Austria	1.91	1.77	1.08	2.35	0.81
Azerbaijan	2.09	1.86	1.12	2.14	0.98
Bahamas	0.12	0.07	1.61	0.10	1.21
Bangladesh	7.50	30.18	0.25	34.71	0.22
Barbados	0.06	0.06	0.99	0.08	0.74
Belarus	2.04	1.99	1.02	2.29	0.89
Belgium	2.36	2.28	1.03	3.04	0.78
Belize	0.09	0.06	1.50	0.07	1.30
Benin	0.78	1.82	0.43	2.09	0.38
Bolivia	1.01	2.00	0.51	2.30	0.44
Bosnia and Herzegovina	1.13	0.80	1.41	0.93	1.22
Botswana	0.15	0.39	0.39	0.45	0.34
Brazil	32.50	39.77	0.82	45.73	0.71
Brunei Darussalam	0.06	0.08	0.76	0.11	0.57
Bulgaria	0.80	1.56	0.51	1.79	0.44
Burkina Faso	0.31	2.94	0.10	3.38	0.09
Burundi	1.53	1.75	0.87	2.02	0.76
Cambodia	0.82	2.86	0.29	3.29	0.25
Cameroon	3.98	3.94	1.01	4.53	0.88
Canada	8.31	7.13	1.17	9.48	0.88
Cape Verde	0.07	0.10	0.72	0.11	0.63
Central African Republic	0.29	0.84	0.34	0.97	0.30
Chad	0.20	2.19	0.09	2.52	0.08
Chile	2.66	3.53	0.76	4.05	0.66
China	524.25	282.50	1.86	324.88	1.61
Colombia	6.82	9.35	0.73	10.75	0.63
Comoros	0.08	0.13	0.61	0.15	0.53
Congo, Dem. Rep.	5.51	11.78	0.47	13.54	0.41
Costa Rica	0.61	0.95	0.64	1.10	0.56
Cote d'Ivoire	2.08	3.65	0.57	4.20	0.50

Croatia	0.90	0.91	0.99	1.21	0.75
Cuba	3.04	2.36	1.29	2.71	1.12
Cyprus	0.25	0.23	1.07	0.31	0.80
Czech Republic	1.60	2.22	0.72	2.95	0.54
Denmark	1.30	1.15	1.13	1.54	0.85
Djibouti	0.07	0.16	0.40	0.19	0.34
Dominican Republic	2.42	2.00	1.21	2.30	1.05
Ecuador	2.49	3.00	0.83	3.45	0.72
Egypt	26.67	15.54	1.72	17.87	1.49
El Salvador	0.88	1.24	0.71	1.43	0.61
Eritrea	0.05	1.10	0.05	1.26	0.04
Estonia	0.25	0.27	0.91	0.36	0.68
Ethiopia	2.03	16.63	0.12	19.13	0.11
Fiji	0.07	0.17	0.41	0.20	0.36
Finland	0.92	1.12	0.82	1.49	0.62
France	13.46	13.13	1.02	17.47	0.77
French Polynesia	0.04	0.06	0.72	0.07	0.54
Gabon	0.28	0.30	0.92	0.35	0.80
Gambia	0.06	0.32	0.20	0.37	0.18
Georgia	0.45	0.91	0.49	1.05	0.43
Germany	14.43	17.52	0.82	23.30	0.62
Ghana	4.74	4.71	1.01	5.42	0.88
Greece	4.35	2.33	1.86	3.10	1.40
Grenada	0.02	0.02	0.91	0.02	0.79
Guatemala	1.75	2.76	0.63	3.18	0.55
Guinea	1.48	2.08	0.71	2.39	0.62
Guinea-Bissau	0.10	0.30	0.34	0.35	0.30
Guyana	0.08	0.15	0.51	0.18	0.44
Haiti	0.91	1.94	0.47	2.24	0.41
Honduras	1.12	1.49	0.75	1.72	0.65
Hungary	2.19	2.10	1.04	2.80	0.78
Iceland	0.06	0.07	0.95	0.09	0.72
India	142.51	241.62	0.59	277.87	0.51
Indonesia	25.55	48.22	0.53	55.46	0.46
Iran, Islamic Rep.	27.07	15.19	1.78	17.47	1.55
Ireland	1.09	0.92	1.19	1.22	0.89
Israel	2.34	1.50	1.56	1.99	1.17
Italy	18.80	12.73	1.48	16.93	1.11
Jamaica	0.52	0.55	0.93	0.64	0.81
Japan	19.68	26.87	0.73	35.74	0.55
Jordan	0.90	1.27	0.71	1.46	0.62

