LOW CALORIE- AND CALORIC-SWEETENERS: DIET QUALITY, FOOD INTAKE AND PURCHASE PATTERNS OF U.S. HOUSEHOLD CONSUMERS

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A dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Nutrition, Gillings School of Global Public Health.

Chapel Hill
2013

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Abstract

CARMEN M. PIERNAS SANCHEZ: Low Calorie- and Caloric-Sweeteners: Diet Quality, Food Intake and Purchase Patterns of U.S. Household Consumers
(Under the direction of Barry M. Popkin)

Although most food and beverage products consumed in the U.S. contain caloric-sweeteners (CS), consumption of low calorie sweeteners (LCS) such as aspartame, saccharin or stevia in foods and beverages has increased rapidly over the past 30 years. However, there is limited knowledge about the long-term determinants and consequences of LCS and CS consumption. This dissertation aimed to specifically examine consumption of products containing LCS and CS over the last decade and investigate the dietary quality and food patterns of consumers in the U.S. This research used measures of foods as purchased from the Homescan dataset 2000-2010, and dietary intake data from the National Health and Nutrition Examination Surveys (NHANES) 2003-2010. Aim 1 implemented an innovative approach based on ingredient and nutrition facts panel information to identify sweeteners in food products. Coincident with declining purchases and consumption of CS products over the last decade, we documented an important increasing trend in products containing LCS and a previously unexplored trend in products with both LCS and CS, especially important among households with children. In aim 2, we examined the dietary quality and food patterns of consumers of beverages with LCS and CS from 2000-10. Compared to non/low consumers of LCS- and CS-beverages, consumers had a significantly lower probability of adherence to a "Prudent" dietary pattern and higher average energy from purchases or intake of high calorie food groups such as salty snacks, fast food meals or desserts. LCS-beverage consumers also followed another different pattern of purchases consisting in fruits, vegetables, nuts and also snacks and desserts. Aim 3 used a dynamic panel model and instrumental variables to investigate the long-term effect of CS- and LCS-beverages on dietary quality and food purchasing patterns from 2000-2010. Despite overall declines in calories from all sources, we found that increasing one daily serving of either CS- or LCS-beverages is associated with significantly increased total daily energy, energy from food, and also increased daily energy from carbohydrates, total sugar, and total fat. We also found that increasing one serving of either beverage per day was mainly associated with increased purchases of caloric desserts and sweeteners. In conclusion, as consumers appear to be turning to LCS for their sweet options, our study opens up new pathways that relate consumption of both LCS- and CS-beverages to poorer dietary patterns

and increased purchases of overall energy, carbohydrates, sugar, and caloric desserts and sweeteners. It is essential to understand if sweetener consumption translates into a better or worse dietary quality before continuing with more complex studies that relate sweetener intake to health outcomes. Our findings suggest that any type of sweetened beverage consumption could have a negative effect on diet, which can potentially inform future intervention strategies and nutrition policy recommendations aimed at improving diet and nutrition in the U.S.

Dedication

To my advisor Barry Popkin, who helped me and guided me throughout my entire stay in the U.S. I learned from him to be productive and not be afraid of taking risks. He has an incredible way to look at the big picture of anything and know if something is important in seconds. He opened up his research group to me and gave me all kinds of resources to be successful. Most importantly, he trusted me in all circumstances, from speaking to the media and newspapers to giving an oral presentation. During these 4 years, he was always there to provide fast guidance and help. I would also like to acknowledge my dissertation committee, Shu Wen Ng, Michelle A Mendez, Penny Gordon Larsen and David Guilkey. They all have been very helpful and have spent a lot of time reviewing my work. Shu Wen has been much more than a committee member and I will miss her a lot. I met her when she was finishing her dissertation and she has been always there to listen to me and help me in any ways. Shu Wen is that kind of person that anybody wants to have in their research team.

I also want to thank many other fellows from the UNC Food Research Program. First, Phil Bardsley, who taught me everything that I know about Stata. He had an incredible patience to listen to me and understand what I wanted. Donna Miles was a crucial person in my dissertation research. She helped creating all my datasets and I will always be grateful for all her time and effort. I would also like to thank the rest of the UNCFRP team, especially to Meghan Slining, Emily Ford, Dan Blanchette (in memoriam) and Izabela Annis. Finally, I thank my fellow students, Jennifer Poti, Kevin Mathias, Chris Ford, Dalia Stern, Lindsey Smith and Lauren Butler. I will miss them all because each of them have taught me something unique and important.

To my “Tres Morenas”, Carolina Batis, Niha Zubair and Lee Kaye. They have demonstrated me how good friends they are. Together, we traveled, we laughed, we cried, etc… but most importantly, we trusted and supported each other, and that is something that I will always remember from them. Also, I would like to remember all the other students that I have met during the program, especially to Amanda, Beth Widen, Heather Paich, Verne, and Justin.

To my Spanish group in Chapel Hill. They have been my family over these 5 years. Each of them have had a unique role in the group, but each of them always offered me support and friendship.

They made life after work funnier and fuller. I already miss them all.

To my parents and the rest of my family, including my brother, my grandparents and my in laws. My family is the core of my life. Everything I do is for them. They are always present in any aspect of my life because with them all of this make sense. My parents not only gave me the best education but have been role models for me in every aspect of life. Also, I would like to thank my best friends, especially to Puri, with which I started being a scientist. She has been supporting me from distance and I will never forget all the good moments together.

To Jose, my husband. He has been there in every single second of my life during this dissertation. He continues teaching me every day and offering me all his kindness and support. He understood any problem I had and was always willing to sacrifice anything for me. I am grateful for his never ending love.

To anyone else that made this dissertation possible.

Thanks.

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List of Abbreviations and Symbols

BMI	Body mass index
CPG	Consumer packaged goods
CS	Caloric sweeteners
FDA	Food and Drug Administration
LCS	Low-calorie sweeteners
NFP	Nutrition Facts Panel
NHANES	National Health and Nutrition Examination Surveys
RTE	Ready to eat
UPC	Universal Product Code
USDA	U.S. Department of Agriculture

Chapter 1. Introduction

Background

Coincident with the rising incidence of obesity, type 2 diabetes and metabolic syndrome in the United States, consumption of low-calorie sweeteners (LCS) have increased. While intake of caloric sweeteners (CS) in general and CS-beverages in particular is commonly associated with poor health outcomes, the association between LCS consumption and the risk of obesity and cardio-metabolic problems still remains under great controversy.

Several biological mechanisms have been hypothesized to link LCS consumption to increased energy, carbohydrate, sugar intake and poor dietary quality. Behaviorally, consumption of LCS products could be linked to higher intake of calories or larger portion sizes motivated by the general perception that these “diet” products are lower in calories and sugar; hence allowing consumers to offset these beverages with less healthful foods. Dietary patterns may be one pathway linking LCS and CS consumption to health outcomes, but little is known about actual patterns of sweetener use – both LCS and CS – as well as determinants and consequences of these patterns.

Moreover, LCS consumption has typically been poorly assessed because of the lack of standardized ways to determine the presence of sweeteners in food products, partly due to the lack of access to product ingredient lists, as well as the lack of awareness of the presence of LCS, CS or both sweeteners in food products as self-reported by participants. Using measures of food purchases and measures of food consumption in U.S. adults, we aimed to investigate if consumption of LCS and CS is associated with lower nutritional quality and poorer dietary patterns.

The Nielsen's Homescan Consumer Panel Dataset is a unique longitudinal dataset of prospective commercial measures on store purchases at the household level. We analyzed data on more than 600,000 scanned foods and beverages purchased from grocery, drug, mass-merchandise, club, supercenter and convenience stores in a nationally representative sample of U.S. households from 2000 to 2010. The Homescan dataset has been linked with updated Nutrition Facts Panel data and ingredients lists from Gladson and other sources to precisely identify the inclusion of LCS and CS in consumer packaged goods (CPG) products in the U.S. market. Homescan contains data on all foods purchased yearly by over 60,000 households per year, each followed for at least one year, and up to ten years. We also studied dietary intake data (at home and away from home intake) from the National Health and Nutrition Examination

Surveys (NHANES) 2003-2010, to better identify patterns of actual consumption of products containing LCS and CS in the U.S.

Research Aims

Aim 1. Describe trends in purchases and intake of products containing LCS and CS over the last decade in the U.S.:

1a. We categorized all products (foods and beverages) by sweetener type (LCS only, CS only, both LCS and CS or neither sweetener) and identified all sources of sweeteners in the U.S. using household-level purchases from Homescan 2000-2010 (store products) and individual-level dietary intake from NHANES 2003-2010 (store and away from home products). We estimated per capita and per consumer trends in purchases (Homescan, 2000-2010) and intake (NHANES, 2003-2010) of beverages and foods containing LCS and CS.

1b. We explored the longitudinal associations between patterns of purchases of LCS and CS-foods and beverages and household characteristics (i.e. age, gender, race/ethnicity, SES, household size) in Homescan, 2000-2010.

Aim 2. Characterize the dietary quality, food intake and purchasing patterns of LCS- and CS-beverage consumers:

2a. We developed a food grouping system that includes equivalent food and beverage groups between Homescan and NHANES. Then we investigated the association between dietary intake patterns (NHANES, 2003-2010) and food purchasing patterns (Homescan, 2000-2010) and the different profiles of consumption of LCS and CS-beverages. We performed factor analyses to find data-driven dietary patterns in each dataset individually. We used longitudinal measures of food purchases from Homescan to derive factor scores and create long term dietary patterns to investigate if beverage consumers tracked on a certain dietary pattern over time.

Aim 3. Investigate the effect of LCS- and CS-beverage purchases on dietary quality and food purchasing patterns over time:

3a. Using Homescan (2000-2010), we investigated the longitudinal associations between purchases of CS- and LCS-beverages and dietary quality using a dynamic panel model and instrumental variables. Dietary quality was modeled as the outcome variable and was defined using continuous measures of energy intake, macronutrients and foods and beverage groups.

Chapter 2. Literature review

The relationship between low-calorie sweetener consumption and health outcomes is unclear

Obesity and other cardio-metabolic risks are major public health concerns in the United States [1-3]. Increased energy intake, and particularly higher intake of energy-dense foods are current behaviors that have been related to these chronic diseases [4-8]. In this context, artificial or low-calorie sweeteners (LCS) have gained attention as dietary tools that help reduce the sugar and energy content of foods and beverages while maintaining their sweet taste [9, 10]. Different types of LCS are currently approved by the U.S. Food and Drug Administration (FDA), such as saccharin, sucralose, aspartame, acesulfame K, neotame and stevia. Currently the American Diabetes Association and the American Heart Association among others recommend the use of LCS as means to reduce sugar and energy intake for those with diabetes and/or trying to lose weight [11]. While intake of caloric sweeteners (CS) in general and CS-beverages in particular is commonly associated with poor health outcomes [12], the benefit of consuming LCS on energy balance and metabolic health is still questioned by many [9, 13-17]. The newly released USDA Dietary Guidelines for Americans 2010 did not state a specific recommendation for LCS use, but affirmed that "replacing added sugars with non-caloric sweeteners may reduce calorie intake in the short-term, yet questions remain about their effectiveness as a weight management strategy"[18].

The relationship between LCS, energy intake and obesity has been investigated previously in large epidemiologic studies and randomized trials yielding conflicting results. Previous short-term trials in adults have shown a positive relationship between LCS consumption and appetite and increased energy intake compared to non LCS consumers [16, 19-21]. However, subsequent randomized control trials and crossover trials found no association with self-reported hunger and satiety and reported beneficial effects of LCS consumption on energy intake, weight loss and weight maintenance [22-30]. Most of these conflicting studies are short-term trials performed under laboratory conditions using different vehicles for LCS such as foods, beverages, capsules or supplements. In large epidemiologic studies involving adults, a positive effect of LCS consumption on weight reduction was found in the Nurses' Health Study II [31]; whereas the San Antonio Heart Study and other longitudinal studies showed a positive association between LCS use and body mass index (BMI) [32] and cardio-metabolic risk [33-35]. These contradictory long-term cohort studies did not take into account the mediating effect of diet. As consumers appear to be increasingly turning to LCS use [9], a better understanding of the effect of sweetener consumption on dietary quality and dietary patterns is needed before a policy recommendation can be issued.

Dietary patterns potentially mediate the relationship between LCS and energy intake and obesity

Dietary patterns associated with consumption of LCS are potential intermediates in the causal pathway between LCS and energy intake, obesity and cardio-metabolic outcomes (CM), but very few studies have explored dietary habits in this context [36, 37]. In addition, none of these studies actually controlled for individual preferences, when for instance, LCS consumption might reflect an enhanced sweetness inclination [38]. Previous research found that the greater the sweetness of a product, as a consequence of a higher amount of added sweetener, the higher the consumption of sweet foods or beverages [39]. In this context, sweetness preference has been found to be equally influenced by both CS and LCS [40]. Also, repeated exposure to LCS uncoupled with energy can modify the natural relationship between sweet taste and energy and has been hypothesized to affect appetite and energy intake by disrupting hormonal and neurobehavioral pathways that control hunger and satiety [16, 41-44].

Consuming LCS products could be associated with increased consumption of other sweet foods in the short term, which could translate into a set of behaviors that potentially affect diet in the long-term towards a lower dietary quality, higher energy intake and obesity. Dietary intake is also influenced by the important mechanisms and behaviors involved in food selection and food choices. Behaviorally, consumption of LCS products could be linked to higher intake of calories or larger portion sizes motivated by the general perception that these "diet" products are lower in calories and sugar; hence allowing consumers to offset these beverages with less healthful foods. Unraveling the physiological and psychological causes and consequences of LCS consumption was not possible with this study. However, this epidemiological longitudinal exploration examined if consumption of LCS and CS in foods and beverages was associated with higher or lower dietary quality in the long term. In this study, many other unmeasured individual characteristics that affect food selection and choices were adequately controlled.

Longitudinal observational data is needed to understand long-term dietary patterns

To date, only two long-term studies have investigated LCS and dietary patterns longitudinally [37, 45], but none of these included a representative sample of the U.S. population and both used measures of LCS and dietary intake from the mid-80s. Most research on overall diet patterns in the U.S. included cross-sectional data from national surveys, i.e. National Health and Nutrition Examination Surveys (NHANES), which collected dietary intake using short-term recalls or food-frequency questionnaires [46, 47]. These sources of dietary information do not capture usual intake or further dynamics of consumption. To date, no studies have explored patterns of LCS and CS consumption and the long-term dietary patterns associated with sweetener use. The Homescan Consumer Panel is a unique set of prospective commercial measures of food purchases at the household level collected by the Nielsen Co. This data set includes current information about each episode of purchases by participating households, from 2000 to 2010, along with important socio-demographic and environmental information for about 60,000 households per year in the U.S.

Identification of sweeteners in foods and beverages in the U.S. marketplace is challenging

Consumption of LCS-sweetened foods or beverages is increasing in the U.S. [9], a trend that will continue rising as manufacturers attempt to reduce the energy density of foods products [48]. Then, identification and categorization of LCS in the marketplace is critical. However, since LCS use is approved by the Food and Drug Administration (FDA), producers and manufacturers do not provide information about LCS content on labels, making obtaining accurate and direct measures of the LCS concentration in the food supply very challenging. An important limitation of both national surveys and Homescan is that none of the main primary food-composition tables include information on the exact amount of sweetener in products. Furthermore, the implementation of national policies and industry efforts to reformulate and reduce the energy density of products increases the need for more comprehensive nutrient databases capable to capture newly introduced or reformulated products in the U.S. market. Due to several constraints, the USDA food composition tables are not updated frequently enough to capture the rapidly occurring changes in the food supply. For example, in a two-year period, NHANES can capture consumption of about 5,000 unique foods, whereas U.S. consumers purchase over 170,000 products with unique formulations [48]. Consequently, dietary intake collected by NHANES might not be representative of the vast variety of foods sold commercially. As a consequence of the lack of a standardized way to quantify the amount of sweetener in products in the U.S. markets and because beverages are the main sources of intake of sweeteners and easier to classify [9], most research is focused on LCS- and CS-beverages [31, 32, 37, 45]. Very few studies have focused on overall LCS or CS consumption [9, 49, 50] and none has been able to identify LCS and CS in mixtures. Most studies identified any sweetened product from previous studies or by searching the food description and linking them with nutrition composition [9, 31, 32, 37, 45, 49, 50]. These previous definitions were not taking into account that some products might contain LCS but might not be advertised as “diet” or “low-calorie”. By using Homescan and Nutrition Facts Panel (NFP) data, we were able to improve the definition and classification of products containing LCS and CS by using ingredient lists and other label information available to identify LCS- and CS-products. We used NFP data and ingredient information of each uniquely bar-coded product, information provided by the commercial Gladson Nutrition Database and other databases (i.e. Mintel GNPD). A unique Universal Product Code (UPC) is assigned to each food product to track retail sales and purchases. Gladson contains information on U.S. brands and private label processed and packaged food products and includes around 170,000 uniquely formulated UPCs and full lists of ingredients, brand name and descriptions on each label. Gladson NFP data is updated frequently to capture new products and/or reformulations.

Consumer awareness might affect sweetener consumption and dietary patterns

Consumer awareness is another important issue to consider when studying this topic [51, 52]. For example, those concerned about sugar content and energy intake will most likely look for products labeled as “sugar free” or “low sugar”. However, there are new or reformulated products that contain LCS in combination with CS (i.e. products that substitute part of the sugars with LCS) that are currently being introduced by the industry in their push to reduce calories and added sugars. Some of these products might not be advertised as “sugar free” or “low sugar” and consumers probably don’t know that they are consuming LCS. Our focus is on consumers who know they are consuming products advertised as “low sugar/calorie” and truly contain LCS. However, even if we include products marketed as “diet”, we are still assuming that consumers are aware of the presence of LCS in those products.

Studying measures of foods as purchased (Homescan) and foods as consumed (NHANES)

Data from two different datasets, Homescan and NHANES, was included in the present research. The ultimate goal was not to combine both datasets but rather to complement each other flaws. Each dataset offers different sources of information given the nature of their design and the purpose for which they were created. In relation to our aims, the main advantage of Homescan is that all products containing sweeteners were easily classified by searching in the ingredient lists and label claims. NHANES does not include ingredient lists for their food categories and the only way to ascertain the presence of LCS and CS in a product is by looking at each food description. At the most, if the person reporting his/her intake actually knows it's an LCS product, we could only know if it was "sweetened with a low calorie sweetener", but not if the product contained LCS only or in addition to CS. Homescan also includes at least 10 months of purchasing data per household whereas NHANES collects 2 days maximum of intake, being Homescan a better proxy for usual diet. Also, Homescan might be less affected by recall bias and/or misreporting compared to NHANES, although we expected some degree of misreporting given the burden of time required to scan all purchases. Finally, Homescan is a longitudinal dataset that allowed us to explore the associations of sweetener use on overall diet patterning. On the other hand, NHANES collects actual consumption of products whereas Homescan does not account for wastage, storage or sharing of foods (purchases are not exactly consumption) and does not allocate specific amounts of foods to each member of the household. NHANES captures all sources of consumption whereas Homescan only captures consumption from stores, missing away from home eating.

Chapter 3. Trends in purchases and intake of foods and beverages containing caloric- and low-calorie sweeteners over the last decade in the U.S.

Overview

Current food databases might not capture rapidly occurring changes in the food supply, such as the increased use of caloric (CS) and low-calorie sweeteners (LCS) in products. We explored trends in purchases and intake of foods and beverages containing LCS, CS or both sweeteners over the last decade in the U.S., as well as household and SES predictors of these trends. We analyzed household purchases from Homescan 2000-10 (n=140,352 households; 408,458 individuals); and dietary intake from NHANES 2003-10 (n=34,391 individuals). We estimated per-capita purchases and intake (g or mL/d) and percent of consumers of foods and beverages containing LCS, CS, or both LCS+CS. We estimated change in purchases associated with SES and household composition using random-effects longitudinal models.

From 2000-10, percent of households purchasing CS products decreased, whereas for LCS and LCS+CS products increased among all types of households and particularly among those with children. African-American, Hispanic, and households with children had a higher % CS beverage purchases (+9%; +4%; +3% respectively, P<0.001) and lower % LCS beverage purchases (-12%; -5%; -2% respectively, P<0.001). In summary, during a period of declining purchases and consumption of CS products, we have documented an increasing trend in products that contain LCS and a previously unexplored trend in products with both LCS and CS, especially important among households with children.

Introduction

The consumption of food and beverages containing added caloric sweeteners (CS) have been systematically linked with weight gain among adults and children [14, 33, 34, 53-55]. At the same time, many still question if low calorie sweeteners (LCS) are a good option for weight and diabetes control [56, 57]. Overall, the majority of food and beverage products consumed in the U.S. contain CS [58]. However, consumption of LCS in foods and beverages has increased rapidly over the past 30 years [9, 58-61], a trend that will continue rising after the implementation of national policies and industry efforts that encourage manufacturers to reformulate and reduce the energy density of food products [62]. In this context, nutrition research needs far more comprehensive nutrient databases capable of capturing newly introduced or reformulated products in the U.S. marketplace [63]. Since LCS use is approved by the Food and Drug Administration, producers and manufacturers do not provide information about LCS content on labels, so obtaining accurate and direct measures of the LCS concentration in the food supply is problematic. On the other hand, the USDA food composition tables are not updated frequently enough to capture the rapidly occurring changes in the food supply [62]. In each two-year wave, the National Health and Nutrition Examination Surveys (NHANES) food databases can only capture consumption of about 7,600 unique foods, out of over 85,000 products with unique formulations that U.S. consumers currently purchase [60]. As a consequence of the lack of a standardized way of quantifying the exact amount of LCS in products, most research is focused on consumption of LCS beverages [31, 32, 36, 37] . Very few studies have explored consumption of LCS in foods [9, 59] and none have been able to identify products that contain both LCS and CS.