Kazakhstan	3.45	3.23	1.07	3.71	0.93
Kenya	4.38	7.83	0.56	9.01	0.49
Kiribati	0.01	0.02	0.65	0.02	0.57
Korea, Dem. Rep.	4.98	5.03	0.99	5.79	0.86
Kuwait	0.63	0.61	1.04	0.81	0.78
Kyrgyz Republic	1.00	1.07	0.94	1.23	0.82
Lao PDR	1.17	1.25	0.94	1.44	0.81
Latvia	0.34	0.44	0.78	0.51	0.68
Lebanon	1.30	0.89	1.46	1.02	1.27
Lesotho	0.08	0.39	0.19	0.45	0.17
Liberia	0.26	0.76	0.34	0.87	0.30
Libya	2.02	1.21	1.67	1.39	1.45
Lithuania	0.57	0.64	0.89	0.74	0.78
Luxembourg	0.14	0.11	1.30	0.14	0.98
Macedonia, FYR	0.61	0.44	1.39	0.50	1.21
Madagascar	1.17	4.03	0.29	4.64	0.25
Malawi	1.18	2.84	0.41	3.27	0.36
Malaysia	2.60	5.72	0.45	6.58	0.40
Maldives	0.09	0.07	1.31	0.08	1.14
Mali	1.34	2.63	0.51	3.03	0.44
Malta	0.13	0.09	1.42	0.12	1.07
Mauritania	0.15	0.70	0.22	0.80	0.19
Mauritius	0.16	0.25	0.64	0.29	0.55
Mexico	18.63	23.65	0.79	27.20	0.69
Moldova	0.56	0.75	0.75	0.86	0.66
Mongolia	0.17	0.55	0.32	0.63	0.28
Montenegro	0.26	0.13	2.01	0.15	1.75
Morocco	6.92	6.38	1.09	7.34	0.94
Mozambique	0.54	4.54	0.12	5.23	0.10
Myanmar	6.25	10.55	0.59	12.13	0.52
Namibia	0.10	0.43	0.24	0.49	0.21
Nepal	3.78	5.27	0.72	6.06	0.62
Netherlands	3.52	3.46	1.02	4.61	0.76
New Caledonia	0.04	0.05	0.71	0.07	0.53
New Zealand	1.09	0.90	1.21	1.20	0.91
Nicaragua	0.33	1.15	0.28	1.32	0.25
Niger	0.93	2.96	0.31	3.40	0.27
Nigeria	17.41	30.38	0.57	34.94	0.50
Norway	1.00	1.01	0.99	1.35	0.74
Pakistan	11.34	34.09	0.33	39.20	0.29
Panama	0.42	0.74	0.57	0.85	0.49

Paraguay	0.82	1.28	0.64	1.47	0.56
Peru	4.28	5.87	0.73	6.75	0.63
Philippines	16.87	18.42	0.92	21.18	0.80
Poland	6.96	8.01	0.87	10.66	0.65
Portugal	3.33	2.22	1.50	2.96	1.13
Republic of Korea	14.39	10.15	1.42	13.50	1.07
Romania	4.87	4.59	1.06	5.27	0.92
Russian Federation	26.49	30.10	0.88	34.61	0.77
Rwanda	2.02	2.06	0.98	2.37	0.85
Samoa	0.04	0.04	1.08	0.04	0.94
Sao Tome and Principe	0.04	0.03	1.23	0.04	1.07
Saudi Arabia	4.46	5.44	0.82	7.24	0.62
Senegal	1.01	2.47	0.41	2.84	0.35
Serbia	1.75	2.02	0.87	2.32	0.75
Seychelles	0.01	0.02	0.67	0.02	0.58
Sierra Leone	0.48	1.10	0.44	1.27	0.38
Slovak Republic	0.92	1.14	0.80	1.52	0.60
Slovenia	0.46	0.43	1.06	0.57	0.80
Solomon Islands	0.04	0.10	0.39	0.12	0.34
South Africa	3.83	10.30	0.37	11.85	0.32
Spain	10.64	9.68	1.10	12.88	0.83
Sri Lanka	1.44	4.22	0.34	4.85	0.30
St. Lucia	0.02	0.04	0.69	0.04	0.60
St. Vincent and the Grenadines	0.02	0.02	1.04	0.03	0.91
Sudan	3.88	6.85	0.57	7.88	0.49
Suriname	0.07	0.11	0.65	0.12	0.56
Swaziland	0.09	0.23	0.40	0.27	0.35
Sweden	1.93	1.96	0.99	2.60	0.74
Switzerland	1.51	1.64	0.92	2.19	0.69
Syrian Arab Republic	4.88	4.24	1.15	4.87	1.00
Tajikistan	1.18	1.50	0.79	1.72	0.69
Tanzania	4.85	8.53	0.57	9.81	0.49
Thailand	10.58	13.77	0.77	15.84	0.67
Timor-Leste	0.04	0.20	0.19	0.23	0.16
Togo	0.19	1.21	0.16	1.39	0.13
Trinidad and Tobago	0.15	0.27	0.55	0.36	0.41
Tunisia	3.29	2.17	1.52	2.50	1.32
Turkey	25.95	14.62	1.78	16.81	1.54
Turkmenistan	0.93	1.01	0.92	1.16	0.80
Uganda	5.95	6.36	0.94	7.31	0.81
Ukraine	9.41	9.68	0.97	11.13	0.85