This study explores trends in purchases and intake of foods and beverages that contain LCS, CS and both sweeteners over the last decade. We analyze prospective measures of purchases by households included in the Nielsen Homescan Longitudinal dataset from 2000-10 [64]. Homescan captures unique food products that have barcodes or Universal Product Codes (UPC) assigned to track retail sales and purchases of U.S. brands and private label packaged food products for more than 600,000 UPCs that are sold every year in the U.S. Products containing LCS and CS were identified by searching on the ingredient list from the nutrition facts panel of each uniquely barcoded product, which also contains updated and complete measures of the nutritional content of the purchased products [65]. We estimated per-capita purchases (g or mL/d) and percent of households purchasing foods and beverages containing LCS, CS or both LCS and CS. In addition, we examined the demographic characteristics of households with different patterns of sweetener use. Finally, we used individual-level dietary intake in NHANES 2003-10 to estimate trends in intake per capita and percent consumers of foods and beverages containing LCS or CS.

Methods

Sample

This study uses data on food purchases from the Nielsen Homescan (The Nielsen Co.) from 2000-2010; and data on food consumption from the U.S. Department of Agriculture (USDA) National Health and Nutrition Examination Survey (NHANES) from 2003-2010 (both described below). We included these two U.S. nationally representative datasets to investigate consumption of sweeteners from different perspectives, from sales to actual intake of products that contain sweeteners.

Primary Measure

Identification and classification of foods and beverages with sweeteners

Low calorie sweeteners (LCS) could be derived from natural (i.e., sugar alcohols, stevia) or artificial (i.e., aspartame, saccharine) sources. For the purpose of this research, LCS are defined as food additives that provide <3.8 kcal/g and/or are used in very low quantities so that the caloric amount they provide is negligible. All other sweeteners that provide ≥3.8 kcal/g are considered as caloric sweeteners (CS) as this cut-point reflects the caloric value of a gram of carbohydrate. Because the exact amounts of low-calorie sweeteners (LCS) in particular food products are not readily accessible, we studied LCS and CS consumption using information of purchases and intake of foods and beverages containing these sweeteners. To separate specific products by sweetener type in each dataset, we screened all groups of foods and beverages that were found in previous research to contain added sweeteners [58], which include dairy, grains, desserts, dressings, processed fruits, snacks, discretionary sweeteners, soft drinks, juice/fruit drinks, coffee/tea and milk beverages.

Study design and population

1) Food purchase data: The Nielsen Homescan Consumer Panel.

We selected households with adults and children from the Nielsen Homescan (The Nielsen Co.) [64] from 2000-2010 (n=140,352 unique households comprised of 408,458 individuals), an ongoing nationally representative longitudinal survey of 35,000 to 60,000 households per year that contains information on consumer purchases of consumer packaged food items at the Universal Product Code (UPC) level. Participating households are provided with home scanners with which they record yearly food purchases from grocery, drug, mass-merchandise, club, supercenter and convenience stores. Households also report socio-demographic (SES) and household information including gender and age of each family member, income, education and race/ethnicity of the main head of the household. Households included in Homescan are sampled and weighted to be nationally representative. The Homescan dataset has been used frequently by researchers to analyze food demand, consumption and sale strategies[60, 66, 67].

Each uniquely barcoded product captured in Homescan has been linked with Nutrition Facts Panel (NFP) data and ingredient information using the commercial Gladson Nutrition Database [65]. Gladson contains national brands and private label items at the UPC level and these data are updated weekly as new products enter the market. Further details regarding matching these commercial datasets at the UPC level, and other methodological facts are available in the following sources [58, 60, 62]. To ensure comparability across products, we applied weighted factors to those items sold as concentrates (e.g., beverage powders) to reflect the volume of the product in the "ready to drink/eat" form.

We classified products containing sweeteners in Homescan 2000-2010. For each food/beverage group, we conducted keyword searches by looking at the ingredient lists provided for each UPC purchased by participating households. A detailed list of key terms is available elsewhere[58]. Briefly, the main sweeteners identified as CS included fruit juice concentrate (not reconstituted), cane sugar, beet sugar, sucrose, corn syrup, high fructose corn syrup, agave-based sweeteners, honey, molasses, maple, sorghum/malt/maltose, rice syrup, fructose, lactose, inverted sugars; terms to identify LCS included artificial sweetener, aspartame, saccharin, sucralose, cyclamate, acesulfame K, stevia, sugar alcohols (i.e. xylitol, etc.) and brand name versions of each sweetener. Foods and beverages were then classified as containing CS only; LCS only; or both LCS+CS.

Classically, consumers are defined as persons who reported any consumption greater than 0 g or mL on any given day, usually over a 24-h period [61, 68, 69]. However, for each household Homescan captures purchases over an entire year. To define a consumer in a meaningful way and exclude unusual or one-time purchases, we divided the total purchases per year by pre-defined portions: 100 mL for beverages and 50 g for foods. For the purpose of this research, a household was considered a consumer in Homescan if it had purchases of at least 52 portions per year, or one portion per week.

2) Dietary intake data: The National Health and Nutrition Examination Surveys (NHANES).

We selected adults and children (n=34,391) who participated in one of the four waves of the U.S. Department of Agriculture (USDA) National Health and Nutrition Examination Survey (NHANES) from 2003-2010: NHANES 2003-04 (n=8,272), NHANES 2005-06 (n=8,549), NHANES 2007-08 (n=8,528) and NHANES 2009-10 (n=9,042). These nationally representative surveys are based on self-weighting, multistage and stratified probability samples of non-institutionalized U.S. households. Dietary intake data is collected using two non-consecutive 24-h recalls. The NHANES surveys implemented a fully automated, computer-assisted multiple-pass dietary recall methodology that involves a 5-step process to reduce underreporting of diet. Dietary intake data is linked to the USDA food composition tables, which provide nutrient information and food descriptions for each food item consumed by the participants. Socio-demographic information, such as age, gender, race/ethnicity and income is also collected for each participant. Further details of each of these surveys are available elsewhere [46, 47, 66, 67, 70, 71].

We classified foods and beverages containing sweeteners in NHANES 2003-2010. Consistent with previous work [59], we conducted keyword searches by looking at the food description of each food-code that represents a specific food or beverage consumed. We classified items as LCS-products if their food description included the following terms: "with low/no calorie sweetener", "sugar-free" and "dietetic/low sugar". Items that included terms such as "sugar", "sweetened" or didn't specify the type of sweetener but are typically sweetened (i.e. soft-drink, cola-type) were considered CS-products. Foods and beverages were classified as LCS-foods; LCS-beverages; CS-foods and CS-beverages. Products that contain both LCS and CS cannot be separated in NHANES.

Consumers in NHANES were defined as those who consumed at least one pre-defined portion over the 24-h recalled (100 mL for beverages and 50 g for foods). Together with dietary intake, information on where the foods or beverages were consumed is provided by each individual. Information on location of consumption was used to estimate intake from store-bought foods in addition to total intake.

Statistical Analysis

All analyses were performed using Stata 12 (StataCorp, Stata Statistical Software, Release 12, 2011). Survey commands were used to account for survey design and weighting to generate nationally representative results. In both datasets, race/ethnicity was used to classify participants as Hispanic, non-Hispanic White, non-Hispanic African-American and Others. Age was used to generate age groups: 2-6 y-old; 7-12 y-old; 13-18 y-old; 19-39 y-old; 40-59 y-old and >60 y-old. The ratio of family income to poverty threshold, calculated from self-reported household income, was used to categorize income according to the percent of the poverty level: "Lower income, <185%", "Middle income, ≥185-<400%" and "Higher income, ≥400%".

In Homescan, we used estimates of total purchases per year to estimate total volume purchased per day (mL/day for beverages; gr/day for foods) by a household. Then, the total purchases of each household were divided by the number of people in the household to get a per capita estimate of purchases. We also estimated the percent of households purchasing foods and beverages by sweetener type. Then, we estimated trends in per-capita and percent of consumers using measures of intake per day (mL/day for beverages; gr/day for foods) in NHANES. Since Homescan includes measures of store purchases, some of the estimates from NHANES are reported as total intake and also as consumption from store and away-from-home products. Estimates of trends in per capita and percent of consumers were obtained using multivariable simple linear and logistic regression models to adjust for household size, race and income (Homescan) and age, gender, race and income (NHANES).

We also investigated SES and household predictors of purchases of products with CS and LCS in Homescan. We estimated change in percent of purchases of each type of food or beverage associated with SES and household variables using average marginal effects from random-effects longitudinal regression models. To control for differences in total spending across households with different grocery expenditures and sizes, the outcomes for these models were defined as the percent of volume purchased (mL or g) from each type of product respect to the total purchases of that category (i.e., volume from LCS beverages divided by total volume from all beverages). As exposures, we modeled changes with time, presence of different family members by age and gender, presence of children, race/ethnicity, income, and the following interactions: race/ethnicity and presence of children; race/ethnicity and income. For NHANES, we calculated per capita daily intake and the difference in percent intake of CS and LCS products by race/ethnic group. Estimates are presented as means (95% CI) or *β* coefficients (96% CI). Statistically significant linear trends were tested using adjusted Wald test. Statistically significant differences were tested using Student's *t* test. A two sided *P* value of 0.001 was set to denote statistical significance for Homescan and 0.05 for NHANES due to the sample sizes available.

Results

Both the Homescan and the NHANES samples had a higher proportion of adults, females and non-Hispanic Whites (Table 3.1). In Homescan, there was a higher proportion of 40-59-y-olds and middle income individuals whereas in NHANES there was a higher proportion of 19-39-y-olds and higher income individuals.

Sources of LCS and CS in the US

In the most recent period (2007-10), beverages were the main sources of LCS in terms of volume compared to foods (Figure 3.1a-b). Volume (mL/d) of LCS beverages represented 32% of all beverages among adults and 19% among children. Purchases of beverages containing LCS only represented around 26% of all beverage purchases whereas those containing both LCS and CS represented around 15%. Results for both foods and beverages are shown (Supplemental Tables 3.1-3.4), but we focus on presentation of the beverage results.

Trends in purchases and intake of LCS and CS products

While the percent of households that purchase beverages containing CS decreased slightly, purchases of beverages with LCS only and LCS+CS increased from 2000 to 2010 significantly among households with and without children (Figures 3.2a-b, Supplemental table 3.1). Per capita volume (mL/day) purchased from CS beverages decreased significantly over this period (Figures 3.2a-b, Supplemental table 3.1). Per capita volume purchased from LCS beverages increased from 2000 to 2006 and then decreased from 2006 to 2010, for LCS+CS beverages increased gradually from 2000 to 2010. Although the percentage point changes are smaller, the trends for beverages and foods were similar (Supplemental table 3.1).

Percent of consumers and per capita intake of beverages containing LCS increased significantly whereas intake of CS beverages decreased significantly among children/adolescents (store and total) and adults (total) from 2003-2010 (Figures 3.3a-b, Supplemental table 3.2).

Household and SES predictors of purchases of LCS and CS products

Using random-effects longitudinal models, we investigated household and SES factors associated with changes in purchases of beverages and foods with LCS, CS and both LCS+CS in Homescan 2000-10 (Table 3.2, Supplemental tables 3.3-3.4). Percent of purchases of CS beverages was significantly higher among households with children, particularly in households with at least one an adolescent male; among households with young and middle age adults; among African-American and Hispanic compared to White households and among lower income households. Percent of purchases of LCS beverages was significantly lower among households with children and African-

American and Hispanic compared to White households, and significantly higher among higher income households. Percent of purchases of LCS+CS beverages was slightly higher among households with adult females, among White households compared to the other ethnic groups and among higher income households. Similar results were observed between different races within households that had or not children; and within households of different income categories (Supplemental table 3.3). Changes in foods containing sweeteners were smaller but consistent with the changes in beverage purchases associated with race and presence of children in the household (Supplemental table 3.4).

In NHANES, intake per capita (total and from stores) and the difference in percent intake of LCS beverages was significantly higher in White children and adults compared to the other races (Table 3.3). Intake per capita (total and store) of CS beverages was significantly higher among White and African-American adults compared to the other races; but not different between White, African-American and Hispanic children. In addition, the difference in percent intake of CS beverages was significantly higher among African-American children and adults.

Discussion

Using measures of purchases and intakes from nationally representative samples of U.S. households, we have investigated recent trends in purchases and consumption of products containing LCS, CS or both sweeteners. Ingredient information from each barcoded product consumed by U.S. households was used to create a novel system of identification of sweeteners in the food supply. We showed a previously unexplored trend in consumption of products containing both LCS and CS. Over the last decade, although purchases and intakes of CS foods and beverages continued to decline, they remained high, whereas purchases and intakes of products containing LCS or both LCS+CS rose among all types of households.

In terms of volume, beverages were the main source of LCS in the food supply, accounting for up to a third of the beverages that are currently consumed and purchased in the U.S. Previous research investigated the use of CS and LCS in consumer packaged goods in the U.S. [58]. Around two thirds of all uniquely formulated products consumed in the U.S. contained CS, whereas a smaller percent of products contained either LCS only or both LCS+CS, which are mainly beverages. We found that an increasing percent of households purchased beverages with LCS only or LCS+CS. The trend in LCS+CS beverages increased more markedly among household with children and even exceeded the trend in LCS beverages after 2006. Still, purchases of CS beverages were higher than LCS or LCS+CS in 2010. In NHANES, the percent of consumers (adults and children) increased for

LCS products but decreased for CS products from 2003-2010. Per capita purchases in Homescan decreased for CS beverages but increased for LCS and LCS+CS beverages. Trends in per capita intake decreased for CS beverages but increased for LCS beverages only among children. Recent reports using national surveys have shown similar trends in percent of adults and children consuming beverages or foods containing LCS and CS [59, 61, 72-75].

We also investigated household and SES factors associated with changes in purchases of beverages and foods with LCS, CS and both LCS+CS. Among African-American, Hispanic and households with children, we found a higher percent of CS purchases but lower percent of LCS beverage purchases. Higher income was associated with lower CS but higher percent of LCS beverage purchases. Changes in purchases of LCS+CS were very small, and only associated with presence of adult females and higher income households. In terms of intake, Whites consumed overall more LCS products than other race groups (total and consumption from stores). Consistent with our results, previous works reported a higher prevalence and per capita consumption of LCS foods and beverages among Whites and higher income individuals [59, 61, 76, 77]; but a higher prevalence and per capita consumption of CS beverages among children, males, African-Americans, Hispanics and lower income individuals [59, 68, 76-79]. Although we found significant increases in products containing LCS and LCS+CS among households with children; households with children had a higher percent of purchases of CS beverages but lower percent of purchases of LCS and LCS+CS beverages. This might be due to the fact that the actual amount of purchases per capita from LCS and LCS+CS products is still lower than purchases of CS beverages.

Over the period studied, purchases from Homescan and intake from NHANES trended similarly. However, these trends are might not be exactly comparable in absolute terms. Homescan collects all grocery purchases that happened over an entire year; whereas NHANES collects dietary intake reported for the day before the interview, so our definition of consumers reflects the different timing captured by each dataset. In Homescan, we considered consumers as households that purchased at least one standard portion per week; whereas in NHANES a consumer was considered as a respondent with at least one standard portion over the previous 24 hours. Therefore, prevalences of consumption from Homescan are much larger than in NHANES. Interestingly, the trend in percent of households purchasing CS beverages declined very slightly from 2000 to 2010, whereas in NHANES the percent of consumers of CS beverages decreased significantly from 2003 to 2010. These contradicting trends might reflect the different timing captured by each dataset but they could also reflect a potential underreporting in dietary intake data of unhealthier products such as CS beverages. Another source of variation comes from the different identification of products containing sweeteners. To our understanding, the use of ingredients lists to classify products (Homescan) is a more accurate approach than defining them according to their food description (NHANES). Moreover, identification of products that contain both LCS+CS is not currently possible in NHANES.

Food purchasing and expenditure surveys such as Homescan have previously been used to measure household food availability, and although these datasets do not provide measures of individuals' actual intake, they are useful to characterize the wide variability in food consumption patterns at the population level [66, 80-82]. Since Homescan data is self-reported and the recording time-consuming, several reports have investigated the validity of Homescan against retailer's transaction data and diary survey data [83-85]. There is potential for recording errors in Homescan (i.e. missing trips, missing purchases), and although the overall accuracy of the data is consistent with other commonly used economic datasets, this might constitute another source of differences between NHANES and Homescan. Another challenge of using Homescan is that estimates of per capita purchases might not be comparable with per capita intake from NHANES. For example, in a given household all purchases of LCS beverages might be consumed by a single member of the household, rather the being shared among all household members. Then, per capita estimates represent the amount available from all purchases to each member of the household. Another limitation affecting Homescan is that away-from-home intake (i.e. restaurants, school) is not available. In the last period (NHANES 2009-10), non-store sources of intake of LCS and CS foods and beverages accounted for a range of 0 to 30% of total intake (Table 2S). Estimates of store purchases collected by Homescan do not account for sharing, wastage and storage of products, constituting another source of variation between datasets. Finally, although estimates of store purchases are weighted to be nationally representative, questions still remain about potential selection bias in response rates, participation and attrition, resulting in larger samples of middle age/older and middle income households [86].

In the context of the growing interest in the role of CS and LCS in the obesity epidemic [11] and the importance of these factors on weight gain and incident obesity [53-55, 57, 87], we have reported new trends in purchases and intake of foods and beverages that contain CS, LCS and both LCS and CS over the last decade. Although products containing LCS are lower in calories and sugar than their regular counterparts, the effect of LCS on toxicity, glucose metabolism, satiety, sweetness preference and overall dietary quality is unclear [24, 36, 41, 44, 88-94]. Products containing CS are higher in empty calories and CS beverages have been specifically linked to obesity because they have lower satiety rate compared to solid sweetened foods [95]. Although the prevalence of consumption of ≥500 ml per day of CS beverages is still high among in children, adolescent and younger adults [96], recent randomized controlled trials in these age groups have found decreased weight gain, fat accumulation [56, 97] and higher weight loss [98] when CS beverages were replaced with beverages containing LCS. The debate regarding the role of sweeteners in the obesity epidemic still continue despite the fact that most intervention strategies and nutrition policy recommendations in the U.S. are currently focused on caloric beverages [99].

In conclusion, consumption of CS products declined over the past decade, but remained high, especially in households with children, and in African American, Hispanic and lower income households. However, we have shown an increased trend in purchases and intake of foods and beverages that contain LCS. For the first time, we showed an important but previously unexplored trend in purchases of products that contain both LCS and CS, which has been heretofore impossible to document in the NHANES surveys. As new beverages and food choices become available in the food supply, a better understanding of the role of these new varieties of products on energy balance and dietary quality is warranted.

Tables and Figures

Table 3.1. Demographic characteristics of the populations of HOMESCAN (household and per capita purchase data) and NHANES (per capita dietary intake data)*

	HOMESCAN† 2000-2010		NHANES 2003-2010	
Total population				
Individuals	408,458		34,391	
Households	140,352		-	
Children (2-18-y-old) [n (%)]	99,833	(20.4)	13,421	(24.3)
Adults (>19-y-old) [n (%)]	308,625	(79.6)	20,970	(75.7)
Gender **[n (%)]**				
Male	195,007	(48.4)	16,956	(48.6)
Female	213,451	(51.6)	17,435	(51.4)
Race-Ethnicity **[n (%)] ‡**				
White	318,822	(73.4)	14,234	(68.0)
African American	39,005	(11.8)	8,055	(12.2)
Hispanic	32,128	(10.8)	7,949	(9.6)
Other	18,503	(4.0)	4,153	(10.1)
Age Groups **[n (%)]**				
Children 2-6y	27,471	(6.4)	4,041	(7.0)
Children 7-12y	33,985	(7.0)	4,335	(8.4)
Children 13-18y	38,377	(7.1)	5,045	(8.9)
Adults 19-39y	93,797	(29.7)	7,782	(29.5)
Adults 40-59y	141,253	(31.3)	6,284	(28.2)
Adults >60y	73,575	(18.6)	6,904	(18.0)
Income **[n (%)] §**				
Lower income (< 185%))	87,666	(26.3)	15,800	(32.6)
Middle income (≥185% to <400%))	189,167	(39.9)	9,352	(30.4)
Higher income (≥400%)	131,625	(33.8)	9,239	(37.0)

*Sample size (%). Percentage of the population estimated with weights to adjust for unequal probability of sampling.

† For Homescan, the average age and income from 2000-10 were used to create the categories.

‡ Race/ethnicity was self-reported by the head of the household in Homescan or by each participant in the NHANES surveys.

§ Ratio of family income to poverty threshold (calculated from self-reported household income), was used to categorize income according to the percent of the poverty level.

Table 3.2. Change in percent volume (mL/day) purchased from each type of beverage using estimated average marginal effects from random-effects longitudinal regression models, among U.S. households from the Homescan Longitudinal dataset, 2000-2010*.