United Arab Emirates	1.69	1.77	0.95	2.35	0.72
United Kingdom	13.26	12.91	1.03	17.17	0.77
United States	71.63	64.59	1.11	85.91	0.83
Uruguay	0.43	0.69	0.62	0.80	0.54
Uzbekistan	7.65	5.57	1.37	6.40	1.20
Vanuatu	0.03	0.05	0.76	0.05	0.66
Venezuela	3.48	5.83	0.60	6.70	0.52
Vietnam	12.38	18.20	0.68	20.93	0.59
Yemen	1.94	4.39	0.44	5.05	0.39
Zambia	0.52	2.49	0.21	2.87	0.18
Zimbabwe	0.39	2.52	0.15	2.90	0.13

Note: Kiribati is not included in the projections analysis due to unavailable data. The columns accounting for need-side food wastage incorporate factors of 15% and 33% wastage in low/middle-income and high-income countries, respectively. The columns not accounting for need-side food wastage do not incorporate these wastage factors. Supply-side wastage is included in all estimates.

Supplemental data 6.2: Sensitivity Analysis of Fruit and Vegetable Supply, Need, and Supply:Need Ratio, Overall and by Country Income Level

	n	**Supply**	**Need**	**Supply:Need Ratio**
Full Sample, all countries	170	1.15 (0.01 – 524.25)	2.29 (0.02 – 324.88)	0.66 (0.04 – 1.75)
Low Income	34	0.97 (0.05 – 7.50)	2.71 (0.15 – 34.71)	0.37 (0.04 – 0.86)
Lower-middle Income	43	1.01 (0.01 – 142.51)	1.72 (0.02 – 277.87)	0.55 (0.16 – 1.49)
Upper-middle Income	50	1.52 (0.01 – 524.25)	1.97 (0.02 – 324.88)	0.76 (0.21 – 1.75)
High Income	43	1.60 (0.04 – 71.63)	2.19 (0.07 – 85.91)	0.77 (0.41 – 1.40)

Notes: All numbers provided as median (range). Supply and Need are reported in billions of kilograms of fruits and vegetables. Country Income Level defined according to World Bank categories: Low-income economies ($1,025 or less), Lower-middle-income economies ($1,026 to $4,035), Upper-middle-income economies ($4,036 to $12,475), High-income economies ($12,476 or more).

Supplemental data 6.3: Sensitivity Analysis of Projected Need and Supply:Need Ratios (Assuming Current Levels of Agricultural Production), Overall and by Country Income Level

		2025		2050	
	n	**Need**	**Supply:Need Ratio**	**Need**	**Supply:Need Ratio**
Full Sample, all countries	169				
High fertility		2.21 (0.02 – 310.96)	0.64 (0.03 – 1.95)	2.74 (0.02 – 380.34)	0.50 (0.02 – 1.95)
Medium fertility		2.16 (0.02 – 302.40)	0.66 (0.03 – 2.01)	2.48 (0.02 – 335.52)	0.57 (0.02 – 2.21)
Low fertility		2.10 (0.02 – 293.83)	0.68 (0.03 – 2.07)	2.23 (0.02 – 293.93)	0.65 (0.02 – 2.52)
Low Income	34				
High fertility		3.65 (0.19 – 37.53)	0.27 (0.03 – 0.89)	5.89 (0.33 – 48.38)	0.16 (0.02 – 0.78)
Medium fertility		3.55 (0.19 – 36.28)	0.28 (0.03 – 0.92)	5.28 (0.30 – 42.11)	0.18 (0.02 – 0.88)
Low fertility		3.45 (0.18 – 35.03)	0.29 (0.03 – 0.94)	4.70 (0.27 – 36.43)	0.20 (0.02 – 1.01)
Lower-middle Income	42				
High fertility		2.35 (0.04 – 297.58)	0.48 (0.12 – 1.47)	3.49 (0.05 – 380.34)	0.35 (0.05 – 1.40)
Medium fertility		2.28 (0.04 – 288.77)	0.50 (0.13 – 1.52)	3.08 (0.05 – 335.52)	0.39 (0.06 – 1.58)
Low fertility		2.21 (0.04 – 279.95)	0.51 (0.13 – 1.56)	2.70 (0.04 – 293.93)	0.45 (0.07 – 1.80)
Upper-middle Income	50				
High fertility		1.85 (0.02 – 310.96)	0.76 (0.15 – 1.95)	1.86 (0.02 – 327.36)	0.69 (0.07 – 1.95)
Medium fertility		1.79 (0.02 – 302.40)	0.79 (0.15 – 2.01)	1.64 (0.02 – 290.93)	0.78 (0.08 – 2.21)
Low fertility		1.74 (0.02 – 293.83)	0.81 (0.15 – 2.07)	1.44 (0.02 – 257.35)	0.88 (0.09 – 2.52)
High Income	43				
High fertility		1.91 (0.06 – 74.60)	0.93 (0.53 – 1.83)	2.17 (0.07 – 92.40)	0.79 (0.42 – 1.75)
Medium fertility		1.86 (0.06 – 72.69)	0.95 (0.54 – 1.87)	1.96 (0.07 – 83.32)	0.88 (0.47 – 1.94)
Low fertility		1.81 (0.06 – 70.79)	0.98 (0.56 – 1.92)	1.76 (0.06 – 74.67)	0.99 (0.53 – 2.16)

Notes: All numbers provided as median (range). Need is reported in billions of kilograms of fruits and vegetables. Country Income Level defined according to World Bank categories: Low-income economies ($1,025 or less), Lower-middle-income economies ($1,026 to $4,035), Upper-middle-income economies ($4,036 to $12,475), High-income economies ($12,476 or more). Fertility is defined according to the United Nations World Population Prospects, 2012 Revision: high fertility (more than 5 children per woman), medium fertility (2-3 children per woman), and low fertility (less than 2.1 children per woman.