BEVERAGES	LCS only†				CS only†				LCS and CS			
Predictors		[95%CI]		P value‡		[95%CI]		P value‡		[95%CI]		P value‡
Gender-age categories												
Female												
2-6 y-old	-0.5	-0.8	-0.2	0.002	1.4	1.1	1.8	0.000	-0.3	-0.5	0.0	0.026
7-12 y-old	-0.4	-0.7	-0.2	0.001	0.4	0.1	0.7	0.015	0.3	0.1	0.5	0.002
13-18 y-old	-0.7	-1.0	-0.5	0.000	0.3	-0.1	0.6	0.110	0.2	0.0	0.3	0.134
Male												
2-6 y-old	-0.7	-1.0	-0.4	0.000	1.5	1.1	1.9	0.000	-0.2	-0.5	0.0	0.042
7-12 y-old	-0.7	-1.0	-0.5	0.000	0.8	0.5	1.1	0.000	0.1	-0.1	0.3	0.185
13-18 y-old	-1.6	-1.8	-1.3	0.000	2.0	1.7	2.4	0.000	0.0	-0.2	0.2	0.830
Female												
19-39 y-old	-0.4	-0.6	-0.2	0.000	-0.1	-0.4	0.1	0.318	0.3	0.2	0.4	0.000
40-59 y-old	1.1	0.9	1.3	0.000	-2.2	-2.5	-2.0	0.000	0.6	0.5	0.8	0.000
>60 y-old	1.1	0.8	1.3	0.000	-1.7	-2.0	-1.4	0.000	0.4	0.2	0.5	0.000
Male												
19-39 y-old	-1.8	-2.0	-1.6	0.000	2.6	2.4	2.8	0.000	-0.4	-0.5	-0.3	0.000
40-59 y-old	0.0	-0.2	0.2	0.839	1.3	1.1	1.5	0.000	-0.5	-0.6	-0.3	0.000
>60 y-old	1.0	0.7	1.2	0.000	0.7	0.4	1.0	0.000	-0.6	-0.8	-0.5	0.000
Presence of children												
Presence vs. Absence	-1.8	-2.1	-1.6	0.000	3.0	2.6	3.3	0.000	-0.4	-0.7	-0.2	0.000
Race/ethnicity												
African-American vs. White	-12.0	-12.5	-11.6	0.000	9.3	8.8	9.8	0.000	-0.6	-0.8	-0.3	0.000
Hispanic vs. White	-5.3	-5.8	-4.8	0.000	3.9	3.3	4.5	0.000	-1.0	-1.3	-0.6	0.000
Other vs. White	-5.9	-6.6	-5.3	0.000	5.8	5.0	6.6	0.000	-2.1	-2.5	-1.7	0.000
Income												
Middle vs. Low Income	1.2	1.0	1.3	0.000	-2.0	-2.2	-1.8	0.000	0.4	0.3	0.6	0.000
High vs. Low Income	2.7	2.5	2.9	0.000	-4.6	-4.8	-4.3	0.000	0.9	0.8	1.1	0.000

* Coefficients can be interpreted as the change in the percent of grocery expenditure (volume purchased, mL/d) on each type of beverage respect to the total purchases of beverages. Changes with presence of different family members by age and gender, presence of children, race/ethnicity and income are shown. Results for other predictors are shown in Table 3S.

† LCS, low-caloric sweetened beverages or foods; CS, caloric-sweetened beverages or foods.

‡ Significance level: $P<0.001$

Table 3.3. Race/ethnic differences in consumption of foods and beverages by sweetener type, NHANES 2003-2010*.

Per Capita Intake ‡	CHILDREN (2-18 years old)				ADULTS (≥19 years old)			
	Beverages (mL/d)		*Foods (g/d)*		*Beverages (mL/d)*		*Foods (g/d)*	
	LCS †	*CS †*	*LCS †*	*CS †*	*LCS †*	*CS †*	*LCS †*	*CS †*
Reported intake from stores								
White	64.4	364.6 [b]	2.8 [a]	111.2	178.3	348.9 [ab]	7.2	95.6
African American	39.9	324.1 [ab]	1.6 [a]	98.0 [a]	77.6 [a]	382.6 [b]	3.2 [a]	86.5
Mexican American	31.0 [a]	337.0 [ab]	2.8 [a]	88.7 [a]	82.5 [a]	311.3 [a]	3.7 [a]	72.5 [a]
Other	31.4 [a]	309.8 [a]	2.3 [a]	88.5 [a]	89.5 [a]	237.2	4.5 [a]	66.3 [a]
Total reported intake								
White	76.5	549.9 [b]	3.4	147.2	226.1	489.3 [ab]	7.4	125.0
African American	46.7	473.7 [a]	2.0 [a]	134.2	96.9 [a]	532.9 [b]	3.6 [a]	114.1
Mexican American	37.1 [a]	502.8 [ab]	3.1 [a]	119.0 [a]	113.3 [a]	451.9 [a]	3.9 [a]	92.7 [a]
Other	39.8 [a]	461.0 [a]	2.4 [a]	117.0 [a]	141.6 [a]	334.3	4.7 [a]	89.6 [a]
Difference in Percent Intake‡	*Beverages (mL/d)*		*Foods (g/d)*		*Beverages (mL/d)*		*Foods (g/d)*	
	LCS †	*CS †*	*LCS †*	*CS †*	*LCS †*	*CS †*	*LCS †*	*CS †*
Reported intake from stores								
African American vs. White	-1.9 %	8.0 %	-0.2 % [c]	-2.6 %	-5.2 %	11.0 %	-0.5 %	-2.3 %
Mexican American vs. White	-3.3 %	1.7 % [c]	0.0 % [c]	-6.1 %	-5.2 %	1.8 % [c]	-0.4 %	-6.1 %
Other vs. White	-3.1 %	0.3 % [c]	-0.1 % [c]	-6.3 %	-4.6 %	-1.0 % [c]	-0.4 %	-6.9 %
Total reported intake								
African American vs. White	-1.1 %	4.0 %	-0.1 % [c]	-1.8 %	-4.4 %	10.2 %	-0.4 %	-0.7 %
Mexican American vs. White	-2.0 %	1.8 % [c]	-0.1 % [c]	-4.2 %	-3.9 %	3.4 %	-0.3 %	-3.8 %
Other vs. White	-1.6 %	-1.1 % [c]	-0.1 % [c]	-4.2 %	-3.2 %	-1.7 % [c]	-0.3 %	-4.4 %

* Means per capita of beverages (mL/d) and foods (g/d) and difference in percent intake of beverages (mL/d) and foods (g/d)
†LCS, low-caloric sweetened beverages or foods; CS, caloric-sweetened beverages or foods.
‡Multivariable regression models were used to adjust for age, gender, year and income.
[a,b,c] Estimates in the same column (i.e. LCS beverages) sharing a letter are not significantly different at the 5% level, Bonferroni-adjusted Student's test.
[c] Not significantly different between race/ethnic groups at the 5% level, Student's test.

Supplemental Table 3.1. Trends in per capita purchases and % household purchasing foods and beverages by sweetener type, Homescan 2000-2010*.

PER CAPITA PURCHASES†	2000	2001	2002	2003	2004	YEAR 2005	2006	2007	2008	2009	2010	P trend‡
BEVERAGES – Households with children												
LCS only	74.9	75.5	83.4	91.6	94.7	100.1	100.3	94.5	91.2	90.7	93.3	0.000
CS only	290.2	290.0	293.7	289.1	273.9	264.5	263.4	252.8	251.0	246.1	242.3	0.000
LCS and CS	20.8	23.3	25.2	27.7	34.7	43.8	47.8	52.4	54.4	62.2	61.7	0.000
BEVERAGES – Households without children												
LCS only	94.8	95.4	103.3	111.4	114.6	120.0	120.2	114.4	111.0	110.6	113.2	0.000
CS only	279.3	279.1	282.8	278.2	263.0	253.6	252.5	241.8	240.1	235.2	231.4	0.000
LCS and CS	23.0	25.5	27.4	29.8	36.8	45.9	50.0	54.6	56.5	64.4	63.9	0.000
FOODS – Households with children												
LCS only	0.9	1.1	1.4	1.4	1.8	2.2	2.3	2.2	2.3	2.9	2.5	0.000
CS only	173.5	177.6	181.6	184.2	181.8	182.3	186.3	184.0	183.2	183.6	180.9	0.000
LCS and CS	4.8	5.5	6.2	7.7	10.2	11.7	11.3	12.1	12.5	12.5	13.0	0.000
FOODS – Households without children												
LCS only	1.3	1.5	1.7	1.8	2.1	2.6	2.6	2.6	2.6	3.3	2.8	0.000
CS only	186.5	190.5	194.6	197.1	194.7	195.3	199.2	196.9	196.2	196.5	193.8	0.000
LCS and CS	6.3	7.0	7.7	9.2	11.7	13.2	12.8	13.6	14.0	14.0	14.5	0.000
% HOUSEHOLDS PURCHASING†	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**P trend‡**
BEVERAGES – Households with children												
LCS only	50.6%	51.1%	52.6%	55.5%	57.8%	60.9%	61.8%	60.2%	57.7%	57.3%	57.4%	0.000
CS only	99.5%	99.3%	99.4%	99.4%	99.2%	99.1%	99.0%	98.8%	98.8%	98.7%	98.7%	0.000
LCS and CS	41.1%	43.5%	42.5%	48.8%	58.4%	62.7%	64.7%	65.6%	66.5%	68.4%	69.1%	0.000
BEVERAGES – Households without children												
LCS only	53.3%	53.8%	55.3%	58.2%	60.4%	63.5%	64.3%	62.8%	60.3%	59.9%	60.0%	0.000
CS only	98.5%	98.1%	98.2%	98.3%	97.6%	97.3%	97.0%	96.6%	96.5%	96.2%	96.2%	0.000
LCS and CS	33.3%	35.6%	34.6%	40.6%	50.2%	54.6%	56.8%	57.7%	58.7%	60.8%	61.5%	0.000
FOODS – Households with children												
LCS only	6.9%	8.2%	9.8%	10.6%	12.4%	14.0%	14.5%	14.1%	14.0%	18.0%	17.1%	0.000
CS only	100.0 %	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	0.752
LCS and CS	47.9%	50.8%	52.4%	57.7%	63.8%	66.6%	66.6%	69.1%	70.2%	71.2%	71.5%	0.000
FOODS – Households without children												
LCS only	7.8%	9.3%	11.1%	11.9%	14.0%	15.7%	16.3%	15.9%	15.8%	20.1%	19.1%	0.000
CS only	100.0 %	99.9%	99.9%	99.9%	99.9%	99.9%	99.8%	99.8%	99.9%	99.8%	99.8%	0.000
LCS and CS	41.9%	44.8%	46.4%	51.7%	58.1%	61.0%	61.1%	63.7%	65.0%	66.0%	66.3%	0.000

* Means per capita for beverages (mL/d) and foods (g/d). LCS, low-caloric sweetened beverages or foods; CS, caloric-sweetened beverages or foods. † Multivariable linear (per capita estimates) and logistic (% purchasing) regression models were used to adjust for household size, race and income. ‡ Statistically significant linear trends were tested using Wald tests, $P<0.001$.

Supplemental Table 3.2. Trends in prevalence and per capita intake of beverages and foods by sweetener type, NHANES 2003-2010*.

Per Capita Intake†	STORE 2003-04	STORE 2005-06	STORE 2007-08	STORE 2009-10	STORE *P* trend ‡	TOTAL 2003-04	TOTAL 2005-06	TOTAL 2007-08	TOTAL 2009-10	TOTAL *P* trend ‡
Children 2-18-y										
LCS Beverages	30.7	39.3	69.4	69.9	0.000	42.7	46.8	83.2	76.8	0.001
CS Beverages	417.9	368.1	294.8	314.5	0.000	616.2	539.6	473.7	460.0	0.000
CS Foods	2.8	3.2	1.8	2.5	0.529	2.8	3.4	2.2	3.6	0.757
CS Foods	110.3	107.0	98.5	98.7	0.014	141.1	145.2	132.2	133.4	0.019
Adults ≥ 19-y										
LCS Beverages	125.6	163.0	161.3	151.1	0.138	172.4	214.2	204.4	184.5	0.716
CS Beverages	369.7	325.0	337.3	325.6	0.098	536.4	468.6	463.3	441.0	0.002
LCS Foods	4.3	8.2	5.1	7.1	0.143	4.4	8.5	5.4	7.3	0.137
CS Foods	90.5	89.8	89.1	90.0	0.871	120.2	120.1	116.2	114.8	0.125

% Consumers†	STORE 2003-04	STORE 2005-06	STORE 2007-08	STORE 2009-10	STORE *P* trend ‡	TOTAL 2003-04	TOTAL 2005-06	TOTAL 2007-08	TOTAL 2009-10	TOTAL *P* trend ‡
Children 2-18-y										
LCS Beverages	6.4%	8.4%	14.8%	17.1%	0.000	7.8%	10.3%	17.0%	18.9%	0.000
CS Beverages	65.7%	56.0%	54.2%	52.8%	0.000	80.6%	72.4%	72.2%	71.7%	0.001
LCS Foods	1.5%	1.8%	1.2%	1.8%	0.848	1.5%	1.9%	1.4%	2.3%	0.357
CS Foods	62.2%	61.5%	57.0%	57.2%	0.025	73.4%	73.7%	70.6%	70.8%	0.060
Adults ≥ 19-y										
LCS Beverages	17.7%	21.8%	21.3%	21.6%	0.010	21.1%	26.2%	24.8%	24.9%	0.037
CS Beverages	47.8%	42.8%	44.0%	42.4%	0.007	59.5%	53.6%	54.7%	52.1%	0.000
LCS Foods	2.4%	4.6%	3.3%	4.1%	0.048	2.6%	4.9%	3.5%	4.3%	0.058
CS Foods	50.9%	48.7%	49.9%	51.0%	0.756	61.4%	61.1%	60.0%	59.6%	0.206

* Per capita means for beverages (mL/d) and foods (g/d). LCS, low-caloric sweetened beverages or foods; CS, caloric-sweetened beverages or foods

† Multivariable linear (per capita estimates) and logistic (% purchasing) regression models were used to adjust for age, gender, race and income

‡ Statistically significant linear trends were tested using Wald tests, $P<0.05$

Supplemental Table 3.3. Change in percent volume (mL/day) purchased from each type of beverage using estimated average marginal effects from random-effects longitudinal regression models, among U.S. households from the Nielsen Homescan Longitudinal dataset, 2000-2010.

BEVERAGES	LCS only†				CS only†				LCS and CS			
Predictors	β	[95%CI]		P value‡	β	[95%CI]		P value ‡	β	[95%CI]		P value ‡
Year												
2001	-0.1	-0.3	0.1	0.476	-1.2	-1.5	-1.0	0.000	0.5	0.3	0.6	0.000
2002	0.7	0.5	0.9	0.000	-2.3	-2.6	-2.1	0.000	0.3	0.2	0.5	0.000
2003	1.5	1.3	1.7	0.000	-4.6	-4.8	-4.3	0.000	0.9	0.7	1.0	0.000
2004	2.6	2.4	2.8	0.000	-7.5	-7.8	-7.3	0.000	2.4	2.3	2.6	0.000
2005	3.3	3.1	3.5	0.000	-10.5	-10.8	-10.3	0.000	3.6	3.5	3.8	0.000
2006	2.9	2.7	3.1	0.000	-11.9	-12.1	-11.6	0.000	4.4	4.2	4.5	0.000
2007	2.3	2.1	2.5	0.000	-13.0	-13.2	-12.7	0.000	5.6	5.4	5.7	0.000
2008	1.6	1.4	1.8	0.000	-12.8	-13.0	-12.6	0.000	6.2	6.1	6.4	0.000
2009	1.4	1.2	1.6	0.000	-12.9	-13.1	-12.6	0.000	7.3	7.1	7.4	0.000
2010	1.7	1.5	1.9	0.000	-13.4	-13.7	-13.2	0.000	7.5	7.4	7.7	0.000
Gender and age categories												
Female												
2-6 y-old	-0.5	-0.8	-0.2	0.002	1.4	1.1	1.8	0.000	-0.3	-0.5	0.0	0.026
7-12 y-old	-0.4	-0.7	-0.2	0.001	0.4	0.1	0.7	0.015	0.3	0.1	0.5	0.002
13-18 y-old	-0.7	-1.0	-0.5	0.000	0.3	-0.1	0.6	0.110	0.2	0.0	0.3	0.134
Male												
2-6 y-old	-0.7	-1.0	-0.4	0.000	1.5	1.1	1.9	0.000	-0.2	-0.5	0.0	0.042
7-12 y-old	-0.7	-1.0	-0.5	0.000	0.8	0.5	1.1	0.000	0.1	-0.1	0.3	0.185
13-18 y-old	-1.6	-1.8	-1.3	0.000	2.0	1.7	2.4	0.000	0.0	-0.2	0.2	0.830
Female												
19-39 y-old	-0.4	-0.6	-0.2	0.000	-0.1	-0.4	0.1	0.318	0.3	0.2	0.4	0.000
40-59 y-old	1.1	0.9	1.3	0.000	-2.2	-2.5	-2.0	0.000	0.6	0.5	0.8	0.000
>60 y-old	1.1	0.8	1.3	0.000	-1.7	-2.0	-1.4	0.000	0.4	0.2	0.5	0.000
Male												
19-39 y-old	-1.8	-2.0	-1.6	0.000	2.6	2.4	2.8	0.000	-0.4	-0.5	-0.3	0.000
40-59 y-old	0.0	-0.2	0.2	0.839	1.3	1.1	1.5	0.000	-0.5	-0.6	-0.3	0.000
>60 y-old	1.0	0.7	1.2	0.000	0.7	0.4	1.0	0.000	-0.6	-0.8	-0.5	0.000
Presence of children												
Presence vs. Absence	-1.8	-2.1	-1.6	0.000	3.0	2.6	3.3	0.000	-0.4	-0.7	-0.2	0.000
Race/ethnicity												
African-American vs. White	-12.0	-12.5	-11.6	0.000	9.3	8.8	9.8	0.000	-0.6	-0.8	-0.3	0.000
Hispanic vs. White	-5.3	-5.8	-4.8	0.000	3.9	3.3	4.5	0.000	-1.0	-1.3	-0.6	0.000

Other vs. White	-5.9	-6.6	-5.3	0.000	5.8	5.0	6.6	0.000	-2.1	-2.5	-1.7	0.000
Income												
Middle vs. Low Income	1.2	1.0	1.3	0.000	-2.0	-2.2	-1.8	0.000	0.4	0.3	0.6	0.000
High vs. Low Income	2.7	2.5	2.9	0.000	-4.6	-4.8	-4.3	0.000	0.9	0.8	1.1	0.000
Race/ethnicity-Presence of children												
No Children												
African-American vs. White	-12.6	-13.1	-12.2	0.000	9.8	9.2	10.3	0.000	-0.6	-0.9	-0.3	0.000
Hispanic vs. White	-5.6	-6.2	-5.0	0.000	4.1	3.4	4.8	0.000	-1.0	-1.3	-0.6	0.000
Other vs. White	-6.0	-6.8	-5.3	0.000	5.9	5.0	6.7	0.000	-2.1	-2.6	-1.7	0.000
Children												
African-American vs. White	-10.4	-11.0	-9.9	0.000	7.8	7.2	8.5	0.000	-0.6	-1.0	-0.3	0.000
Hispanic vs. White	-4.5	-5.1	-3.9	0.000	3.4	2.6	4.1	0.000	-0.9	-1.3	-0.5	0.000
Other vs. White	-5.6	-6.4	-4.8	0.000	5.7	4.7	6.7	0.000	-2.1	-2.6	-1.6	0.000
Race/ethnicity-Income												
Low income												
African-American vs. White	-11.3	-11.9	-10.7	0.000	7.7	6.9	8.4	0.000	-0.4	-0.8	0.0	0.069
Hispanic vs. White	-5.0	-5.8	-4.2	0.000	3.4	2.5	4.4	0.000	-0.9	-1.5	-0.4	0.001
Other vs. White	-5.1	-6.2	-4.0	0.000	4.3	2.9	5.7	0.000	-1.4	-2.1	-0.6	0.001
Middle income												
African-American vs. White	-11.8	-12.2	-11.3	0.000	8.7	8.1	9.3	0.000	-0.5	-0.8	-0.2	0.001
Hispanic vs. White	-5.3	-5.9	-4.7	0.000	4.0	3.2	4.7	0.000	-0.8	-1.2	-0.4	0.000
Other vs. White	-5.4	-6.2	-4.6	0.000	5.5	4.5	6.4	0.000	-2.2	-2.7	-1.7	0.000
High Income												
African-American vs. White	-12.7	-13.2	-12.2	0.000	10.6	10.0	11.2	0.000	-0.8	-1.1	-0.4	0.000
Hispanic vs. White	-5.4	-6.1	-4.8	0.000	4.1	3.3	4.9	0.000	-1.1	-1.5	-0.7	0.000
Other vs. White	-6.9	-7.6	-6.1	0.000	6.9	6.0	7.8	0.000	-2.4	-2.9	-1.9	0.000

* Coefficients can be interpreted as the change in the percent of grocery expenditure (volume purchased, mL/d) on each type of beverage respect to the total purchases of beverages. Changes with time, presence of different family members by age and gender, presence of children, race/ethnicity, income, and the interactions race/ethnicity with presence of children and income are shown.
† LCS, low-caloric sweetened beverages or foods; CS, caloric-sweetened beverages or foods.
‡ Significance level: *P*<0.001

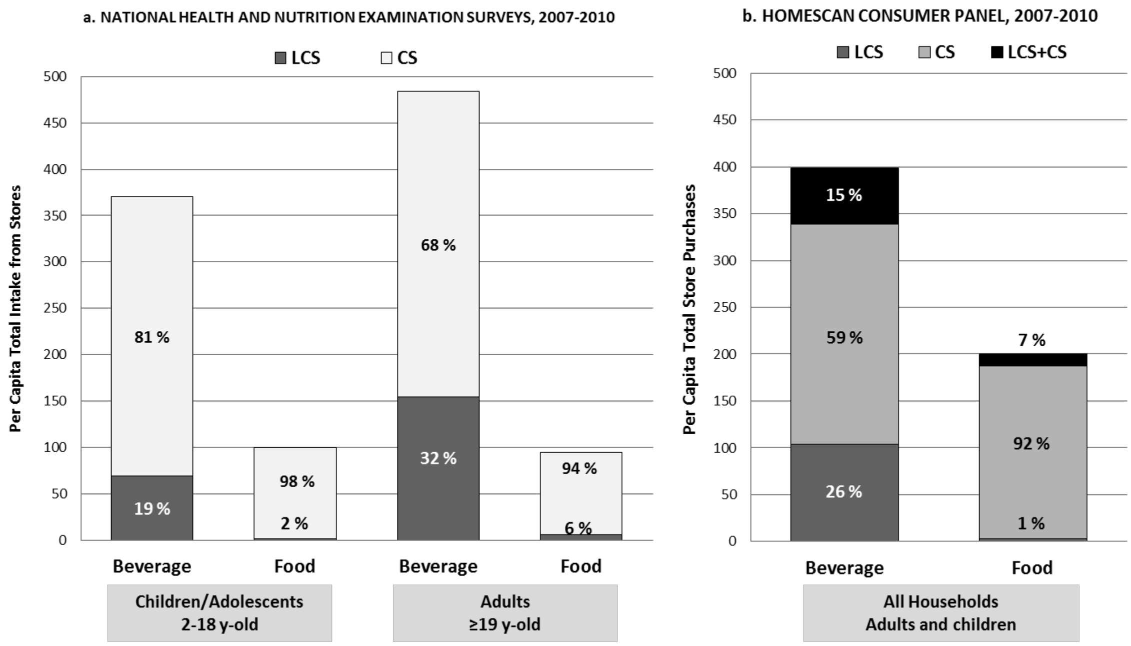
Supplemental Table 3.4. Change in percent volume (gr/day) purchased from each type of food using estimated average marginal effects from random-effects longitudinal regression models, among U.S. households from the Nielsen Homescan Longitudinal dataset, 2000-2010.

FOODS	**LCS only†**				**CS only†**				**LCS and CS**			
Predictors	β	[95%CI]		P value‡	β	[95%CI]		P value‡	β	[95%CI]		P value‡
Year												
2001	0.1	0.0	0.1	0.000	-0.3	-0.4	-0.2	0.000	0.2	0.2	0.3	0.000
2002	0.2	0.2	0.2	0.000	-0.6	-0.7	-0.5	0.000	0.4	0.3	0.5	0.000
2003	0.2	0.1	0.2	0.000	-1.3	-1.4	-1.2	0.000	1.0	0.9	1.0	0.000
2004	0.3	0.3	0.4	0.000	-2.8	-2.9	-2.7	0.000	2.1	2.0	2.2	0.000
2005	0.4	0.4	0.4	0.000	-3.3	-3.4	-3.2	0.000	2.4	2.3	2.5	0.000
2006	0.4	0.4	0.5	0.000	-3.1	-3.2	-3.0	0.000	2.3	2.2	2.3	0.000
2007	0.4	0.4	0.4	0.000	-3.7	-3.8	-3.6	0.000	2.8	2.7	2.8	0.000
2008	0.4	0.4	0.4	0.000	-3.8	-3.9	-3.7	0.000	2.8	2.8	2.9	0.000
2009	0.7	0.6	0.7	0.000	-4.1	-4.2	-4.0	0.000	2.8	2.8	2.9	0.000
2010	0.5	0.5	0.6	0.000	-4.8	-4.9	-4.7	0.000	3.1	3.0	3.2	0.000
Gender and age categories												
Female												
2-6 y-old	-0.1	-0.1	0.0	0.003	0.4	0.3	0.6	0.000	-0.2	-0.2	-0.1	0.001
7-12 y-old	-0.1	-0.1	0.0	0.000	0.6	0.5	0.8	0.000	-0.1	-0.2	0.0	0.021
13-18 y-old	0.0	0.0	0.0	0.386	0.3	0.2	0.4	0.000	0.0	-0.1	0.1	0.843
Male												
2-6 y-old	-0.1	-0.1	0.0	0.000	0.5	0.4	0.7	0.000	-0.2	-0.3	-0.1	0.000
7-12 y-old	-0.1	-0.1	-0.1	0.000	0.9	0.8	1.0	0.000	-0.1	-0.2	0.0	0.001
13-18 y-old	-0.1	-0.1	0.0	0.000	0.8	0.7	0.9	0.000	-0.2	-0.3	-0.1	0.000
Female												
19-39 y-old	0.0	0.0	0.0	0.155	0.2	0.1	0.3	0.000	0.1	0.1	0.2	0.000
40-59 y-old	0.0	0.0	0.1	0.000	-0.4	-0.5	-0.3	0.000	0.2	0.1	0.2	0.000
>60 y-old	0.1	0.0	0.1	0.000	-0.8	-0.9	-0.7	0.000	0.4	0.3	0.4	0.000
Male												
19-39 y-old	-0.2	-0.2	-0.1	0.000	1.1	1.0	1.2	0.000	-0.4	-0.5	-0.4	0.000
40-59 y-old	-0.2	-0.2	-0.2	0.000	1.0	0.9	1.1	0.000	-0.5	-0.6	-0.5	0.000
>60 y-old	-0.1	-0.2	-0.1	0.000	0.5	0.4	0.6	0.000	-0.4	-0.4	-0.3	0.000
Presence of children												
Presence vs. Absence	-0.2	-0.2	-0.1	0.000	1.4	1.3	1.6	0.000	-0.3	-0.4	-0.2	0.000
Race/ethnicity												
African-American vs. White	-0.3	-0.3	-0.3	0.000	2.1	2.0	2.3	0.000	-1.4	-1.5	-1.3	0.000
Hispanic vs. White	0.0	-0.1	0.0	0.223	-1.1	-1.3	-0.9	0.000	-0.3	-0.4	-0.1	0.000
Other vs. White	-0.2	-0.2	-0.1	0.000	-0.8	-1.0	-0.5	0.000	-0.7	-0.8	-0.5	0.000
Income												

Middle vs. Low Income	0.1	0.1	0.1	0.000	-1.0	-1.0	-0.9	0.000	0.4	0.4	0.5	0.000
High vs. Low Income	0.3	0.3	0.3	0.000	-2.3	-2.4	-2.2	0.000	1.0	0.9	1.0	0.000
Race/ethnicity-Presence of children												
No Children												
African-American vs. White	-0.3	-0.3	-0.3	0.000	2.3	2.1	2.5	0.000	-1.5	-1.6	-1.4	0.000
Hispanic vs. White	0.0	-0.1	0.0	0.258	-1.2	-1.5	-0.9	0.000	-0.2	-0.4	-0.1	0.001
Other vs. White	-0.2	-0.3	-0.2	0.000	-0.8	-1.2	-0.5	0.000	-0.7	-0.9	-0.5	0.000
Children												
African-American vs. White	-0.2	-0.3	-0.2	0.000	1.7	1.4	1.9	0.000	-1.1	-1.3	-1.0	0.000
Hispanic vs. White	0.0	-0.1	0.0	0.523	-0.8	-1.1	-0.6	0.000	-0.3	-0.4	-0.1	0.000
Other vs. White	-0.1	-0.2	0.0	0.042	-0.5	-0.9	-0.2	0.005	-0.7	-0.9	-0.5	0.000
Race/ethnicity-Income												
Low income												
African-American vs. White	-0.3	-0.3	-0.2	0.000	1.9	1.6	2.2	0.000	-1.3	-1.5	-1.1	0.000
Hispanic vs. White	0.0	-0.1	0.0	0.368	-1.0	-1.3	-0.6	0.000	-0.3	-0.5	0.0	0.020
Other vs. White	-0.1	-0.2	0.0	0.168	-0.7	-1.2	-0.2	0.005	-0.5	-0.8	-0.2	0.001
Middle income												
African-American vs. White	-0.3	-0.3	-0.2	0.000	2.1	1.8	2.3	0.000	-1.4	-1.5	-1.3	0.000
Hispanic vs. White	0.0	-0.1	0.1	0.970	-1.4	-1.7	-1.1	0.000	-0.2	-0.4	-0.1	0.006
Other vs. White	-0.2	-0.2	-0.1	0.000	-1.0	-1.3	-0.7	0.000	-0.6	-0.8	-0.4	0.000
High Income												
African-American vs. White	-0.3	-0.3	-0.2	0.000	2.4	2.1	2.6	0.000	-1.5	-1.6	-1.3	0.000
Hispanic vs. White	0.0	-0.1	0.0	0.097	-0.8	-1.1	-0.5	0.000	-0.3	-0.5	-0.1	0.000
Other vs. White	-0.2	-0.3	-0.2	0.000	-0.5	-0.8	-0.2	0.002	-0.9	-1.0	-0.7	0.000

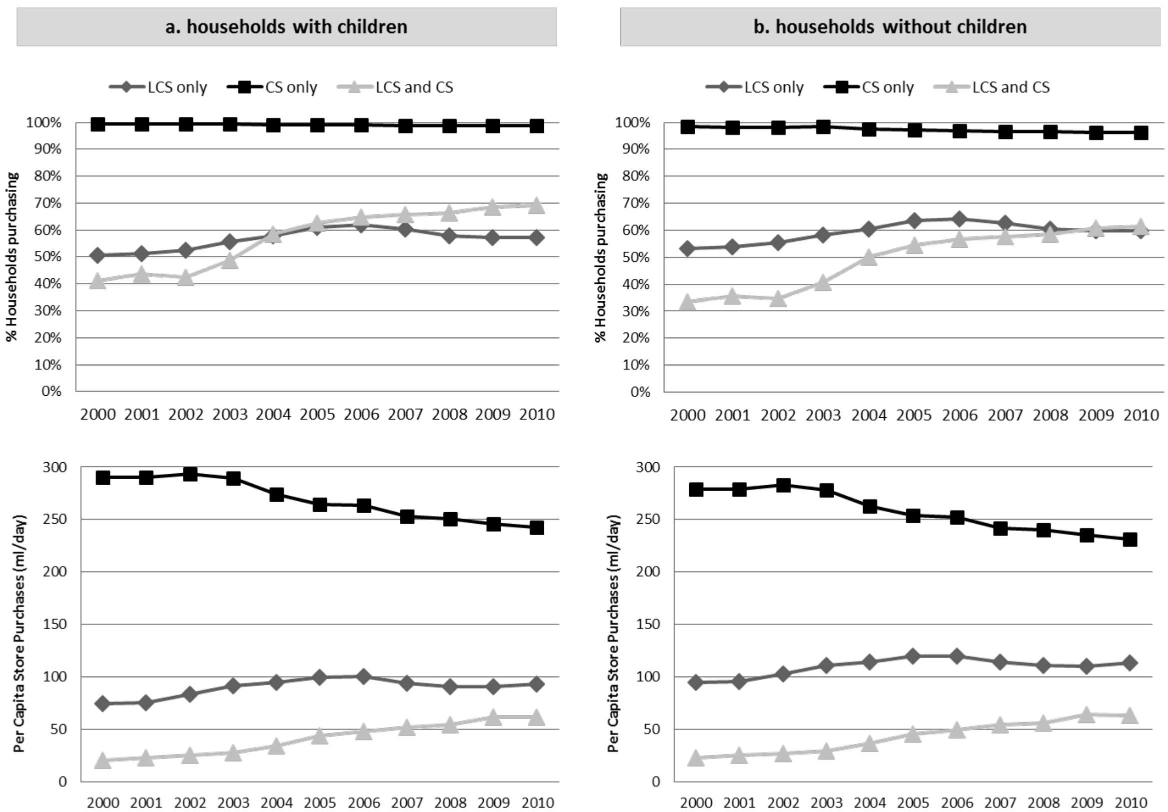
* Coefficients can be interpreted as the change in the percent of grocery expenditure (volume purchased, gr/d) on each type of food respect to the total purchases of foods. Changes with time, presence of different family members by age and gender, presence of children, race/ethnicity, income, and the interactions race/ethnicity with presence of children and income are shown.
† LCS, low-caloric sweetened beverages or foods; CS, caloric-sweetened beverages or foods.
‡ Significance level: *P*<0.001

Figures 3.1a-b. Sources of low-calorie and caloric sweeteners in the US, 2007-2010*



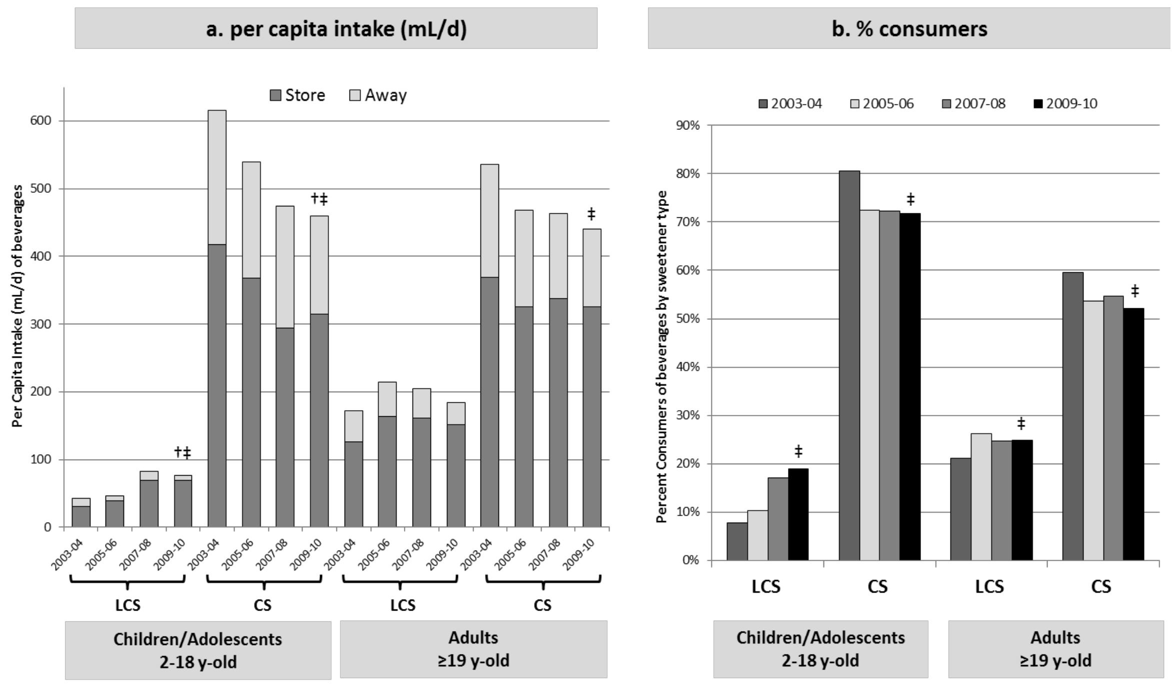
* Means per capita for beverages (mL/d) and foods (g/d). LCS, low-caloric sweetened beverages or foods; CS, caloric-sweetened beverages or foods.

Figures 3.2a-b. Trends in percent households purchasing and per capita purchases of beverages by sweetener type, Homescan 2000-2010*



* Means per capita for beverages (mL/d). LCS, low-caloric sweetened beverages; CS, caloric-sweetened beverages. Multivariable linear (per capita estimates) and logistic (percent of households purchasing) regression models were used to adjust for household size, race and income. All linear trends shown were statistically significant, Wald tests, *P*<0.001.

Figures 3.3a-b. Trends in consumption per capita and percent of consumers of beverages, NHANES 2003-2010*



* Trends in per capita intake of beverages (mL/d) by source of food (store vs. away-from-home); and % consumers from all sources. LCS, low-caloric sweetened beverages; CS, caloric-sweetened beverages. Multivariable linear (per capita estimates) and logistic (percent of households purchasing) regression models were used to adjust for age, gender, race and income.

† Statistically significant linear trend, Wald test, *P*<0.05

‡ Total beverages (store and away-from-home): statistically significant linear trend, Wald test, *P*<0.05

Chapter 4. Low Calorie- and Caloric-Sweetened Beverages: Diet Quality, Food Intake and Purchase Patterns of U.S. Household Consumers

Overview

Using a novel approach that uses ingredient lists of each product to classify sweetened beverages with low-calorie- (LCS) and caloric-sweeteners (CS), we examined the diet quality and patterns of different profiles of beverage consumption from 2000-10. We analyzed household purchases from the Homescan longitudinal dataset 2000-10 (n=501,343 observations from 140,352 households and 408,458 individuals); and individual dietary intake from the National Health and Nutrition Examination Surveys (NHANES) 2003-10 (n=34,393). Given that beverages are the main sources of LCS and CS, we defined these mutually exclusive consumer profiles: LCS-beverages; CS-beverages; LCS&CS-beverages; and non/low-consumers. First, we used multivariable linear and longitudinal random-effects models to investigate the associations between the four beverage profiles and diet quality (total energy and macronutrients) in Homescan and NHANES separately. Then we performed factor analyses and applied factor scores to derive longitudinal dietary patterns to investigate

the association between each beverage consumption profile and the different dietary patterns that emerged.

We found “Prudent” and “Breakfast” patterns that were common in Homescan and NHANES; a “Ready-to-eat meals/Fast food” and “Prudent/snacks/LCS desserts” patterns in Homescan; and a “Protein/Potatoes” and “CS Desserts/sweeteners” pattern in NHANES. Compared to non/low-consumers of beverages, all other profiles had significantly higher total daily energy, energy from carbohydrates and sugars, and a lower probability of adherence to a “Prudent” dietary pattern. LCS-beverage consumers had a higher probability of being associated with two distinct diet patterns, those who followed a “Prudent/snacks” pattern of purchases, and those who followed the “Ready-to-eat meals/Fast food” pattern. In conclusion, as LCS-beverages appear to be displacing those with CS over the last 10 years, our findings suggest that overall dietary quality is lower in LCS-, CS- and LCS&CS-beverage consumers relative to individuals who do not consume any type of sweetened beverages.

Introduction

Consumption of foods and beverages containing low-calorie sweeteners (LCS) alone or in combination with caloric-sweeteners (CS) has increased dramatically over the last decade in the U.S. [59, 100]. As consumers turn to lower sugar and calorie items, a better understanding of actual patterns of sweetened beverage (SB) consumption – containing either LCS and CS sweeteners -- and determinants and consequences of these patterns is warranted.

Intake of CS in general, as well as sugar- or high-calorie sweetened beverages (CS-beverages) in particular, is commonly associated with poor health outcomes [12]. However, the association between LCS consumption and the risk of obesity and cardio-metabolic problems still remains under controversy[13-15]. Several biological mechanisms have been hypothesized to link LCS consumption to increased energy, carbohydrate, sugar intake and poor dietary quality [16, 29, 32]. Behaviorally, consumption of LCS products could be linked to higher intake of calories or larger portion sizes motivated by the general perception that these “diet” products are lower in calories and sugars, hence allowing some consumers to offset these beverages with less healthful foods. Such dietary patterns may be one pathway linking LCS consumption to health outcomes such as cardio-metabolic disorders.

Although the physiological causal pathways are not well understood and difficult to test, to date few studies have explored in depth what dietary patterns are followed by consumers of LCS- and CS-beverages. Previous studies have typically examined the independent effects of LCS and CS-beverages on metabolic outcomes after controlling or stratifying their analyses by “Western” or

"Prudent" dietary patterns [36, 37, 64, 101]. However, to date no studies have investigated the adherence of LCS- and CS-beverage consumers to longitudinal dietary patterns over time. Moreover, LCS consumption has typically been poorly assessed because of the lack of standardized ways to determine the presence of sweeteners in food products, partly due to the lack of access to product ingredient lists, as well as the lack of awareness of the presence of LCS, CS or both sweeteners in food products as self-reported by participants.

In this study, we analyzed prospective measures of purchases by households included in the Nielsen Homescan Longitudinal dataset 2000-2010, which captures more than 400,000 barcoded food products [64]. Each product is linked to data that contains detailed ingredient information from the nutrition facts panel to identify the presence of LCS and CS in products currently sold in the U.S. Since sweetened beverages are major sources of CS and LCS sweeteners in the diet, we created profiles to characterize households that purchase LCS-beverages, CS-beverages, both LCS&CS-beverages, as well as non/low-consumers of both beverage types. Then, we investigated overall food purchasing patterns of the households characterized by these different beverage consumer profiles. To complement our analyses of purchasing patterns with dietary intake patterns, we used the National Health and Nutrition Examination Surveys (NHANES) from 2003 to 2010 to explore individual-level dietary patterns of the same beverage consumer profiles. We hypothesized that consumers of LCS-beverages would follow two distinct patterns, one characterized by reduced energy intake and another characterized by a lower dietary quality and higher energy intake. We also hypothesized that consumers of CS-beverages would have poorer dietary quality and higher energy intakes.

Methods

Study design and population

We used two data sources: household level purchasing data from the Nielsen Homescan (The Nielsen Co.) [64] from 2000-2010; and individual dietary intake data from the U.S. Department of Agriculture (USDA) National Health and Nutrition Examination Survey (NHANES) from 2003-2010.

1) Food purchase data: The Nielsen Homescan Consumer Panel (Homescan). Homescan is an ongoing nationally representative longitudinal survey of 35,000-60,000 households per year that captures information on consumer purchases of more than 400,000 barcoded products that are sold in the U.S. over this period. For the present study, we selected households with adults and children from the Nielsen Homescan (The Nielsen Co.)[64] from 2000-2010 (n=140,907 unique households; n=410,763 individuals). Homescan participants are provided with home scanners with which they scan their purchases from every shopping event for at least 10 months and up to ten years. Each uniquely barcoded product captured in Homescan has been linked with Nutrition Facts Panel (NFP) data and ingredient information using the commercial Gladson Nutrition Database and the Mintel's Global New Product Database [65, 102]. Households also report sociodemographic (SES) and other information including gender and age of each family member; and income, education and race/ethnicity of the main head of the household. Households included in Homescan are sampled and weighted to be nationally representative. Overall, calories from Homescan food purchase data represent approximately two-thirds of the total caloric intake [102].