Chapter 7 - Summary, Conclusions, and Public Health Implications

Key Findings

The main objective of this dissertation was to expand upon knowledge of the role of societal drivers of cardiometabolic disease in the US and globally. I focused primarily on food and agricultural policy as it relates to risk, and more specifically on food availability and agricultural subsidies. Previous research has elucidated the modifiable causes of cardiometabolic disease at the individual-level – obesity, physical inactivity, and diets high in calories, saturated fats, sugars, and salt, but low in unsaturated fats, fiber, and fruits and vegetables. Although individual-level behavior change can help to promote health and prevent disease, understanding how these individual-level risk factors are influenced – either helped or hindered – by the environments within which we live and policies under which we live could improve population health on a potentially larger scale.

Using publicly available data from the World Health Organization, World Bank, and Food and Agricultural Organization and controlling for gross domestic product per capita, foreign direct investment, mortality, total calorie availability, and office-based jobs (indicating sedentary work environments), my co-authors and I found that higher availability of sugar and sweeteners and animal fats as a percentage of total calories is associated with increased diabetes prevalence, while higher availability of fruits and vegetables is associated with decreased diabetes prevalence. This finding is among the first to show cross-sectional associations between diabetes prevalence and multiple societal factors, including food availability, and led me to explore one major determinant of food availability – agricultural policy and more specifically, subsidies for commodity crops.

To do this, I examined how consumption of subsidized food commodities and their derivatives are distributed across the US adult population and how their consumption is associated with cardiometabolic risk at the individual level. I chose the US for two main reasons: (1) the enormous burden that poor diet places on death and disability – 26% of all deaths and 14% of all disability in the US [12] – and (2) the availability of individual-level data and relatively abundant and accessible information about food and agricultural policy. Moreover, it is generally understood that the most heavily subsidized food commodities in the US (corn, soybeans, rice, wheat, sorghum, dairy, and livestock) are used to produce foods that are high in animal fats, sugar and sweeteners, and refined grains. Fruits and vegetables, on the other hand, are less subsidized. This aligns with the foods whose availability was found to be associated with diabetes prevalence as described above.

Using the National Health and Nutrition Examination Surveys (NHANES), a nationally representative dataset with comprehensive individual-level dietary intake, demographic, and measured health outcome data, I created a scoring algorithm to calculate the proportion of an individual's total daily calorie intake that comes from subsidized food commodities. I found that more than half of all calories consumed by US adults aged 18-64 years are derived from subsidized food commodities, and that younger, less-educated, and poorer individuals tend to consume diets with significantly higher proportions of subsidized commodities. Individuals who consume a diet with a higher proportion of calories from subsidized food commodities have worse cardiometabolic health outcomes – specifically, higher prevalence of obesity, abdominal adiposity, elevated lipids, and dysglycemia. Subsidized food commodities consumed in the form of meat products (for example, grains used as feed instead of other uses, as well as the livestock subsidy) appeared to be the main drivers of the associations for obesity, abdominal adiposity, and elevated lipids.

Considering the relative abundance of subsidized commodities in the average adult American diet, combined with the lack of any commodity subsidy for fruits and vegetables and the finding that availability of fruits and vegetables is associated with lower diabetes prevalence, I next investigated whether, at the global level, there is actually sufficient supply of fruits and vegetables to meet population nutritional needs for preventing cardiometabolic disease (i.e., 5 servings of fruits and vegetables per person per day). My co-authors and I found a 22% global gap in supply of fruits and vegetables relative to need, and this ranged from 58% in low-income countries to no gap in high-income countries.

Taken together, this dissertation demonstrates a statistically significant detrimental effect of availability of sugars/sweeteners, animal fats, and refined grains on cardiometabolic risk – but an abundance of these items in the food supply. We also demonstrated a protective effect of availability of fruits and vegetables – but a significant dearth of these items in the food supply. The risk can be seen at both the population- and individual-levels, whether examining a population's food supply or an individual's daily dietary intake. Although nutritional guidelines seem to take the population's needs for healthier foods into consideration, food and agricultural policies that influence the availability of these healthier foods have not yet done the same.