2) Dietary intake data: The National Health and Nutrition Examination Surveys (NHANES). The U.S. Department of Agriculture (USDA) NHANES surveys capture dietary intake data for a nationally representative self-weighting, multistage and stratified probability sample of non-institutionalized U.S. households [46, 47, 70, 71, 103]. For this study, we included adults and children (n=34,391) who participated in four NHANES waves from 2003-2010: NHANES 2003-04 (n=8,272), NHANES 2005-06 (n=8,549), NHANES 2007-08 (n=8,528) and NHANES 2009-10 (n=9,042). Dietary intake data is collected using two non-consecutive 24-h recalls and is linked to the USDA food databases and food composition tables, which provide nutrient information and food descriptions for each food item consumed by the participants [103]. Sociodemographic information, such as age, gender, race/ethnicity and income is also collected for each participant.

Classification of sweetened beverages and definition of consumer profiles

Sweetened beverages, including soda-type carbonated beverages and sweetened-flavored waters, were classified as LCS-beverages or CS-beverages in each dataset. In Homescan, we conducted keyword searches for CS and LCS (including terms such as “sugar”, “high fructose corn syrup”, “sucralose” or “aspartame”), using the ingredient lists provided for each barcoded product purchased by participating households [58]. In NHANES, we conducted keyword searches by looking at the food description of each food-code that is captured by the USDA food database. We classified beverages as LCS if their food description included the following terms: “with low/no calorie sweetener”, “sugar-free” and “dietetic/low sugar”. Otherwise they were considered CS-beverages.

We created beverage consumer profiles based on purchases (Homescan) or intake (NHANES) of LCS- and CS-beverages, as these sweetened beverages have been the major sources of LCS and CS sweeteners in the U.S. population over the last decade [100]. Our definitions of beverage consumer profiles capture an overall preferred consumption of LCS- or CS-beverages but are not restrictive in order to have balanced sample sizes across the different profiles. Since Homescan captures household purchases over an entire year, we divided the total volume of LCS- and CS-beverages purchased per year by the standard serving size of a can (12 oz or 355 mL) and we found that those households in the top quartile of the population distribution had about 208 servings of LCS-beverages per capita per year (approximately 4 per week). We classified households with purchases of ≥4 servings/capita weekly of either LCS- or CS-beverages as consumers of that beverage type if they also reported purchasing <1 serving/capita of the other type of beverage per week. Households with ≥4 servings/capita weekly of any combination of LCS- and CS-beverages were classified as combined LCS&CS beverage consumer households. All other households were considered non/low-consumers. Similarly in NHANES, we divided the average volume of LCS and CS-beverages drank per day by the standard serving size of a can (12 oz or 355 mL) and we found that individuals in the top intake decile for LCS-beverages consumed on average 0.6 servings per day. We classified individuals as regular consumers or either LCS- or CS-beverages if they consumed ≥0.5 servings of that beverages and <0.5 servings of the other type of beverage per day. Individuals who reported consuming both type of beverage, with ≥0.25 servings of both LCS- and CS-beverages, were classified as combined LCS&CS beverage consumers. All other participants were considered non/low-consumers.

Factor analysis

Factor analysis is a data-driven approach to derive population-level dietary patterns which represent patterns of purchases or intake of foods and beverages that are consumed in combination. We first grouped all foods and beverages that were purchased or reported in food groups that were comparable between Homescan and NHANES (Supplemental Table 4.1). Then, we performed factor analyses in each dataset separately using standardized measures of purchases or intake of all food and beverage groups other than LCS and CS-beverages. Intake variables were defined as % energy from each food group. For each factor, every food group has a specific factor loading, which is the correlation coefficient between each food group and that factor or diet pattern. Also, each participant has a score for each factor; higher scores indicate higher adherence to that factor or pattern. We performed a varimax rotation after the factor analysis so that the emerging factors or patterns were as uncorrelated as possible. We retained 4 factors in each dataset based on the Kaiser criterion (eigenvalue>1) and the interpretability of the resulting patterns. Then, factor loadings from each of those 4 factors with a z score >0.2 were extracted.

In order to create dietary patterns longitudinally in Homescan, we calculated applied factor scores by using the Bartlett method, which is considered the most refined method to create unbiased and orthogonal factor scores over time [104]. We used factor loadings from 2010 to obtain predicted factor scores for earlier years (2000 to 2009) by using maximum likelihood estimates that are most likely to represent the true factor scores. By using applied factor scores, we were able to consistently define the same dietary pattern over the time period studied. Since the NHANES sample combines four cross-sectional waves of data, we performed a single factor analysis in the entire sample using standardized measures of intake (% energy from each food group respect to the total energy excluding LCS- and CS-beverages) with a varimax rotation.

Statistical Analysis

All analyses were performed using Stata 12 (StataCorp, Stata Statistical Software, Release 12, 2011). Survey commands were used to account for survey design and weighting to generate nationally representative results. In both datasets, race/ethnicity was used to classify participants as Hispanic, non-Hispanic White, non-Hispanic African-American and Others. Age was used to separate adults (<19 y-old) and children (2-18 y-old). The ratio of family income to poverty threshold, calculated from self-reported household income, was used to categorize income according to the percent of the poverty level: “Lower income, <185%”, “Middle income, ≥185-<400%” and “Higher income, ≥400%”.

To examine dietary quality by beverage consumer profile, we estimated measures of daily energy (including total daily calories, total calories excluding LCS- and CS-beverages, total food calories and total beverage calories) and daily energy from macronutrients (including carbohydrates, total sugar, fat, protein and saturated fat) using total yearly purchases in Homescan and average daily intake in NHANES. All the models used in Homescan were adjusted by confounders such as household size, year, income and race/ethnicity; whereas the models used in NHANES were adjusted by age, gender, race/ethnicity and income because these variables were found to be differentially associated with beverage consumption [100]. In addition, we stratified all the analyses in Homescan by household structure, because the interaction between beverage profiles and household type (single-person, multi-person with adults only and multi-person with children) was significant. We also stratified all analyses in NHANES to obtain estimates for adults and children separately. We used average marginal effects from random-effects longitudinal linear regression models in Homescan to investigate the prospective associations between beverage consumer profiles and energy and macronutrient composition of the household purchases. In NHANES, we used average marginal effects from linear regression models to investigate the cross-sectional associations between beverage profiles and dietary energy and macronutrient composition of each individual's diet.

Next, we examined the associations between dietary patterns derived from factor analyses and beverage consumer profiles in each dataset. Using factor scores for each of the four patterns that were retained; we created categories based on tertiles for each pattern so that individuals in the highest tertile of each pattern were more likely to follow that particular pattern. In Homescan, we used average marginal effects from random-effects longitudinal logistic regression models to investigate the prospective associations between dietary purchasing patterns and beverage consumer profiles. The model includes a binary outcome (highest tertile of a factor vs. middle/lower tertile); time-varying variables such as categories of beverage consumer profile as the main exposure; the interaction between the beverage profile and household type and confounders. Similarly in NHANES, we used average marginal effects from logistic regression models to investigate the cross-sectional associations between dietary intake patterns and beverage consumer profiles. The model also includes a binary outcome (highest tertile of a factor vs. middle/lower tertile); and categories of beverage consumer profiles as the main exposure plus confounders. In each dataset, margins commands were used after the fully adjusted models to predict the probability of being in the highest tertile of each dietary pattern given their beverage profile. Because this model has a categorical outcome, we obtain the predicted probability of the outcome based on the model coefficients of the main exposure plus further adjustments performed in the model. Aside from adherence to population-level dietary patterns, we also investigated the mean % energy from purchases or intake of key food groups that characterized the main dietary patterns identified using multivariable random-effects longitudinal models (Homescan) and multivariable models (NHANES). Estimates are presented as means (95% CI) or predicted probabilities. Statistically significant differences were tested using Student’s *t*-test with the Bonferroni correction. A two sided *p*-value of 0.05 was set to denote statistical significance.

Results

Sociodemographic characteristics and beverage consumption profiles in Homescan and NHANES

In Homescan, the two most common profiles were non-/low consumers of sweetened beverages (42%) followed by combined LCS/CS beverage consumers (28%) (Table 4.1). Households classified as LCS- or CS-beverages had purchases of almost 2 servings per day of each beverage type. In NHANES, most individuals were classified as non/low-consumers or CS-beverage consumers. In NHANES, consumers of

LCS-beverages or CS-beverages had on average almost 2 servings of the respective type of beverage per day.

Beverage profiles and energy and macronutrient composition of food purchases and intakes

Compared to non/low-consumers, households purchasing larger amounts of any type of sweetened beverage had significantly higher average total daily energy including beverage calories and total daily energy from foods only, we as well as higher energy from each macronutrient (Figure 4.1a; Supplemental Table 4.2). Similarly, in NHANES, individuals who consumed any type of sweetened beverage also had higher daily energy intakes overall and from foods. Compared to non/low- consumers, CS- and LCS&CS- beverage consumers also reported higher energy intakes from beverages, and each macronutrient (Figure 4.1b; Supplemental Table 4.3).

Dietary patterns based on food purchases and intakes obtained from factor analyses

Four dietary patterns or factors explaining the maximum variability in each population were retained (Table 4.2). We found that “Prudent” and “Breakfast” patterns were common in both Homescan and NHANES. The “Prudent” pattern was characterized by positive factor loadings for food groups that reflect more like a “home-cooking” pattern such as grains, vegetables, fruits and cooking fats among others, and negative loadings for salty snacks and fast food meals (only in NHANES). The “Breakfast” pattern was characterized by positive loadings for unsweetened milk, juice and ready-to-eat (RTE) cereals. In addition, we found a “RTE meals/Fast food” purchasing pattern characterized by positive loadings for mixed, frozen and fast food meals; and another “Prudent+snacks/LCS desserts” purchasing pattern with positive loadings for fruits, nuts, vegetables and also snacks and LCS desserts in Homescan. In NHANES, we found a “Protein/Potatoes” intake pattern with positive loadings for meat, poultry and, potatoes including French fries; and finally a “CS Desserts/sweetener” intake pattern with positive loadings for CS desserts and sweeteners.

Associations between beverage profiles and overall dietary patterns

Households purchasing any type of sweetened beverage had significantly lower probability of adherence to the “Prudent” or “Breakfast” purchasing pattern compared to non/low-consumers (Figure 4.2a). However, households who purchased any type of sweetened beverage had a higher adherence to the “RTE meals/Fast food” purchase pattern; whereas those purchasing LCS-beverages had a particularly higher probability of following the “Prudent+snacks/LCS desserts” purchase pattern compared to the other beverage profiles. Although these associations are consistent across the different types of households, the magnitude of the adherence to each pattern varied depending on the type of household (Figures 4.2b-d). The “Breakfast” and the “RTE meals/Fast food” patterns are more predominant among households with children. These results were also found in NHANES, where individuals consuming any type of beverage had lower predicted probabilities of adherence to a "Prudent" or "Breakfast" intake pattern compared to non/low-consumers (Figures 4.3a-c). We also found that beverage consumers of any type had higher probability of adherence to the "Protein/Potatoes" intake pattern. However, there were no significant differences between beverage consumers and non/low-consumers in adherence to the "CS Desserts/sweeteners" pattern except for LCS-beverages.

Associations between beverage profiles and food group purchases or intakes

Comparing food group patterns by beverage consumer profile in Homescan and NHANES, we found that households and individuals purchasing or drinking any type of sweetened beverage had higher purchases and intake (% kcal) of protein groups (meat, fish, eggs, etc), mixed/frozen and fast food meals, salty snacks and desserts (Table 4.3). On the other hand, compared to both CS-beverage profiles, both non/low-consumers of sweetened beverages and consumers of LCS-beverages, had higher % kcal from nuts, fruits and vegetables, and RTE cereal. In Homescan, LCS-beverage consumers had a higher % kcal purchased of CS desserts whereas LCS-beverage consumers in NHANES reported a lower % kcal from CS desserts.

Discussion

Our research used longitudinal data on food purchases along with dietary intake data to identify different consumer profiles of sweetened beverages and investigate the dietary intake patterns related to adherence of these profiles over the last decade. Overall, consumers of any type of sweetened beverage had higher total energy, including energy from food and most macronutrients, compared to non/low-consumers. This was observed based on both household purchases and dietary intake data. Sweetened beverage consumers also had a significantly lower probability of adherence to a "Prudent" dietary pattern and higher average energy from purchases or intake of energy dense food groups such as salty snacks, fast food meals or desserts. In addition, LCS-beverage consumers had a significantly higher probability of following a "Prudent+snacks/LCS desserts" pattern compared to the other beverage profiles and had average higher intakes of fruits, vegetables and nuts. Consistent with what we had hypothesized, LCS-beverage consumers seem to follow two distinct dietary patterns that are characterized by both high and low calorie food groups.

Consumption of CS-beverages has been extensively associated with poor health outcomes independently of energy intake and dietary patterns, with several attributed effects such as incomplete compensatory reduction of intake at subsequent meals, increased insulin response due to a higher glycemic index and even throughout potential metabolic effects of fructose [9, 12, 23, 95, 105]. Other studies that examined the effect of CS-beverages on overall diet have found positive associations with non-beverage calories, lower intake of fruit and vegetables, and higher intakes of fast foods and snacks [36, 106-108]. Consistently, our study identified profiles of consumers of CS-beverages that were associated with higher total energy and food purchases, with significantly lower adherence to a "Prudent" dietary pattern. Through the afore-mentioned direct and indirect effects, CS-beverages are potential sources of excess calories and currently constitute one of the major public health targets to improve dietary quality and health in the U.S. population [99].

Despite the fact that LCS in foods and beverages can reduce the sugar and caloric content of products, widespread controversy still exists regarding consumption of LCS-beverages and its effects on metabolic health [9, 23]. Some researchers postulate a direct effect throughout enhanced sweetness preference, disrupted biochemical pathways that control hunger and satiety and increased insulin concentration after preloads of aspartame [16, 29, 32]. Although several large epidemiological studies have found increased risk of diabetes and metabolic syndrome [33-35, 105], residual confounding and reverse causality were hypothesized to explain such effects [37, 109]. A cohort analysis of the Health Professionals study found that adjusting for

BMI and diet strongly attenuated a previously significant LCS-beverage effect on type 2 diabetes [14]. However, a recent study found an increased risk of type 2 diabetes even after adjustment for body mass index, energy intake and dietary patterns [101]. Another study found that dietary patterns rather modify the association between LCS-beverage intake and the risk of health outcomes. Those consuming LCS-beverages in the context for a Prudent-style diet had reduced risk of cardio-metabolic outcomes [36]. Results from a recent short-term RCT found that those randomized to substitute CS-beverages by water or LCS-beverages didn't increased their overall energy intake or their calories from sweets or desserts compared to water [94]. In relation to food purchasing patterns, a cross-sectional study in the Homescan population found that, among single-person households in 1999, those that purchased LCS-beverages made better nutrition choices regarding energy content of foods compared to CS-beverage consumers [110]. In our study we have found that compared to non/low-consumers, consumers of LCS-beverages have a lower probability of following a "Prudent" dietary pattern characterized by food groups that reflect more "home-cooking" but higher probability of adherence to a "RTE meals/Fast food" dietary pattern. However, consumers of LCS-beverages also had a high probability of following a pattern characterized by fruits, vegetables, salty snacks and desserts with LCS, which potentially reflects a "dieting" pattern. Clearly more research is needed to establish the biochemical pathways that can directly relate LCS with obesity and health outcomes. However, we have identified potential dietary patterns that link LCS consumption to increased energy intake and poor dietary quality, which could indirectly mediate the effects of LCS-beverages on overall health.

We approached this topic from two different perspectives, one looking at the long-term purchasing patterns of packaged foods and beverages at the household level, and the other was looking at the overall diet at the individual level. Household level food purchasing surveys such as Homescan are useful datasets to study home food availability, and although Homescan does not provide measures of individuals' food intake, it still captures the wide variability in the home food patterns that the members of the households are exposed to [66, 82]. In this context, it is difficult to know for example, within a household that purchases both LCS and CS-beverages, which person in the household is consuming LCS- vs. CS-beverages or both types. However, regardless of the actual eating patterns of each member in a particular household, we found that households with any type of beverage purchases are more likely to be exposed to worse dietary patterns. Unlike other studies, we were able to identify and classify sweeteners using ingredients lists in the Homescan dataset. For NHANES, we rely on the food description and the awareness of each person in their self-reported dietary intake to determine if a product has LCS, CS or both. Moreover, Homescan dietary patterns reflect long-term usual patterns because includes measures of purchases over an entire year and up to ten years of data for many of the households studied. NHANES though represents cross-sectional patterns of eating that reflect not only home eating but also away from home eating. Although we were unable to include non-store sources of foods or random weight products without barcodes (e.g. loose fruits, vegetables, nuts), packaged foods still constitute a high percent of the total energy purchase and intake. In addition, the application of dietary pattern techniques to nutritional epidemiology studies offer unique advantages such as the identification of combinations of food groups that are typically consumed together and better represent the eating behaviors of a population [111, 112]. Factor analysis is a data-driven method that is particularly valid for studies that aim to identify the major dietary patterns of a particular sample and to reproduce these dietary patterns longitudinally [111]. On the other hand, in both Homescan and NHANES we encounter several sources of bias. In Homescan, the process of recording the data is self-reported by scanning the groceries at home, which might result time-consuming for participant households. Despite the potential for misreporting errors, several reports pointed out that the overall accuracy of the dataset is consistent with other economic datasets [84, 85]. Dietary intake surveys are not exempt from both random and systematic bias. By including one day of intake, we were not able to capture usual intake patterns. Also, given the widespread perception that beverages, desserts and other junk foods are things to reduce in our diets, these food groups could potentially be under-reported by both Homescan and NHANES participants. Overall, our analyses of associations of dietary patterns do not establish causal effects and we were unable to disentangle whether the dietary pattern is a determinant of the beverage pattern or vice versa.

Our results have important public health and nutritional implications, particularly given the controversy surrounding consumption of LCS-beverages. Despite the common perception that sweetened beverages, particularly CS-beverages and more recently LCS-beverages, can have a direct effect in the risk of obesity and other cardio-metabolic outcomes, this study used novel methods to open up new ways to indirectly link consumption of LCS- and CS-beverages with poor diet quality and health. We found that any beverage consumption profile is associated with poorer dietary purchasing and dietary intake patterns. LCS-beverage consumers seem to follow two different directions, one pattern of purchases consisting in fruits, vegetables, nuts but also snacks and desserts; and another pattern characterized by more convenient food groups such as RTE meals and fast foods. We observed consistent associations with the two “Prudent” and “Breakfast” dietary intake patterns in LCS- and CS-beverage consumers in NHANES. In conclusion, although causal associations need to be further studied, this study highlights the importance of other food groups that appear to be eaten in combination with sweetened beverages in many intervention and policy efforts that aim to reduce calories and improve the dietary quality of the American diet.

Tables and Figures

Table 4.1. Population demographics, sample sizes and average sugar sweetened beverage consumption by consumer profile in Homescan 2000-2010 and NHANES 2003-2010.

HOMESCAN 2000-2010 HOUSEHOLD LEVEL	TOTAL SAMPLE	NON/LOW CONSUMERS		LCS BEVERAGES		CS BEVERAGES		LCS & CS BEVERAGES	
		Definition of consumer profiles							
Servings of LCS beverages per week		0 to <2		≥ 4		< 1		≥ 2 ≥ 3 ≥ 1	
Servings of CS beverages per week		0 to <2		< 1		≥ 4		≥ 2 ≥ 1 ≥ 3	
Total observations 2000-2010 [n, %]	501,343	221,023	42.1%	53,955	9.0%	88,176	21.1%	138,189	27.8%
Single person	136,011	88,001	61.8%	16,520	11.3%	15,981	14.4%	15,509	12.5%
Multi person without children	241,599	95,061	37.4%	30,616	11.1%	41,420	19.9%	74,502	31.6%
Multi person with children	123,733	37,961	31.2%	6,819	4.7%	30,775	28.1%	48,178	36.0%
Household sociodemographic characteristics [n, %]									
White	419,548	179,783	40.6%	49,512	10.2%	69,769	19.8%	120,484	29.4%
African-American	42,680	22,955	51.0%	1,607	3.3%	10,549	28.2%	7,569	17.4%
Hispanic	24,385	10,133	39.7%	1,789	6.0%	5,453	25.6%	7,010	28.8%
Lower income (< 185%)	88,608	39,403	41.9%	6,633	6.0%	20,578	27.3%	21,994	24.8%
Middle income (≥185 to <400%)	211,957	91,833	41.3%	19,944	7.6%	40,652	22.8%	59,528	28.3%
Higher income (≥ 400%)	200,778	89,787	42.9%	27,378	12.2%	26,946	15.6%	56,667	29.2%
Household size [mean ± SE]	501,343	2.1	± 0.0	2.0	± 0.0	2.8	± 0.0	2.9	± 0.0
Number of servings of LCS-beverages/day (mean ± SE)									
All Households	501,343	0.09	± 0.00	1.83	± 0.01	0.03	± 0.00	1.31	± 0.00
Single person	136,011	0.08	± 0.00	1.63	± 0.01	0.02	± 0.00	1.13	± 0.01
Multi person without children	241,599	0.10	± 0.00	1.91	± 0.01	0.03	± 0.00	1.35	± 0.01
Multi person with children	123,733	0.09	± 0.00	1.91	± 0.02	0.03	± 0.00	1.30	± 0.01
Number of servings of CS-beverages/day (mean ± SE)									
All Households	501,343	0.15	± 0.00	0.05	± 0.00	1.74	± 0.00	1.13	± 0.00
Single person	136,011	0.11	± 0.00	0.04	± 0.00	1.45	± 0.01	0.80	± 0.01
Multi person no children	241,599	0.16	± 0.00	0.05	± 0.00	1.72	± 0.01	1.06	± 0.00
Multi person children	123,733	0.21	± 0.00	0.06	± 0.00	1.94	± 0.01	1.35	± 0.01

NHANES 2003-2010 INDIVIDUAL LEVEL	TOTAL SAMPLE	NON/LOW CONSUMERS		LCS BEVERAGES		CS BEVERAGES		LCS & CS BEVERAGES	
		Definition of consumer profiles							
Servings of LCS beverages per day		0 to <1/4		≥ 1/2		< 1/2		≥ 1/4	
Servings of CS beverages per day		0 to <1/4		< 1/2		≥ 1/2		≥ 1/4	
Total Population [n, %]	34,393	15,236	40.6%	3,220	14.4%	14,188	38.0%	1,749	7.0%

Adults	20,971	8,828	38.7%	2,889	17.9%	8,145	36.5%	1,109	6.9%
Children	13,422	6,408	46.6%	331	3.6%	6,043	42.4%	640	7.4%
Individual sociodemographic characteristics [n, %]									
Male	16,958	6,663	34.6%	1,437	12.1%	7,996	45.9%	862	7.3%
Female	17,435	8,573	46.1%	1,783	16.6%	6,192	30.6%	887	6.7%
White	14,235	6,153	39.7%	2,128	18.0%	5,030	34.5%	924	7.8%
African-American	8,055	3,566	41.3%	406	5.6%	3,780	48.2%	303	5.0%
Hispanic	7,950	3,264	37.1%	443	6.6%	3,897	51.2%	346	5.1%
Lower income (< 185%)	15,801	6,936	40.2%	925	7.6%	7,279	46.3%	661	5.9%
Middle income (≥185 to <400%)	9,353	4,109	40.4%	954	14.2%	3,730	37.6%	560	7.8%
Higher income (≥ 400%)	9,239	4,191	41.2%	1,341	20.4%	3,179	31.2%	528	7.3%
Number of servings of LCS-beverages/day [mean ± SE]									
All	34,393	0.02	± 0.00	1.89	± 0.04	0.00	± 0.00	1.24	± 0.06
Adults	20,971	0.02	± 0.00	1.93	± 0.04	0.00	± 0.00	1.39	± 0.07
Children	13,422	0.02	± 0.00	1.27	± 0.14	0.00	± 0.00	0.83	± 0.04
Number of servings of CS-beverages/day [mean ± SE]									
All	34,393	0.06	± 0.00	0.00	± 0.00	1.88	± 0.03	1.26	± 0.04
Adults	20,971	0.05	± 0.00	0.00	± 0.00	1.99	± 0.04	1.27	± 0.05
Children	13,422	0.10	± 0.00	0.01	± 0.00	1.58	± 0.04	1.23	± 0.05

* Mean ± SE or sample size (%); Estimates were weighted to adjust for unequal probability of sampling; LCS low-calorie sweetener; CS caloric sweetener; 1 serving equals the size of a can (12 oz or 355 mL).
† Race/ethnicity is self-reported by the head of the household in Homescan or by each participant in the NHANES datasets.
‡ Ratio of family income to poverty threshold (calculated from self-reported household or individual income) was used to categorize income according to the percent of the poverty level.

Table 4.2. Dietary and purchasing patterns derived from factor analysis in the Homescan and NHANES populations.

	HOMESCAN Dietary purchasing patterns				NHANES Dietary intake patterns			
FOOD GROUPS	***Factor 1 Prudent***	***Factor 2 Breakfast***	***Factor 3 RTE meals/ Fast food***	***Factor 4 Prudent/ Snacks/ LCS desserts***	***Factor 1 Prudent***	***Factor 2 Breakfast***	***Factor 3 Protein/ potatoes***	***Factor 4 CS dessert/ CS sweetener***
WATER/OTHER DRINKS, Unsweetened								
JUICE, Sweetened, LCS								
JUICE, Sweetened, CS		0.29				0.25		
MILK, Unsweetened		0.50		-0.21		0.71		
MILK, Sweetened, LCS								
MILK, Sweetened, CS								
COFFEE/TEA, Unsweetened					0.28	-0.33		
COFFEE/TEA, Sweetened, LCS								
COFFEE/TEA, Sweetened, CS						-0.22		
ALCOHOL		-0.25				-0.33		-0.28
YOGURT, plain/unsweetened								
YOGURT, sweetened LCS								
YOGURT, sweetened CS								
CHEESE, all types	0.25	-0.24	0.20				0.27	
COOKING FAT/OIL	0.28	-0.34	-0.52	-0.23	0.25		0.22	0.36
NUTS				0.65	0.22			
DRESSINGS/SAUCES	0.24	-0.36					0.28	
PROTEIN GROUP; meat/fish/eggs	0.31	-0.38		-0.28		-0.26	0.55	-0.29
VEGETABLES	0.38			0.26	0.49			
POTATOES		-0.25		-0.27	-0.28		0.38	
FRUIT, plain	0.20			0.44	0.46	0.31		
FRUIT, processed and sweetened LCS								
FRUIT, processed and sweetened CS								
RTE MIXED/FROZEN Meals			0.67	-0.27			-0.84	
FAST FOOD Meals			0.45	-0.26	-0.61			
GRAINS, pasta/rice	0.40		-0.47		0.60			
RTE CEREAL, sweetened LCS		0.31						
RTE CEREAL, sweetened CS		0.71				0.68		
SALTY SNACKS	-0.27	-0.22		0.20	-0.25			
DESSERTS/SWEET SNACKS, LCS				0.31				

DESSERTS/SWEET SNACKS, CS	-0.92							0.72
SWEETENERS, LCS								
SWEETENERS, CS			-0.53	-0.30				0.60
OTHER			-0.24					

* Factor loadings are estimated for all food and beverage groups excluding LCS and CS-beverages in each dataset separately using standardized measures of purchases (Homescan) or intake (NHANES): % energy from each food group respect to the total energy excluding LCS- and CS-beverages. A varimax rotation is performed after the factor analysis so that the emerging factors are as different as possible and less correlated to each other. Four factors are retained in each dataset based on the Kaiser criterion (eigenvalue>1) and the interpretability of the resulting patterns. Factor loadings lower than 0.20 are not shown.

Table 4.3. Comparison of food group patterns by beverage consumption profile in the HOMESCAN and NHANES populations.

Food Groups [% kcal]	HOMESCAN Household Purchases								NHANES Individual Intake							
	Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages		Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
Juice, sweet CS	3.11	± 0.01	2.65	± 0.01	3.00	± 0.01	2.87	± 0.01	4.45	± 0.10	2.46	± 0.11[b]	2.89	± 0.08[a]	2.55	± 0.17[ab]
Milk, unsweet	4.73	± 0.01[a]	4.44	± 0.02	4.75	± 0.01[a]	4.52	± 0.01	5.32	± 0.11	3.45	± 0.13[a]	3.55	± 0.10[a]	3.14	± 0.16[a]
Cooking fats/oils	7.29	± 0.01	7.14	± 0.02	7.44	± 0.02	7.23	± 0.02	0.93	± 0.03[a]	0.75	± 0.04[b]	0.91	± 0.03[a]	0.79	± 0.05[ab]
Nuts	2.31	± 0.01	2.49	± 0.02	1.88	± 0.01	2.09	± 0.01	2.28	± 0.08[a]	2.06	± 0.13[ab]	1.51	± 0.08[c]	1.70	± 0.19[bc]
Protein groups	6.05	± 0.01	6.34	± 0.02	6.20	± 0.01	6.29	± 0.01	12.56	± 0.17	14.79	± 0.35[a]	14.11	± 0.23[a]	14.35	± 0.36[a]
Fruits and vegetables	3.16	± 0.01	3.08	± 0.01	2.71	± 0.01	2.82	± 0.01	6.30	± 0.11	5.14	± 0.16	3.99	± 0.08[a]	3.91	± 0.16[a]
RTE and fast food meals	8.05	± 0.02	8.14	± 0.02	8.39	± 0.02	8.31	± 0.02	19.87	± 0.26	23.25	± 0.48[a]	24.93	± 0.35[b]	24.85	± 0.65[ab]
Potatoes	1.72	± 0.00[a]	1.71	± 0.01[a]	1.90	± 0.01	1.85	± 0.00	3.06	± 0.08	3.78	± 0.18	4.35	± 0.11[a]	4.64	± 0.23[a]
Grains	6.06	± 0.01	5.77	± 0.02	5.71	± 0.02[a]	5.69	± 0.01[a]	11.16	± 0.15[a]	10.62	± 0.23[ab]	10.18	± 0.16[b]	10.29	± 0.26[b]
RTE cereal, sweetened CS	4.87	± 0.01	4.78	± 0.02	4.53	± 0.02	4.63	± 0.01	3.82	± 0.09[a]	3.52	± 0.13[a]	2.79	± 0.09[b]	2.79	± 0.15[b]
Salty snacks	2.61	± 0.01	2.86	± 0.01[a]	2.71	± 0.01	2.83	± 0.01[a]	3.95	± 0.08	5.43	± 0.18[a]	4.81	± 0.10[a]	5.61	± 0.26
Desserts/ sweeteners, LCS	0.74	± 0.00	1.13	± 0.01	0.55	± 0.01	0.78	± 0.00	0.42	± 0.03[b]	0.75	± 0.07[a]	0.27	± 0.02	0.59	± 0.12[ab]
Desserts/ sweeteners, CS	32.27	± 0.03	32.58	± 0.04	33.46	± 0.04	33.33	± 0.03	12.63	± 0.18[a]	11.51	± 0.31[b]	13.20	± 0.21[a]	12.85	± 0.44[ab]

* Mean ± SE; LCS low-calorie sweetener; CS caloric sweetener

† Multivariable longitudinal linear regression random effects models, adjusted for year, race, income and household size (Homescan) and multivariable linear regression, adjusting for year, age, gender, race and income (NHANES)

[a,b,c] Estimates in the same row sharing a letter are not significantly different at the 5% level, Bonferroni adjusted Student's *t* test

Supplemental Table 4.1. Food and beverage groups used in the Homescan and NHANES datasets.

FOOD CATEGORY	FOOD GROUP
Carbonated sweetened and plain beverages	Water/other drinks, unsweetened, carbonated/plain/flavored bottled water
	Sugar sweetened beverages, sweetened, LCS
	Sugar sweetened beverages, sweetened, CS
Juice [fruit juice and fruit drinks]	Sweetened, LCS
	Sweetened, CS
Milk and dairy drinks	Plain white milk & unsweetened dairy drinks
	Sweetened, LCS
	Sweetened, CS
Coffee and Tea [ready-to-drink, bags, grounds]	Unsweetened
	Sweetened, LCS
	Sweetened, CS
Alcohol	Wine, beer, alcoholic mixers
Dairy	Yogurt and other dairy, plain/unsweetened
	Yogurt and other dairy, sweetened LCS
	Yogurt and other dairy, sweetened CS
	Cheese, all types
Fats, Sauces, Dressings	Cooking fats [oil, butter] and fat-based dressings
	Nuts & nut spreads unsweetened
	Dressings/Sauces
Protein Group	Meat, fish, poultry [fresh/frozen/processed], eggs
Vegetables	All types [fresh/frozen/canned]
	Potatoes [including French fries] and starchy vegetables
Fruits	Plain [fresh/frozen/canned]
	Processed fruit, sweetened LCS
	Processed fruit, sweetened CS
Mixed, frozen, fast food meals [ready-to-eat and prepared dishes]	Grain/meat based dishes, Mexican dishes, Soups
	Sandwiches, Burgers, Pizza
Grains	Plain pasta, rice, bread, unsweetened cereal
	RTE cereals, sweetened LCS
	RTE cereals, sweetened CS
Discretionary	Salty Snacks [chips, crackers, pretzels]
	Desserts and sweet snacks, LCS [cakes, cookies, pies, ice cream, candy]
	Desserts and sweet snacks, CS [cakes, cookies, pies, ice cream, candy]
	Sweeteners, LCS [sweetener packets, jams, jellies]
	Sweeteners, CS [sugar, honey, jams, jellies]
Other	Other non-grouped food items [baby food, cooking supplies, etc]

*LCS low-calorie sweetener; CS caloric sweetener

Supplemental Table 4.2. Total daily household purchases of energy (kcal/day) and macronutrients (kcal/day, %) by beverage profile, HOMESCAN 2000-10.

	ALL HOUSEHOLDS							
	Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
LCS- and CS-beverage purchases								
Total kcal/day	56.3	± 0.4	52.9	± 0.7	191.0	± 0.6	138.6	± 0.5
Total ml/day	257.1	± 1.4	577.3	± 1.9	548.9	± 1.7	692.0	± 1.5
Total energy from purchases [kcal/day]	2824.3	± 4.3	3097.2	± 6.1	3391.6	± 5.3	3500.5	± 4.7
Total energy excluding LCS/CS	2764.7	± 4.2	3039.5	± 5.9	3208.3	± 5.1	3363.4	± 4.6
Total energy from food	2439.0	± 3.8	2706.1	± 5.4	2831.3	± 4.7	2987.9	± 4.1
Total energy from beverages excluding LCS/CS	325.8	± 0.8	332.3	± 1.2	377.8	± 1.1 [a]	375.5	± 0.9 [a]
Total energy from beverages including LCS/CS	384.3	± 1.0 [a]	387.5	± 1.5 [a]	564.9	± 1.2	513.0	± 1.1
Macronutrients [kcal/day or %]								
Carbohydrates [kcal/day]	1494.0	± 2.4	1613.6	± 3.4	1853.9	± 3.0	1873.9	± 2.6
Sugar [kcal/day]	736.2	± 1.4	771.6	± 2.0	989.4	± 1.7	954.3	± 1.5
Total Fat [kcal/day]	1008.1	± 1.7	1126.9	± 2.4	1185.2	± 2.1	1249.8	± 1.8
Protein [kcal/day]	294.7	± 0.6	331.1	± 1.0 [a]	332.7	± 0.8 [a]	359.2	± 0.7
Saturated Fat [kcal/day]	330.9	± 0.6	368.6	± 0.8	390.9	± 0.7	411.2	± 0.6
Carbohydrates [%]	52.7	± 0.0	51.8	± 0.0	54.6	± 0.0	53.5	± 0.0
Sugar [%]	25.8	± 0.0	24.6	± 0.0	29.0	± 0.0	27.1	± 0.0
Total Fat [%]	35.5	± 0.0 [a]	36.4	± 0.0	34.7	± 0.0	35.5	± 0.0 [a]
Protein [%]	10.9	± 0.0 [a]	11.0	± 0.0 [a]	9.9	± 0.0	10.3	± 0.0
Saturated Fat [%]	11.7	± 0.0 [a]	11.9	± 0.0	11.4	± 0.0	11.7	± 0.0 [a]
	SINGLE PERSON HOUSEHOLDS							
	Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
LCS- and CS-beverage purchases								
Total kcal/day	27.7	± 0.5	23.1	± 0.8	160.7	± 0.8	99.1	± 0.8
Total ml/day	146.9	± 1.6	458.2	± 2.4	429.1	± 2.4	537.5	± 2.3
Total energy from purchases [kcal/day]	1646.7	± 5.1	1818.4	± 7.4	1999.1	± 7.5	2087.7	± 7.1
Total energy excluding LCS/CS	1616.1	± 5.0	1790.4	± 7.2	1852.9	± 7.3	1991.6	± 7.0
Total energy from food	1419.2	± 4.6	1596.8	± 6.6	1629.7	± 6.7	1764.3	± 6.3
Total energy from beverages excluding LCS/CS	197.1	± 1.1	193.3	± 1.6	223.2	± 1.6 [a]	226.9	± 1.5 [a]
Total energy from beverages including LCS/CS	227.3	± 1.2	219.5	± 1.8	372.8	± 1.9	323.4	± 1.8
Macronutrients [kcal/day or %]								
Carbohydrates [kcal/day]	856.5	± 2.8	930.7	± 4.2	1096.5	± 4.2	1110.3	± 4.0
Sugar [kcal/day]	425.1	± 1.7	445.3	± 2.5	609.7	± 2.5	577.8	± 2.4
Total Fat [kcal/day]	589.8	± 2.0	668.5	± 3.0	690.0	± 3.0	744.1	± 2.8
Protein [kcal/day]	174.3	± 0.9	195.9	± 1.4 [a]	196.0	± 1.4 [a]	214.4	± 1.3

	Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
Saturated Fat [kcal/day]	194.8	± 0.7	220.5	± 1.0	229.6	± 1.0	246.2	± 1.0
Carbohydrates [%]	52.3	± 0.1	51.3	± 0.1	55.1	± 0.1	53.3	± 0.1
Sugar [%]	25.8	± 0.1	24.5	± 0.1	30.2	± 0.1	27.5	± 0.1
Total Fat [%]	35.4	± 0.0 [a]	36.5	± 0.1	33.9	± 0.1	35.2	± 0.1 [a]
Protein [%]	11.1	± 0.1 [b]	11.0	± 0.2 [b]	10.0	± 0.2 [a]	10.4	± 0.1 [a]
Saturated Fat [%]	11.7	± 0.0 [a]	12.0	± 0.0	11.3	± 0.0	11.7	± 0.0 [a]

	MULTI PERSON HOUSEHOLDS WITHOUT CHILDREN							
	Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
LCS- and CS-beverage purchases								
Total kcal/day	56.2	± 0.6	51.3	± 0.9	190.8	± 0.8	134.4	± 0.6
Total ml/day	277.3	± 2.0	605.0	± 2.7	567.2	± 2.4	711.8	± 2.1
Total energy from purchases [kcal/day]	3003.2	± 5.9	3232.0	± 7.8	3495.2	± 7.2	3576.8	± 6.1
Total energy excluding LCS/CS	2942.8	± 5.8	3174.8	± 7.6	3313.0	± 7.0	3443.7	± 6.0
Total energy from food	2601.4	± 5.3	2831.3	± 6.9	2931.8	± 6.4	3067.1	± 5.4
Total energy from beverages excluding LCS/CS	341.7	± 1.2 [a]	342.3	± 1.7 [a]	382.5	± 1.5	376.6	± 1.3
Total energy from beverages including LCS/CS	400.7	± 1.4 [a]	396.5	± 1.9 [a]	568.9	± 1.8	509.9	± 1.5
Macronutrients [kcal/day or %]								
Carbohydrates [kcal/day]	1557.1	± 3.3	1651.3	± 4.3	1874.5	± 4.0 [a]	1879.9	± 3.4 [a]
Sugar [kcal/day]	759.4	± 1.9	779.4	± 2.5	992.4	± 2.3	947.9	± 2.0
Total Fat [kcal/day]	1091.1	± 2.4	1195.7	± 3.2	1244.4	± 2.9	1299.9	± 2.5
Protein [kcal/day]	314.1	± 0.9	347.4	± 1.4 [a]	344.3	± 1.2 [a]	370.1	± 1.0
Saturated Fat [kcal/day]	354.6	± 0.8	387.4	± 1.1	407.4	± 1.0	424.2	± 0.8
Carbohydrates [%]	51.9	± 0.0	51.0	± 0.0	53.7	± 0.0	52.6	± 0.0
Sugar [%]	25.1	± 0.0	23.9	± 0.0	28.2	± 0.0	26.3	± 0.0
Total Fat [%]	36.1	± 0.0 [a]	36.9	± 0.0	35.3	± 0.0	36.0	± 0.0 [a]
Protein [%]	10.8	± 0.0	11.0	± 0.0	9.8	± 0.0	10.3	± 0.0
Saturated Fat [%]	11.7	± 0.0	11.9	± 0.0	11.6	± 0.0	11.8	± 0.0

	MULTI PERSON HOUSEHOLDS WITH CHILDREN							
	Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
LCS- and CS-beverage purchases								
Total kcal/day	79.5	± 1.1 [a]	78.2	± 2.1 [a]	232.8	± 1.2	185.2	± 1.0
Total ml/day	309.4	± 3.1	657.3	± 5.7	640.8	± 3.3	802.2	± 2.9
Total energy from purchases [kcal/day]	3714.0	± 10.5	4141.8	± 19.4	4485.1	± 11.1	4636.0	± 9.7
Total energy excluding LCS/CS	3629.6	± 10.2	4056.8	± 18.8	4258.2	± 10.7	4451.9	± 9.4
Total energy from food	3192.0	± 9.1	3598.5	± 16.9	3746.0	± 9.7	3939.6	± 8.5
Total energy from beverages excluding LCS/CS	437.1	± 2.0	457.9	± 3.6	512.7	± 2.1 [a]	512.9	± 1.8 [a]
Total energy from beverages including LCS/CS	520.6	± 2.4	541.1	± 4.4	741.3	± 2.5	697.1	± 2.2
Macronutrients [kcal/day or %]								
Carbohydrates [kcal/day]	2035.7	± 6.0	2233.7	± 11.1	2510.2	± 6.3	2555.0	± 5.5

Sugar [kcal/day]	1015.8	± 3.5	1086.9	± 6.5	1336.3	± 3.7	1314.0	± 3.2
Total Fat [kcal/day]	1289.5	± 3.9	1463.4	± 7.3	1537.0	± 4.2	1614.8	± 3.7
Protein [kcal/day]	390.1	± 1.3	443.3	± 2.6 [a]	441.8	± 1.4 [a]	471.8	± 1.2
Saturated Fat [kcal/day]	427.7	± 1.4	483.7	± 2.5	511.0	± 1.4	536.2	± 1.3
Carbohydrates [%]	54.8	± 0.0	53.8	± 0.1	56.1	± 0.0	55.2	± 0.0
Sugar [%]	27.2	± 0.0	25.9	± 0.1	29.8	± 0.0	28.3	± 0.0
Total Fat [%]	34.6	± 0.0 [a]	35.3	± 0.1	34.1	± 0.0	34.7	± 0.0 [a]
Protein [%]	11.0	± 0.0	11.3	± 0.1	9.6	± 0.0	10.1	± 0.0
Saturated Fat [%]	11.5	± 0.0 [a]	11.7	± 0.0	11.3	± 0.0	11.5	± 0.0 [a]

* Mean ± SE; LCS low-calorie sweetener; CS caloric sweetener
** Total energy excluding LCS/CS includes total energy from foods plus energy from all beverages excluding LCS/CS
† Multivariable longitudinal linear regression random effects models, adjusted for year, race, income and household size
[a,b] Estimates in the same row sharing a letter are not significantly different at the 5% level, Bonferroni adjusted Student's *t* test

Supplemental Table 4.3. Total daily intake of energy (kcal/day) and macronutrients (kcal/day, %) by beverage profile, NHANES 2003-2010.