The results of my analyses underscore the importance of aligning food and agricultural policies with nutrition recommendations and population needs. Thanks in part to today's agricultural policy, food is abundant and cheap – and people are eating more of it. From 1970 to 2009, food production and supply in the US – the amount of calories (kcal) available to the population –increased from 2,169 to 2,594 kcal/person/day, with the largest increases seen in refined grains (187 kcal) and added fats and oils (168 kcal) [7]. Concurrent to this increase, since 1977, average daily calorie intake in the US has jumped by more than 10 percent. As **Chapter 4** suggests (and Michael Pollan hints), this increase can be traced to the source of all calories: the farm. As Pollan notes, we have witnessed a similar situation before: during the early19th century, corn was over-produced and thus corn whisky became very abundant and very cheap. Americans suddenly began drinking more than ever before – half a pint per day, or five gallons per year, for the typical American man (today the figure is less than a gallon) [55]. In "The Alcoholic Republic" by W.J. Rorabaugh (as I came to learn about through Pollan), the story is this:

> "we drank the hard stuff at breakfast, lunch and dinner, before work and after and very often during. Employers were expected to supply spirits over the course of the workday; in fact, the modern coffee break began as a late-morning whiskey break called "the elevenses." (Just to pronounce it makes you sound tipsy.) Except for a brief respite Sunday mornings in church, Americans simply did not gather – whether for a barn raising or quilting bee, corn husking or political campaign – without passing the jug. Visitors from Europe - hardly models of sobriety themselves - marveled at the free flow of American spirits. "Come on then, if you

> love toping," the journalist William Cobbett wrote his fellow Englishmen in a dispatch from America. "For here you may drink yourself blind at the price of sixpence."

The results were a rising tide of public drunkenness and a spike in alcohol-related diseases, and led to a debate (led by George Washington, Thomas Jefferson, and John Adams) over such excess drinking that culminated a century later in Prohibition [55].

Today, the main public health concern over abundance of food (and corn) is obesity and cardiometabolic diseases, but there is currently a lack of consensus about whether or not this is the result of today's farm policies, as well as a lack of consensus about what to do about it. Public health and nutrition professionals tend to see an obvious link between agricultural policy and obesity and cardiometabolic risk and call for elimination of agricultural subsidies, or at least a shift to include healthier crops [55, 56, 157, 158].

However, as discussed in **Chapter 2**, economist Julian Alston and colleagues have published widely on the subject, arguing that farm policies do not contribute to obesity and that their elimination would actually increase calorie intake in the US [59, 60, 62]. One noteworthy limitation of the work by Alston and colleagues, however, is that they only consider total calories (and obesity) rather than *quality* of calories (and cardiometabolic risk). A key strength and contribution of my work, therefore, is the consideration of diet *quality* rather than just *quantity* of calories. Moreover, although Alston and colleagues conclude that the mixed effects of subsidies on availability and price of various foods means that subsidies do not cause obesity, their economic model found that elimination of all subsidies would increase the production output of fruits and vegetables by 4.42% and decrease the price of fruits and vegetables by 15.6% [59]. In light of my findings that, ecologically, a 20% higher availability of fruits and vegetables (as a percentage of total calorie availability) is associated with a 52% lower diabetes prevalence [10] and that global supply of fruits and vegetables falls 22% short of need [13], Alston's findings actually support the case for changing agricultural policies to promote health.

One noteworthy result of agricultural policy, at least in the US, is that it leads to relative lack of diversity in our diets. The majority of agricultural subsidies goes to commodity crops like corn, wheat, and soy, nearly all of which are primarily fed to livestock or used as sweeteners or other additives. For example, in the US, while over $19 billion has funded the production of corn and soy, which in turn show up in processed foods as sweeteners, thickeners and other additives, over the past 18 years, only $689 million has been spent subsidizing apples (the only subsidized fruit or vegetable) [56]. We eat what is grown; the more we eat, the more farmers grow [158].

Limitations

There are several limitations to this body of work. One overarching limitation is the cross-sectional nature of the analyses. As a result, the design does not establish temporality and thus the findings can only suggest associations and cannot determine causality. This limitation can be partly addressed through future longitudinal analyses, which I plan to perform as part of the next phase of my research.

A second limitation is the estimations and assumptions that were made in the calculation of the Subsidy Consumption Score. I used a single 24-hour recall to assess dietary intake and calculate the proportion of total daily calories from foods derived from subsidized commodities. This may not represent the usual diet of respondents (which varies by week or weekend days). However, a single 24-hour recall is appropriate to assess mean group intakes [120] and provides greater detail on the specific types and amounts of food eaten than does a food-frequency questionnaire. Future plans include the incorporation of a second day of 24-hour recall and a re-calculation of the score using the average of the two days. Additionally, in the calculation to estimate the proportion of total calories from foods derived from subsidized commodities, I only took into account the 7 top commodities receiving 80-90% of agricultural commodity program subsidy dollars. This represents the majority of the direct payments that are given to farmers for production of crops under Title I of the Farm Bill. However, the Farm Bill is comprised of 14 additional titles that range from food stamps and nutrition programs such as Women, Infants, and Children; crop insurance; and conservation programs. For this analysis, I chose to focus on producer-end subsidies, and as a result only included Title I payments. However, future work could modify the scoring algorithm to include additional Farm Bill titles.

Fourth, the societal correlates and fruit and vegetable supply:need analyses utilize macro-level data, which is prone to under- or over-estimation, and also required that I use the variables for which data was available to me. For example, the variables that I used for the societal correlates of diabetes analysis came from 4 different sources (the World Health Organization, World Bank, and Food and Agricultural Organization) that may have vastly different data collection methodologies. Additionally, the Food and Agricultural Organization data on the production of fruits and vegetables did not account for production outside the formal retail sector, and thus may have slightly under-estimated total supply.

Strengths

The work also contains several strengths. The findings from this dissertation provide insight into how food availability impacts health. An overarching strength is the use of both global macro-level data and individual-level data that is nationally representative to the US population.

Second, the analysis of six years of NHANES data was particularly worthwhile, as it allowed us to analyze dietary intake from over 11,000 adults, as well as analyze different sources of subsidized food commodities and their derivatives, utilize measured health biomarkers (rather than rely simply on self-report), and conduct subgroup analyses to assess consumption of food commodities by age, sex, race/ethnicity, and socioeconomic status. The findings of this analysis are generalizable to the US population.

Third, the NHANES analysis is the first study to estimate consumption of subsidized commodities at the *individual* level and to examine individual-level associations between consumption of these subsidized commodities and objectively measured and documented cardiometabolic risk. A primary obstacle to truly understanding the role of subsidies in cardiometabolic health has been the lack of available methods to estimate how much an individual's diet is comprised of subsidized foods. As a result, our study may help to clarify the role of subsidies on health and inform policy-makers about health impacts of food subsidies.

Fourth, my dissertation provides the first systematic and quantitative inventory of the supply of fruits and vegetables relative to population need according to nutritional recommendations. The findings may help to direct agricultural policies towards encouraging the production of such healthier crops.

Public Health Implications and Future Directions

What can be done? History may provide some ideas.

The first idea comes from an unplanned natural experiment in Poland, before and after the country underwent unusually rapid political and economic transformations in the late 1980s to 1991. During the transition, general purchasing power fell after 1989, and the withdrawal of large consumer subsidies, especially for foods of animal origin, reduced purchasing power for those foods sharply and led to a radical decrease in the consumption of meat, whole milk, cream, cheese, eggs, and margarine. As a result, demand for vegetable fats increased and margarine manufacturers, eager to make a profit, responded with efficient new technology and products with low *trans* fatty acid content [161]. Another result of the transition was trade liberalization, which led to increased imports of fresh foods from warmer climates – and a considerable increase in the consumption of fish and fresh vegetables.

At the same time, cardiovascular mortality in Poland, which had been high in 1960 and increasing by 70% in men and 15% in women until 1991, began to decline [161]. From 1986/90 to 1994, cardiovascular deaths declined by approximately 20-25%. To investigate possible reasons for this decline, an ecological study considered the possible roles of concomitant changes in the availability of foods and alcohol, smoking prevalence, socioeconomic indices, and medical care. Findings suggest that changes in type of dietary fat and increased supplies of fresh fruit and vegetables are the best candidates to explain the decrease. Specifically, between 1986/90 and 1994, there was a marked switch from animal fats (estimated availability down 23%) to vegetable fats (up 48%) and increased imports of fruit [161]. This natural experiment reiterates the importance of food availability, including production as well as trade (imports/exports) in promoting health.

A third example comes from the Western Pacific. In the early 1980s, nearly 40% of the average New Zealand sheep and beef farmer's gross income came from government subsidies. In 1984, however, New Zealand's newly elected government, faced with a budget crisis, set out to push free market reforms, and elimination of nearly all farm subsidies was one of the first changes to occur. The removal happened both suddenly and unexpectedly, forcing farmers that had once enjoyed high levels of aid to fend for themselves.

Although it led to an initial period of protests and instability and predictions that 10% of the country's farms would go bankrupt, only 1% of the country's farmers could not adjust and were forced out [162, 163]. Herds were consolidated, and breeds that reflected market demand – producing leaner milk, for instance – rose to prominence [163]. Twenty years later, it has resulted in a thriving agricultural sector and a more vibrant, diversified, entrepreneurial and growing rural economy. For example, 20 years after the change, the value of economic activity in New Zealand's farm sector has grown by 40%, the agricultural sector contributes nearly 20% of GDP (compared to 14.2% previously), and agricultural sector productivity has improved by 5.9% per year (compared to 1% previously) [164].

It is important to note that such a drastic change might not work in all settings; New Zealand is a relatively small country with a unique agricultural sector and high demand for its exports. In some settings, agricultural subsidies may be necessary for ensuring food security. However, the example suggests that anticipated consequences of changing subsidy structures (such as those modeled by Alston and colleagues) may not be what actually happens once changes are implemented. Such changes may instead lead to an agricultural sector that responds with greater efficiency to consumer demand for healthier crops. One alternative example comes from Malawi. There, agricultural subsidies exist, but they are used for fertilizer rather than specific crops [165]. This may be a solution that could work in other countries such as the US, helping to encourage farmers to increase provision of a wider range of healthy crops.

Lastly, the successful North Karelia Project in Finland highlights that it can be feasible – and highly impactful – to shift subsidies and agricultural production from unhealthier towards healthier crops. In 1970, after a health transition following World War II, Finland had the highest cardiovascular mortality in the world (particularly among men), and in North Karelia, a region of Finland where most men were loggers and dairy farmers, the situation was even worse. The typical Finnish diet was high in saturated fats (butter, whole milk and cream, pork and fatty meat), low in unsaturated fats, high in salt, and low in vegetables and fruit [166].