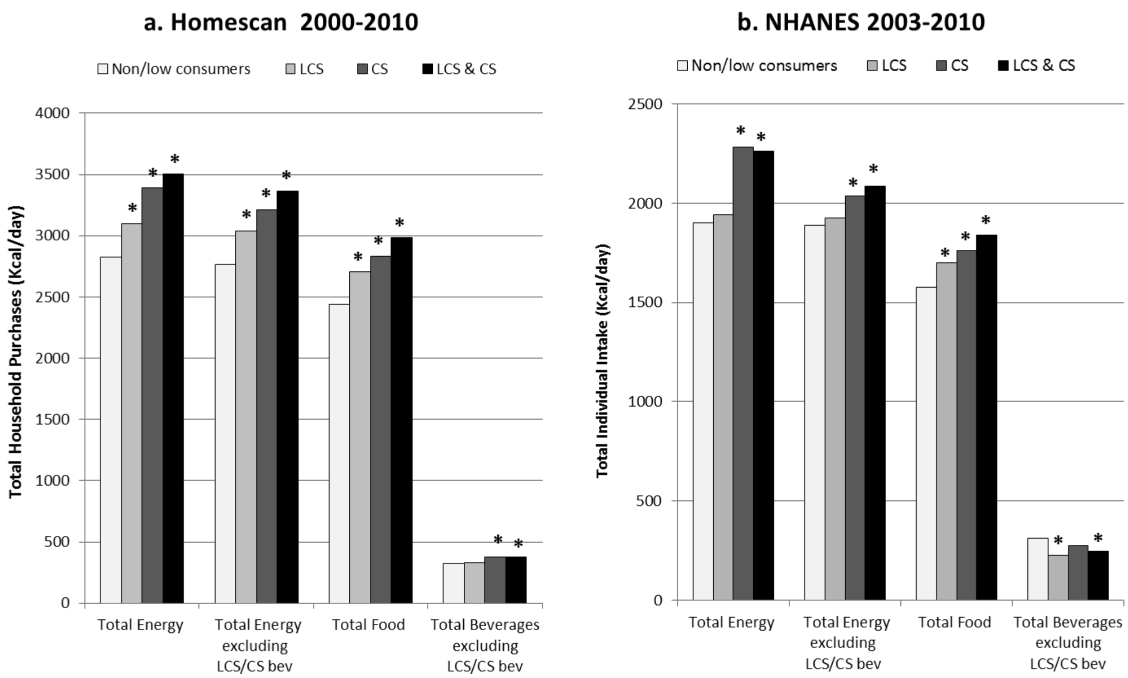
	ALL PARTICIPANTS >2 years old							
	Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
LCS- and CS-beverage intake								
Total kcal/day	11.5	± 0.6	18.3	± 1.3	248.0	± 4.4	175.6	± 6.2
Total ml/day	36.9	± 2.0	675.0	± 15.5 [a]	658.7	± 11.1 [a]	880.4	± 24.4
Total energy intake [kcal/day]	1901.4	± 13.7 [a]	1944.1	± 16.9 [a]	2284.8	± 13.9 [b]	2262.5	± 24.5 [b]
Total energy excluding LCS/CS	1889.9	± 13.7 [a]	1925.8	± 16.8 [a]	2036.8	± 15.1 [b]	2086.9	± 21.7 [b]
Total energy from food	1576.0	± 11.7	1699.9	± 16.6	1761.2	± 12.5	1841.4	± 20.2
Total energy from beverages excluding LCS/CS	313.9	± 3.9	225.9	± 5.9 [a]	275.6	± 5.1	245.5	± 8.9 [a]
Total energy from beverages including LCS/CS	325.4	± 4.0	244.2	± 6.1	523.7	± 5.8	421.1	± 12.1
Macronutrients [kcal/day or %]								
Carbohydrates [kcal/day]	936.9	± 6.9	884.1	± 10.9	1177.7	± 7.1	1102.8	± 12.2
Sugar [kcal/day]	416.3	± 3.3	338.1	± 6.4	599.6	± 4.7	506.9	± 8.3
Total Fat [kcal/day]	643.5	± 5.9	706.3	± 8.7	754.6	± 6.0	792.7	± 11.1
Protein [kcal/day]	304.7	± 2.2	328.4	± 3.2 [a]	328.3	± 2.3 [a]	336.5	± 5.1 [a]
Saturated Fat [kcal/day]	216.0	± 2.1	233.1	± 3.0	255.0	± 2.4 [a]	264.2	± 4.1 [a]
Carbohydrates [%]	50.0	± 0.2 [a]	46.0	± 0.3	52.1	± 0.2	49.4	± 0.3 [a]
Sugar [%]	22.3	± 0.1 [a]	17.6	± 0.2	26.7	± 0.2	22.8	± 0.2 [a]
Total Fat [%]	33.3	± 0.1	35.9	± 0.3	32.6	± 0.1	34.7	± 0.3
Protein [%]	16.2	± 0.1	17.2	± 0.1	14.5	± 0.1	15.0	± 0.1
Saturated Fat [%]	11.2	± 0.1 [a]	11.9	± 0.1 [b]	11.0	± 0.1 [a]	11.5	± 0.1 [b]
	ADULTS >19 years old							
	Non/low consumers		LCS Beverages		CS Beverages		LCS & CS Beverages	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
LCS- and CS-beverage intake								
Total kcal/day	15.8	± 1.1	20.5	± 1.5	257.6	± 5.2	176.8	± 7.7
Total ml/day	50.8	± 3.5	697.7	± 15.3 [a]	677.5	± 12.9 [a]	922.7	± 30.4
Total energy intake [kcal/day]	2011.1	± 15.7 [a]	1972.4	± 18.1 [a]	2278.9	± 17.9 [b]	2257.4	± 32.4 [b]
Total energy excluding LCS/CS	1995.3	± 15.9 [ab]	1951.8	± 17.9 [b]	2021.3	± 18.7 [a]	2080.6	± 29.9 [a]
Total energy from food	1678.9	± 12.9 [a]	1731.1	± 17.7 [ab]	1746.1	± 15.4 [b]	1837.9	± 28.4
Total energy from beverages excluding LCS/CS	316.4	± 5.4	220.7	± 6.4 [a]	275.2	± 6.2 [b]	242.6	± 11.7 [ab]
Total energy from beverages including LCS/CS	332.2	± 5.5	241.3	± 6.8	532.8	± 6.9	419.4	± 15.7
Macronutrients [kcal/day or %]								
Carbohydrates [kcal/day]	959.6	± 7.9	881.7	± 11.3	1166.9	± 8.9	1080.9	± 15.1
Sugar [kcal/day]	407.5	± 4.3	328.5	± 6.5	599.2	± 5.9	493.2	± 9.9
Total Fat [kcal/day]	684.9	± 7.3	718.1	± 9.2	751.0	± 7.5 [a]	792.6	± 14.8 [a]
Protein [kcal/day]	331.1	± 2.7 [a]	337.8	± 3.2 [a]	328.0	± 3.0 [a]	339.7	± 5.8 [a]
Saturated Fat [kcal/day]	224.8	± 2.8 [a]	233.8	± 3.1 [a]	251.6	± 2.9 [b]	263.3	± 5.4 [b]
Carbohydrates [%]	48.3	± 0.2 [a]	45.2	± 0.3	51.8	± 0.2	48.6	± 0.3 [a]

	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
Sugar [%]	20.6	± 0.2	16.8	± 0.2	26.7	± 0.2	22.3	± 0.3
Total Fat [%]	33.5	± 0.2	35.9	± 0.2	32.6	± 0.2	34.7	± 0.3
Protein [%]	16.7	± 0.1	17.5	± 0.1	14.5	± 0.1	15.2	± 0.2
Saturated Fat [%]	10.9	± 0.1 [a]	11.7	± 0.1 [b]	10.9	± 0.1 [a]	11.5	± 0.1 [b]

	CHILDREN 2-18 years old							
	Non/low consumers		**LCS Beverages**		**CS Beverages**		**LCS & CS Beverages**	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
LCS- and CS-beverage intake								
Total kcal/day	27.8	± 1.9	0.5	± 2.3	195.5	± 4.5	151.7	± 6.0
Total ml/day	81.4	± 5.2	394.8	± 26.9	527.1	± 11.9	697.4	± 19.4
Total energy intake [kcal/day]	1819.6	± 15.4 [a]	1774.5	± 47.4 [a]	2089.2	± 17.3 [b]	2118.1	± 40.4 [b]
Total energy excluding LCS/CS	1791.8	± 16.0 [a]	1775.0	± 46.6 [a]	1893.7	± 16.3 [ab]	1966.4	± 39.3 [b]
Total energy from food	1469.2	± 14.6 [a]	1529.5	± 36.7 [ab]	1627.1	± 15.5 [bc]	1720.1	± 35.9 [c]
Total energy from beverages excluding LCS/CS	322.6	± 6.2	245.5	± 17.2 [a]	266.6	± 5.0 [a]	246.4	± 11.9 [a]
Total energy from beverages including LCS/CS	350.4	± 6.4	245.1	± 17.6	462.1	± 5.7	398.1	± 13.2
Macronutrients [kcal/day or %]								
Carbohydrates [kcal/day]	958.8	± 9.1 [a]	876.5	± 35.7 [a]	1133.3	± 9.4 [b]	1108.8	± 20.8 [b]
Sugar [kcal/day]	461.0	± 5.4	380.4	± 23.8	587.5	± 5.3	536.3	± 11.3
Total Fat [kcal/day]	603.9	± 6.3 [a]	633.7	± 20.0 [a]	691.7	± 7.4 [b]	739.6	± 18.5 [b]
Protein [kcal/day]	274.4	± 2.8 [a]	280.5	± 7.5 [a]	285.8	± 2.5 [a]	294.3	± 7.7 [a]
Saturated Fat [kcal/day]	213.7	± 2.1 [b]	223.2	± 9.0 [ab]	244.6	± 2.8 [a]	252.2	± 6.4 [a]
Carbohydrates [%]	53.0	± 0.2 [a]	49.2	± 1.1	54.7	± 0.2	52.9	± 0.5 [a]
Sugar [%]	25.5	± 0.2 [a]	21.4	± 1.0	28.6	± 0.2	25.8	± 0.4 [a]
Total Fat [%]	32.8	± 0.2 [a]	35.7	± 0.8 [b]	32.7	± 0.2 [a]	34.4	± 0.4 [b]
Protein [%]	15.2	± 0.1 [b]	16.0	± 0.4 [b]	13.7	± 0.1 [a]	13.9	± 0.1 [a]
Saturated Fat [%]	11.6	± 0.1 [a]	12.6	± 0.4 [a]	11.6	± 0.1 [a]	11.8	± 0.2 [a]

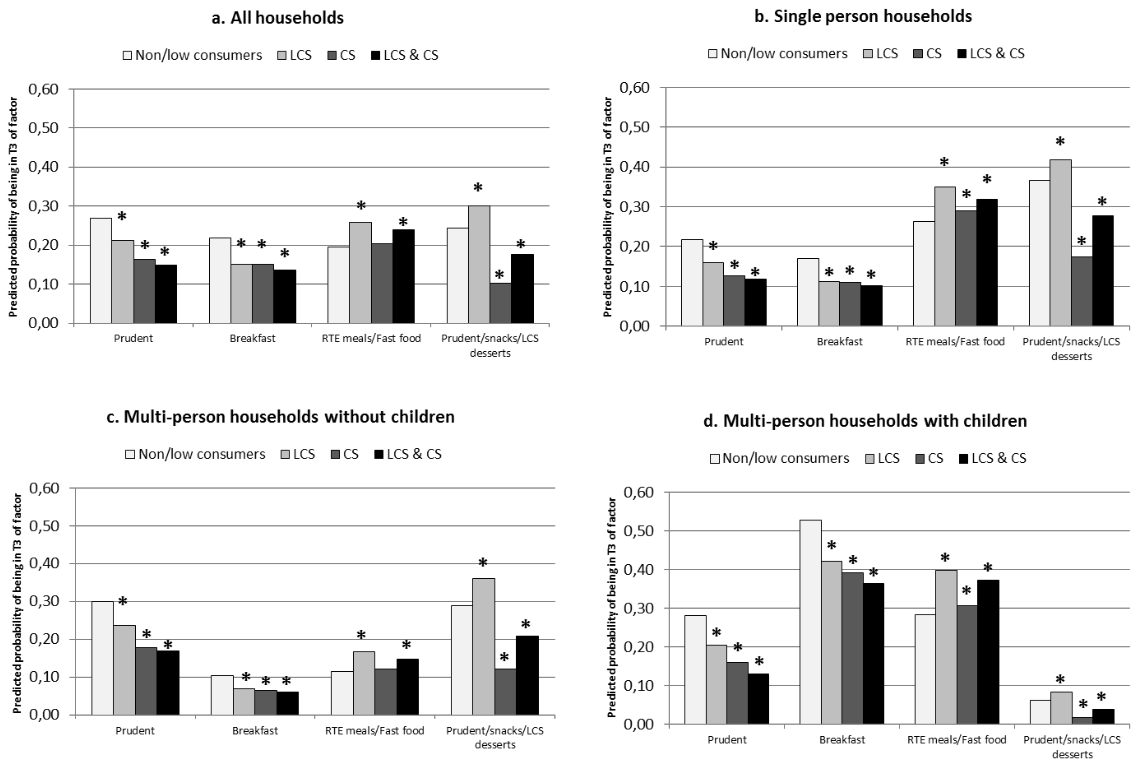
* Mean ± SE; LCS low-calorie sweetener; CS caloric sweetener
** Total energy excluding LCS/CS includes total energy from foods plus energy from all beverages excluding LCS/CS
† Multivariable linear regression, adjusting for year, age, gender, race and income
[a,b,c] Estimates in the same row sharing a letter are not significantly different at the 5% level, Bonferroni adjusted Student's *t* test

Figure 4.1a-b. Total daily household purchases in Homescan and individual intake in NHANES (kcal/day)**



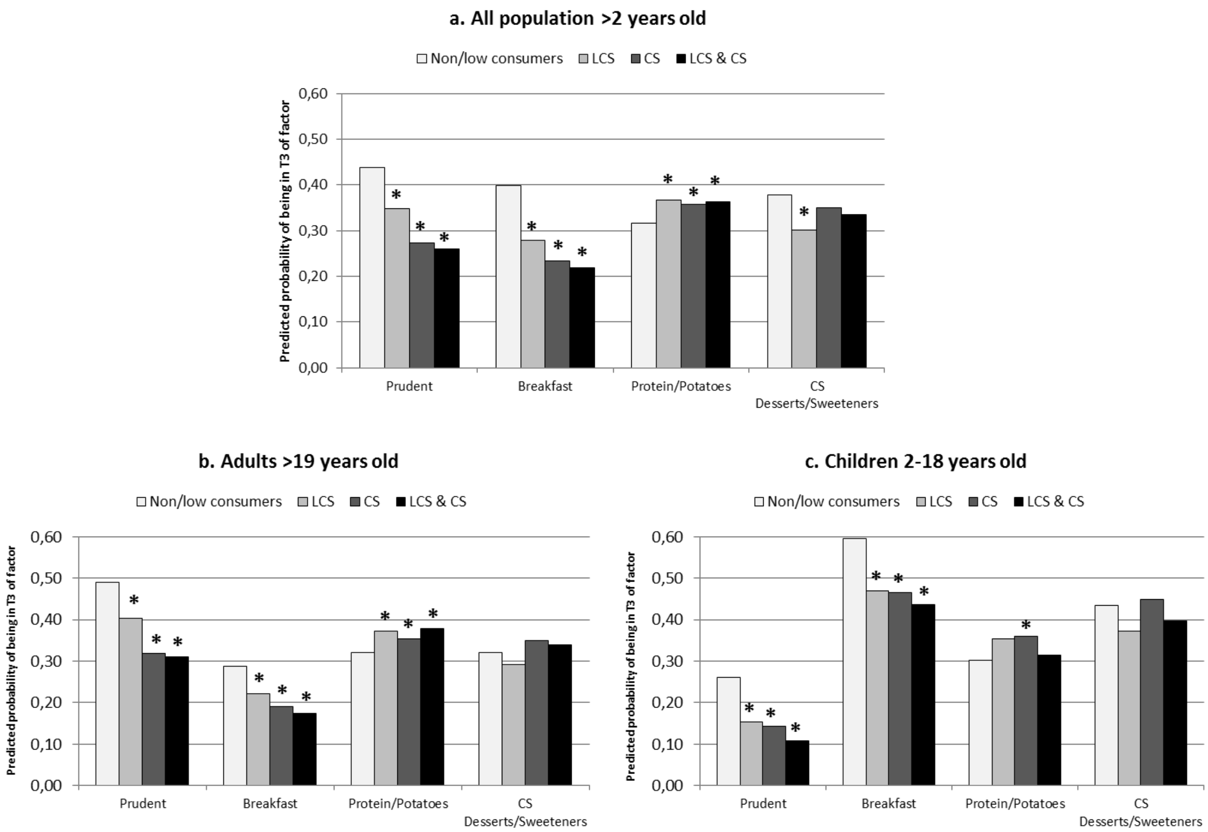
** Mean kcal/day per household in Homescan (a) or individual in NHANES (b). LCS, low-calorie sweetened beverages; CS, caloric-sweetened beverages
* Significantly different from non-consumer, $P<0.05$ Bonferroni adjusted

Figure 4.2a-d. Relationships between beverage consumption profiles and dietary purchasing patterns, HOMESCAN 2000-2010**



** Predicted probability of being in the highest tertile (T3) for each dietary pattern from random-effects longitudinal logistic regression models, adjusting for household size, year, income, race/ethnicity; with interaction between the beverage profile and household type (b-d). LCS, low-calorie sweetened beverages; CS, caloric-sweetened beverages * Significantly different from non-consumer, P<0.05 Bonferroni adjusted

Figure 4.3a-c. Relationships between beverage consumption profiles and dietary intake patterns, NHANES 2003-2010**



** Predicted probability of being in the highest tertile (T3) for each dietary pattern from logistic regression models, adjusting for age, gender, race/ethnicity and income. Stratified models were performed to obtain estimates for adults and children separately (b-c). LCS, low-calorie sweetened beverages; CS, caloric-sweetened beverages

* Significantly different from non-consumer, P<0.05 Bonferroni adjusted

Chapter 5. Dynamic Modeling of the Effect of Low Calorie- and Caloric-Sweetened Beverages on Dietary Quality and Food Purchasing Patterns

Overview

Most health related research tends to examine either the effect of beverage consumption itself or the effect of overall energy intake. We investigated if beverages with caloric- (CS) and low-calorie-sweeteners (LCS) had a negative effect on dietary quality and dietary patterns. We analyzed purchases from the Homescan longitudinal dataset 2000-10 (n=136,011 observations from n=34,294 individuals). Beverages were classified by using keyword searches for caloric- (CS) and low-calorie sweeteners (LCS). Purchases of LCS and CS-beverage were modeled as main exposures (mL/day) in models predicting dietary quality and food patterns. Dietary quality was defined using total purchases in terms of macronutrients and overall calories (kcal/day); and food patterns using purchases of food and beverage groups (kcal/day). To estimate the effect of LCS- and CS-beverages on dietary quality and food patterns, we used a dynamic model that includes instrumental variables to control for unmeasured confounding and autocorrelation of explanatory variables over time. This model included current diet as main outcome and prior or lagged diet and beverage consumption as main explanatory variables, plus other socio-demographic covariates.

From 2000-2010, purchases in terms of energy intake, macronutrients and most food and beverage groups decreased in the Homescan population. Despite secular declines in calories from all sources, an increase in one serving per day of either CS- or LCS-beverages was associated with increased total daily energy, energy from food, and increased daily energy from carbohydrates, total sugar, and total fat ($P<0.05$). We also found that increasing one serving of either beverage per day was associated with increased purchases of caloric desserts/sweeteners (kcal/day) ($P<0.05$), which accounted for an important proportion of the increase in total energy (excluding CS and LCS-beverages). Using an advanced statistical method and classification approach, we showed that consumers of LCS- and/or CS-beverages had poorer dietary quality and increased purchases of overall energy, carbohydrates, sugar, and caloric desserts and sweeteners compared to non-consumers.

Introduction

Although the majority of food and beverage products consumed in the U.S. contain caloric-sweeteners (CS), consumption of low calorie sweeteners (LCS) such as aspartame, saccharin or stevia in foods and beverages has increased rapidly over the past 30 years [59, 100]. This trend will continue rising as people become more health conscious and after the implementation of national policies and industry efforts that encourage manufacturers to reformulate and reduce the energy density of food products [62, 63].