In 1972, the North Karelia Project, led by 27-year old Pekka Puska, was launched as a community-based, and later as a national program to influence diet and other lifestyles that are crucial in the prevention of CVD [167]. The project was a multi-pronged approach, addressing the environment, culture, and economy of the North Karelia region and later, all of Finland. The main goal of the nutrition program was to reduce blood cholesterol levels of the population, and the main focus of the strategy was to reduce the high saturated fat intake, especially from dairy sources, and increase consumption of fruits and vegetables [166, 168].

One specific and innovative intervention was the “Berry Project.” Initially, the community project worked to educate people about the detrimental health effects of consuming large quantities of high-fat dairy products like butter and cream. However, since North Karelia had a high number of dairy farmers, concern arose over the economic impact that sharp reductions in consumption of butter and fatty dairy products might have paired with the promotion of mostly-imported fruits and vegetables [166]. When Puska and his team targeted dairy subsidies, which rewarded cream and butter production and taxed margarine so that it cost as much as butter, they were met with a great deal of resistance. However, as increased health awareness led to reduced consumer demand for butter, the subsidies were eventually removed, opening the market for margarine and vegetable oils. At the same time, farmers were offered alternatives for production. Discussions between the community and project representatives brought up the feasibility of growing berries – which are high in certain beneficial vitamins and anti-oxidants and are well-liked by the Finnish population – in the northern climate, and eventually led to a major collaborative between berry farmers, industry, commercial sectors and the health authorities, financed by the Ministry of Agriculture and the Ministry of Commerce. Concurrent to dwindling dairy consumption, local berry consumption gradually rose, and many farmers switched from dairy to berry production [166, 169, 170].

As a result of the North Karelia Project, by the year 2000, countrywide CVD mortality had plummeted by 80% (attributed to dietary changes and dramatic reductions in cardiometabolic risk factors like hypertension, hypercholesterolemia, and smoking), all-cause mortality dropped by 45%, and male life expectancy increased by 7 years [170, 171].

Conclusions and Future Research

Macro-level analyses using data from the World Health Organization, World Bank, and Food and Agricultural Organization suggest that higher population-level availability of sugar, sweeteners, and animal fats is associated with higher national-level diabetes prevalence, while higher availability of fruits and vegetables is associated with lower prevalence; at the same time, this data shows that at the global level, supply of fruits and vegetables is insufficient to meet population needs. Furthermore, using nationally representative, individual-level data from the US, I found that subsidized food commodities (which include meat and dairy, grains, and corn sweeteners but do not include fruits and vegetables) are abundant in the average American adult diet, and that higher consumption of these subsidized commodities is associated with adverse cardiometabolic risk profiles. At a time when heart disease is the leading killer worldwide and diabetes prevalence is high and increasing, these findings are critically important.

In my dissertation research, I also performed a secondary exploratory analysis to estimate the value of agricultural subsidy dollars in an individual's diet – their Subsidy Dollar Score, or SDS. To do this, I applied information from the Environmental Working Group's Farm Subsidy Database [54] (which provides information about the value of government subsidies [in $US] given to a particular commodity annually through the Farm Bill's Title I) and the USDA's Feed Grains and Crops Database [108] (which provides information about the amount of the grain crops produced in a given year, and the proportion of the commodity that goes to various food, feed, and other uses, as well as the amount of livestock and dairy products produced in a given year). From these databases, I next determined the value (in $US) of a gram of each food commodity. I accomplished this in two ways.

First, I used the Feed Grains and Crops Database to determine total production, for food and feed use, of each grain during the years of interest (2000-2005, which accounts for one year from production to final distribution in the food system) and I used the Farm

Subsidy Database to determine the billions of $US going to each commodity in those same years. From this, I estimated the amount of subsidies (in $US) per kilogram of each grain commodity (corn, soybeans, wheat, rice, sorghum). Similarly, I used USDA Livestock Production and Dairy Production Databases to determine total production of beef, chicken, and pork, and milk, butter, cheese, and eggs, and the Farm Subsidy Database to determine the billions of $US going to each unit of meat, eggs, and dairy products.

Second, for the dairy and livestock subsidies (meat, eggs, and dairy products), I consulted USDA resources to determine the estimated amount of feed grains required to produce 1 pound of beef, chicken, and pork, as well as the estimated amount of feed grains required to feed a dairy cow that produces milk, cheese, butter, and yogurt. For example, the USDA estimates that it takes 7 pounds of corn to produce 1 pound of beef and 2.6 pounds of corn to produce 1 pound of chicken [118].

To calculate the total value of government subsidies in $US that went into the production of each individual's total daily diet – their Subsidy Dollar Score, or SDS – I then summed the dollar value for each commodity across all food items consumed in the reported day. The calculation equation is:

$$SDS = \sum_{i=1}^{n} (Food_i * UnitPrice_{foodi}) + \sum_{j=1}^{n} (Feed_j * UnitPrice_{feedj})$$

where *Food* is the amount (in grams) of each commodity present as food, *Feed* is the amount (in grams or pounds) of each commodity present as feed, $UnitPrice_{food}$ is the unit price ($US) of each commodity as food, and $UnitPrice_{feed}$ is the unit price ($US) of each commodity as feed.

Among the same population of adults aged 18-64 y, I found that the SDS was left-skewed and the median SDS was $0.03 (IQR: $0.02 – $0.04) and mean SDS was $0.03 (95% CI: $0.03 - $0.03), with a range of $0 to $0.64. This translates into an average of $11.72 per person per year, with a range of $0 to $233.76.

While I found (1) significant associations between food availability and diabetes prevalence, (2) a substantial proportion (56%) of calorie intake in the US come from subsidized food commodities, and (3) insufficient global supply of unsubsidized foods like fruits and vegetables, I also found (4) that the typical American diet contains only $0.03 per day [$0 - $0.64]) in agricultural subsidies. This is a nearly negligible proportion of the less than $8 per day that the average American spends on food and beverages or the $25 per person per week that low-income families spend [17, 137]. These initial results from the SDS calculation suggest that subsidies, while important in terms of availability (altering food *production*), may play a smaller role in the final cost of foods and may not affect individual-level *consumption*. It is also important to note that the SDS only includes agricultural subsidy dollars from Title I of the Farm Bill, and thus does not include consumer-end funding for the Supplemental Nutrition Assistance Program (SNAP) or Women, Infants, and Children (WIC).

My finding that a nearly negligible amount of agricultural subsidy dollars ($0.03 on average, ranging from $0 - $0.64, and translating to an average $11.92 annually) can be traced to an individual's daily diet was particularly interesting, but perhaps not unexpected. The results corroborate a 2007 study that graphed, from 1960 through 2003, total expenditure by the US government on direct payments (the subsidy expenditure used in my analysis) on the same scale as consumer expenditure on food. The study found that this measure of subsidy expenditure averaged only 1.1% of consumer expenditure on food [159].

Nonetheless, previous research highlights the relatively low cost per calorie of unhealthier food – the same foods that are derived from subsidies – and the higher cost per calorie of healthier food – the foods that do not receive agricultural subsidies [137]. For a dollar in the US, for example, one can purchase 1,200 calories of potato chips or cookies or just 250 calories worth of carrots [160]. Rao and colleagues recently conducted a global systematic review and meta analysis of prices of healthier versus less healthy foods/diet patterns (per serving, day, and 2,000 kilocalorie) [72]. Comparing extremes (top versus bottom quantile) of food-based diet patterns, healthier diets cost $1.48 per day ($1.01 to $1.95) and $1.54 per 2,000 kilocalorie ($1.15 to $1.94) more than less healthy diets. The largest price differences were seen for meats/protein: healthier options, such as those lower in fat, cost $0.29 per serving and $0.47 per 2,000 kilocalorie more than less healthy options, such as higher fat, processed meats. Although the actual agricultural subsidy dollars may not <u>directly</u> be keeping the costs of foods low, the law of supply and demand posits that an overabundance of cheap commodities being produced and unleashed into the food supply means that their cost will be kept artificially low. Nonetheless, additional work is needed to refine this initial SDS calculation and further investigate how producer-level subsidies impact consumer-level consumption.

Additionally, future research on the SCS is needed to investigate temporal ordering and help to establish causality using longitudinal cohort data and examine how changing agricultural policy and subsidy structures might impact consumption patterns and in turn, health. Existing datasets that could be utilized for the longitudinal data analyses include: the Harvard cohorts (Nurses' Health Study, Nurses' Health Study II, and the Health Professionals Follow-up Study), CARDIA to explore effects in specific age groups, and the MESA (Multi-ethnic Study of Atherosclerosis) and ARIC (Atherosclerosis Risk in Communities) studies to explore effects in ethnic subgroups. This could help to address and clarify the individualistic fallacy (ie, that an individual's health outcomes are solely the result of an individual's health behaviors. Further information about how agricultural policy influences food security is also needed. While we found an insufficient global supply of fruits and vegetables, the next two questions to ask are: (1) could we produce enough fruits and vegetables, and what would it take? and (2) what should the entire food supply look like in 25 and 50 years out to address optimal nutrition needs (including both under nutrition and over nutrition) for all? Additionally, the current analysis did not take national and international fruit and vegetable subsidies into account; future studies could look into how subsidies play a role in whether a country/region produces sufficient fruits and vegetables, as well as how post-harvest losses of fruits and vegetables might be eliminated, or at least reduced. Issues of food justice also arise, particularly when considering how a country's supply of fruits and vegetables might change before and after taking into account imported and exported fruits and vegetables; lower-income countries tend to have net exportation, while higher-income countries tend to have net importation of fruits and vegetables. Lastly, collaborative qualitative work with farmers is needed to understand barriers and incentives for growing different (healthier) crops. This includes the stress that climate change may place on agricultural systems and the need to better price foods proportionate to their health and environmental footprints – and align policies and subsidies accordingly [123, 172, 173].

Chapter 8 - References

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