Increased consumption of caloric-sweetened beverages (CS-beverages) has been generally associated with higher caloric intake and adverse health outcomes [12, 95], whether the same association is still unclear for low-calorie sweetened beverages (LCS- beverages) [9, 14, 23, 36, 37]. Most health related research tends to examine either the effect of beverage consumption itself or the effect of overall energy intake, but the overall effect of CS- and LCS-beverages on dietary quality and food patterns still needs to be investigated.

A few studies have reported cross-sectional associations of healthier dietary patterns with healthier beverage patterns (i.e. intake of water associated with higher intake of vegetables and fruits) [36, 108, 113]. However, investigating the prospective relationship between CS- and LCS-beverages and dietary quality is more challenging because it is difficult to disentangle if there is a particular dietary pattern that is linked to a particular beverage pattern or if specific beverage patterns could explain adherence to a particular diet pattern. In addition, there might be unobserved common factors (i.e. obesity, diabetes, or individual preferences) that drive beverage and dietary patterns in the same direction. Such effect could be explained by traditional epidemiological issues such as reverse causality, unmeasured confounding or measurement error, which are jointly known as endogeneity in econometrics [100, 114]. Endogeneity could contribute to biased and inconsistent estimates of association when examining the association between CS- and LCS-beverage consumption and diet if the above mentioned problems are not adequately addressed [115].

For this study, we implemented a dynamic model using longitudinal measures of yearly purchases by individuals included in the Nielsen Homescan panel dataset 2000-2010 to investigate the association between beverage consumption and dietary quality and food patterns over time. This dynamic model includes market level variables as instrumental variables to control for bias due to endogeneity and also includes a lag structure for several dependent variables selected on the basis of specification tests and supported by the data. This approach allows current diet to depend on prior or lagged diet and beverage consumption, while accounting for endogeneity, correlated errors for the same individual over time, and autocorrelation of diet and beverage consumption. Using this advanced method, we investigated the complex dynamics of diet and food purchasing patterns of CS- and LCS-beverage consumers.

Methods

Study Design and Population

We included household purchasing data from the Nielsen Homescan Consumer Panel dataset (The Nielsen Co.) [64] from 2000-2010. Homescan is an ongoing nationally representative longitudinal survey of 35,000 to 65,000 households per year that contains information on consumer purchases of more than 600,000 barcoded products (more than 170,000 uniquely formulated products) that are sold from all major grocery, drug, mass-merchandise, club, supercenter and convenience stores in 76 markets around the U.S. over this period [60]. Participating households are provided with home scanners with which they record food purchases for every shopping event. Since Homescan captures purchases, only single-person adult households were selected from 2000-2010 (n=136,011 observations from n=34,294 individuals) so that purchasing patterns better reflect individuals' dietary patterns. Households included in Homescan are sampled and weighted to be nationally representative. Overall, calories from Homescan food purchase data represent approximately two-thirds of the total caloric intake [102]. The Homescan dataset has been used frequently by researchers to analyze food demand, consumption and sale strategies [60, 66].

Food Grouping System and Nutrition Facts Panel Data

Purchases of all foods and beverages are grouped into 51 mutually exclusive food and 11 beverage categories by Nielsen. Information on ingredients lists was also used to categorize all foods and beverages with sweeteners using keyword searches for caloric- (CS) and low-calorie sweeteners (LCS). LCS are defined as food additives that provide <3.8 kcal/g and/or are used in very low quantities so that the caloric amount they provide is negligible. All other sweeteners that provide ≥3.8 kcal/g are considered as caloric sweeteners (CS) as this cut-point reflects the caloric value of a gram of carbohydrate. A detailed list of key terms is available elsewhere [58]. Briefly, keyword searches included terms such as "sugar", "high fructose corn syrup", "sucralose" or "aspartame" among others and were performed on the ingredient lists available for each barcoded product [58]. All foods and beverages purchased in Homescan were finally grouped into 9 beverage and 14 food groups. Dairy-based, grain-based and sweeteners were grouped together in the same group as they represent the major source of LCS and CS in food products. Concentrated or powder products were reconstituted to ready-to-drink form.

Each uniquely barcoded product captured in Homescan has been linked with Nutrition Facts Panel (NFP) data and ingredient information using the commercial Gladson Nutrition Database and the

Mintel's Global New Product Database [65, 102]. Gladson and Mintel contain national brands and private label items and these data are updated weekly as new products enter the market. Further details regarding matching these commercial datasets and other methodological facts are available in the following sources. To ensure comparability across products, we applied weighted factors to those items sold as concentrates (e.g., beverage powders) to reflect the volume of the product in the "ready to drink/eat" form. NFP information used in this study included total calories, calories from carbohydrates, total sugar, total fat, protein and saturated fat [62].

Statistical Analysis

Descriptive Statistics

All analyses were performed using Stata 12 (StataCorp, Stata Statistical Software, Release 12, 2011). Survey commands were used to account for survey design and weighting to generate nationally representative results. Households included in Homescan reported several socio-demographic (SES) characteristics and other information including gender and age of each family member; and income, education and race/ethnicity. Race/ethnicity was used to classify participants as Hispanic, non-Hispanic White, non-Hispanic African-American and Others. Age was used to separate adults (<19 y-old) and children (2-18 y-old). The ratio of self-reported income to the poverty threshold was used to categorize income according to the percent of the poverty level: "Lower income, <185%", "Middle income, ≥185-<400%" and "Higher income, ≥400%".

Outcome Specification: Dietary Quality and Food Patterns

The outcomes used in the models were obtained using measures of purchases in terms of total energy (kcal/day); total energy excluding LCS- and CS-beverages; total energy from beverages; energy from foods; total energy from macronutrients (kcal/day), including carbohydrates, total sugar, total fat, protein and saturated fat. Finally, we performed the same analyses using measures of purchases of other foods and beverages groups. We used measures of purchases per year to obtain estimates of total energy, macronutrients and food and beverage groups per day.

Exposure Specification: Sugar-Sweetened Beverage Consumption

Beverages, including carbonated beverages and sweetened-flavored waters, were classified as LCS- and CS-beverages by using keyword searches for caloric- (CS) and low-calorie sweeteners (LCS) using the approach described above. Estimates of servings purchased of beverages per day were obtained by dividing the total volume (mL) of beverages purchased per day by a standard serving size of a can (355 mL). Purchases of LCS- and CS-beverages are modeled as main exposures, so that each of the coefficients obtained from the model represent the predicted increase in the outcome variable in relation to an increase in one serving of each type of beverage. For each outcome, margins commands were used after the fully adjusted models to predict the mean energy purchased (kcal/day) for every serving purchased of LCS-, CS- and for non-beverage consumers. To define each beverage consumer in the margins commands, we specified an increase in 1 serving per day of LCS-beverages but zero servings of CS-beverages for LCS-beverage consumers and vice-versa for CS-beverage consumers. For non-consumers, margins commands were specified using zero servings per day of each LCS- and CS-beverages.

Endogenous Variables

Endogeneity arises in a longitudinal model when one or more explanatory variables are correlated with the error term, which might be caused by unmeasured confounding, reverse causality or measurement error [115]. In our context, endogeneity might happen because an individual that chooses to purchase certain type of beverages also chooses other foods and beverages simultaneously. These choices that are jointly made are likely correlated with unobservable individual characteristics and serially correlated because of preferences, addictions and other unobserved heterogeneity. Endogeneity could contribute to biased and inconsistent estimates of association if these issues are not adequately addressed in the model. Given the above mentioned reasons, purchases of LCS- and CS-beverages are potentially endogenous variables in our models.

Instrumental Variables

In econometrics and more recently in epidemiology, instrumental variables are being used to correct bias due to endogeneity by providing adequate variables that predict endogenous variables [114]. Valid instrumental variables (IVs) should be correlated with endogenous explanatory variables in the model, conditional on the other covariates, but should not be directly associated with the outcome or with the time-varying error term in the model. IVs should not be associated with the dependent variable of interest other than through the endogenous explanatory variables. At minimum, one needs as many IVs as there are endogenous explanatory variables in the model, but additional IVs may lead to more stable parameter estimates. For the present analyses, several market-level IVs were considered as potential IVs, including prices and the proportion of sales of LCS- and CS-beverages in each market; plus the average number of shopping trips per year. Using information on prices paid by participating households, we created the weighted average price per 100 mL for LCS- and CS-beverages for each market. Prices used in this study are real prices adjusted by the inflation rate and costs of living (scaled using the first quarter of 2000 in Los Angeles). We also calculated the proportion of beverage sales of both LCS- and

CS-beverages in each market and finally the average number of household shopping trips for each market and year. If these instruments are exogenous to the outcomes and vary over space and time, then they will be ideal instruments.

Dynamic Panel Model

For this study, we started with a theoretical model where we estimated which variables were endogenous and hence correlated with the error terms, and which variables could be used as potential instruments. There are several considerations to account for when modeling the dynamics of diet and beverage consumption. For example, we assumed that one period model (e.g. diet at time *t*) depends on past values of the outcome (e.g. diet at time *t-1*) plus other explanatory covariates (e.g. beverage at time *t-1*). Our empirical dynamic model relates diet in the current wave to its own lagged value along with lagged measured LCS- and CS-beverage consumption, other time-varying and time-invariant covariates and the error terms (Equation 1):

$$D_{it} = \alpha D_{i,t-1} + \beta B_{i,t-1} + \gamma X_i + \pi Z_{it} + \mu_i + \varepsilon_{it} \qquad (1)$$

$$i = 1, \ldots n \text{ individuals}; \; t = 1, \ldots, n \text{ years}$$

Where D_{it} denotes diet in the current wave; $D_{i,\,t-1}$ denotes diet in the prior wave; $B_{i,\,t-1}$ correspond to continuous lagged values of beverage consumption (servings of LCS- and CS-beverages per day); X_i

is a vector of time invariant covariates (i.e. gender, race); Z_{it} denotes other time-varying control variables, such as age, education and income; α, β, γ, π indicate the vectors of coefficients for the explanatory variables. The error terms are μ_i which represents unobserved time invariant individual characteristics; and ε_{it} that represents the time varying error term. The β coefficients can be interpreted in this model as the increase in the outcome variable for every increase in servings/day of LCS- or CS-beverages.

There are several assumptions to account for in this model. As was previously discussed, there might be correlation between explanatory variables and μi; which results in endogeneity. Also, there might be correlation between explanatory variables and ε_{it}; which results in double endogeneity. Finally, another issue that could affect our results is the serially correlated error terms over time due to individuals' time invariant unobserved heterogeneity, which will result in incorrect standard errors. This correlation of the time varying error ε_{it} over time it's known as autocorrelation. At minimum, we can expect to find that lagged diet is correlated with μ_i so that instrumental variables have to be used to account for it. Another option is to calculate a first difference equation so that μ_i and other time invariant covariates are dropped (Equation 2):

$$\Delta D_{it} = \alpha\ [\Delta D_{i,t-1}] + \beta\ [\Delta B_{i,\ t-1}] + \pi Z_{it} + \Delta\varepsilon_{it} \qquad (2)$$

i= 1, …n individuals; t=1, …, n years

Given the challenges discuss in relation to endogeneity and auto-correlated errors over time, the estimation method used in this study was the generalized method of moments (GMM) developed by Blundell and Bond [116, 117]. This GMM system is useful to estimate equation 1 and 2 simultaneously because implements a large set of moment conditions and includes simultaneously two transformations of the equation of interest, the regression-in-differences (Equation 2) and the regression-in-levels. In the first difference equations, the time invariant error term and other time invariant observed variables are dropped assuming that the time varying error is not correlated with the explanatory variables. For the GMM system approach, we used lagged second and third differences as IVs for the regression-in-differences. Standard IVs such as prices, shopping trips and market sales were used in both the regression-in-differences and the regression-in-levels. Each additional wave adds additional valid instruments for any of the endogenous explanatory variables since there are additional time varying IVs.

Specification and Statistical Tests

We examined the relationship between the IVs and the explanatory variables in order to include the IVs that have best correlation with the explanatory endogenous variables. Then we used the Sargan-Hansen J test to investigate if the instruments used in the model were uncorrelated with the error terms and hence completely exogenous so that the model is correctly specified [118]. Failure to reject the null hypothesis of over-identification indicates that the assumptions made about exogeneity of the IVs are valid. Finally, we performed the Arellano-Bond test of autocorrelation to investigate if there was a second order autocorrelation in the regression-in-differences, which would invalidate the lagged differences as IVs [118]. Although first order autocorrelation might be expected, failure to reject the null hypothesis of no second order autocorrelation will indicate that lagged values of the endogenous variables are valid IVs for the regression-in-differences.

All models were adjusted for age, gender, education, race/ethnicity, income and year since there variables were found to be differentially associated with LCS- and CS-beverage consumption over this period of time [100]. Estimates are presented as beta coefficients (SE) and means (SE). Statistically significant differences between consumers of LCS- and CS-beverage were tested using Student's *t*-tests with the Bonferroni correction. Linear trends were tested using Wald tests. A two sided *p*-value of <0.05 was set to denote statistical significance.

Results

Single person households selected from Homescan were mostly middle-aged adults, predominantly non-Hispanic Whites, with relatively higher education and of middle/higher income (Table 5.1). Individuals included in this analysis are slightly older and there is a lower proportion of Hispanics compared to the overall adult population of Homescan (unreported results).

We examined the population distribution of consumers of each type of beverage and among individuals who consumed neither LCS- nor CS-beverages (Supplemental table 5.1). From 2000-2010, non-consumers represented about 9% of the sample; whereas LCS-beverage consumers represented 11%; CS-beverage consumers represented about 28% and those that purchased both types of beverages represented about 51%. Among LCS- and CS-beverage consumers, most individuals purchased more than zero but less than one serving of either beverage per day. Approximately 12% of consumers purchased one serving or more of either type of beverage per day.

Changes in energy, macronutrient, food group purchases and instrumental variables

We investigated secular population trends in overall energy, macronutrient and food group purchases from 2000-2010 (Supplemental tables 5.2-5.4). Over the last decade, we observed significant decreases in purchases of total daily energy, energy excluding LCS-and CS-beverages, energy from food and beverages and also decreases in total daily energy from all macronutrients (Supplemental table 5.2). In terms of beverage groups, we found overall significant decreases in most beverage groups except for a significant increase in LCS-beverages, sweetened coffee/tea and unsweetened water/flavored beverages (Supplemental table 5.3). Over the same period, we found significant increases in purchases of dairy, low-calorie sweetened-desserts/sweeteners, salty snacks and nuts/seeds, whereas purchases of grains/bread, caloric sweetened-desserts/sweeteners, cooking fat/oil, meat/poultry/fish/eggs and RTE mixed/frozen and fast food meals decreased (Supplemental table 5.4).

Over the period studied, overall prices of foods and specific prices of LCS- and CS-beverages increased significantly (Supplemental table 5.5). Average household yearly dollar expenditures also increased significantly for overall food, beverages and also for LCS- and CS-beverages, whereas the average number of grocery trips per household and year decreased significantly from 2000-2010. The proportion of market sales significantly increased for LCS-beverages but decreased for CS-beverages over the same period.

Dynamic modeling of the effect of consumption LCS- and CS-beverages on dietary quality, macronutrients and food purchasing patterns

The dynamic model included lagged values of the outcome of interest and lagged values of beverage consumption. Instrumental variables were used to control for bias from reverse causality, unmeasured confounding and measurement error. Overall, the proportion of market sales of LCS- and CS-beverages were ideal instrumental variables because they were associated with LCS- and CS-beverages but not with the other outcome variables (Supplemental table 5.6). On the contrary, the number of grocery trips per year was an ideal IV for the rest of variables because it was significantly associated with the outcome variables but not associated with LCS- and CS-beverage purchases. In addition, the specification tests showed for most of our models, that the null hypothesis of over-identification and the null hypothesis of no second order auto-correlation cannot be rejected; indicating that our models with instrumental variables were correctly specified (Tables 5.2-5.3).

Compared to non-consumers, consumers of one serving/day of either LCS- or CS-beverages had significantly higher total daily energy, energy excluding LCS- and CS-beverages and food energy over the entire period (Table 5.2, Figure 5.1). Similarly, consumers of one serving/day of either LCS- or CS-beverages had significantly higher total energy from carbohydrates, sugar and total fat compared to non-consumers (Figure 5.2). Consumers of LCS-beverages had significantly higher daily energy from protein and saturated fat.

Consumers of one serving/day of either LCS- or CS-beverages had significantly higher total daily energy from caloric desserts and sweeteners compared to non-consumers over the entire period (Table 5.3, Figure 5.3). Compared to non-consumers and consumers of CS-beverages, consumers of one serving/day of LCS-beverages had significantly higher total daily energy from caloric-sweetened cereals and cheese. Although non-significant, one serving/day of either type of beverage was associated with higher total daily energy from RTE mixed/frozen and fast food meals.

In order to investigate if the overall effect of consumption of LCS- and CS-beverages was consistent in each year from 2000-2010, we explored the interaction between the explanatory variables and year. Overall, increasing one serving/day of either type of LCS- and CS-beverages was associated with higher energy, macronutrients, and desserts in each year separately ($P<0.05$, unreported results).

Discussion

Using an advanced approach based on a dynamic model and instrumental variables to control for unobserved heterogeneity and biased standard errors, this study investigated the effect of CS-and LCS-beverages on dietary quality and food purchasing patterns over the last decade in the U.S. We have reported secular decreasing trends in purchases of overall energy and calories from macronutrients and calories from most food and beverage groups among individuals included in Homescan from 2000-2010. Despite overall declines in calories from all sources, we found that increasing one serving/day of either CS- or LCS-beverages was associated with significantly higher total daily energy, energy from foods only, and also higher daily energy from carbohydrates, total sugar, and total fat. When we studied the association with specific food groups, we found that increasing one serving of either beverage per day over time was predominantly associated with increased purchases of caloric desserts and sweeteners, which accounted for an important proportion of the increase in overall energy (excluding CS and LCS-beverages). Purchases of other foods such as sweetened cereal and cheese were higher but only among LCS-beverage consumers.

Consumption of CS-beverages has been shown to be associated with higher overall caloric intake and poorer dietary patterns characterized by fast-foods and snacks and low intake of vegetables [36, 107, 108, 113]. In another recent study, we addressed the long term association between different profiles of beverage consumers and dietary patterns over the same period (unpublished manuscript). In that study, households consuming either LCS- or CS-beverages were significantly less likely to follow healthier dietary patterns compared to non-consumers. However, LCS-beverage consumers also had a higher probability of following a “Prudent” pattern that was characterized by fruits, vegetables but also by snacks and diet desserts. Another study reported the differential effect of consumption of LCS-beverages in the context of a “Prudent” vs. a “Western” pattern on the risk of cardiometabolic outcomes [36]. Consumers of LCS-beverages had a lower cardiometabolic risk in the context of a “Prudent” diet compared to a “Western” diet. An earlier cross-sectional study using measures of purchases from Homescan in 1999 compared the food purchasing patterns of CS- and LCS-beverage consumers. The authors concluded that overall LCS-beverage consumers made better food choices than CS-beverage consumers in terms of energy content [110]. The present study showed that, after accounting for endogenous decisions about food choices and other unmeasured confounding factors, individuals that purchase either type of beverage have higher caloric intake from all purchases, especially from food groups and also from most macronutrients compared to those that do not purchase LCS- or CS-beverages.

We showed that total daily energy from carbohydrates, sugars and caloric desserts and sweeteners significantly increased with one serving of either CS- or LCS-beverages compared to non-consumers. The earlier study that used Homescan reported that households consumers of CS- and LCS-beverages had significantly more purchases from candy than non-consumers; whereas LCS-beverage consumers had significantly more purchases of cookies and low fat ice cream than CS-beverage or non-consumers [110]. However, a recent RCT study of beverage consumers randomized to substitute CS-beverages with either LCS-beverages or water did not find a differential effect in energy, macronutrient or dessert intake in the LCS-beverage compared to the water group [94]. This conflicting finding could be explained by the fact that the patients enrolled in the RCT were overweight participants highly motivated to lose weight. In our study, we observed participant's behavior in free-living conditions, and although some LCS-beverage consumers might decrease their purchases of highly caloric items in order to control their diets, the overall effect resulted in increased daily energy from caloric desserts and sweeteners.

The biological plausibility behind our results could be explained by an increased sweetness preference among consumers of sweetened beverages. It has been hypothesized that sweetener consumption might reflect an enhanced sweetness inclination [38, 39]. A laboratory study showed that those that frequently consumed sweet-tasting foods showed a preference for sweeter beverages, an effect that was found for both caloric and low-calorie sweeteners [40]. Also, repeated exposure to LCS uncoupled with energy was hypothesized to modify the natural relationship between sweet taste and energy, an effect that could affect appetite and energy intake by disrupting hormonal and neurobehavioral pathways that control hunger and satiety [16, 41-44]. On the other hand, dietary intake is also influenced by the important mechanisms and behaviors involved in food selection and food choices. From the behavioral point of view, consumption of LCS might constitute a rationale to consume an unhealthful diet or even larger portion sizes motivated by the common belief that these “diet” products are lower in calories. Sweet taste preference is considered to be a universal trait, and involves biological mechanisms related to food reward and other nutritional properties of sugars [38, 119]. Although there are large variations in the preferred sweetness that modulate the patterns of consumption of sweeteners and sweet tasting products, highly processed and intensely sweet foods and beverages are becoming increasingly popular and marketed in the U.S [100, 120].

The longitudinal nature of the Homescan database allowed us to study long-term dynamics in purchasing patterns for a large sample of individuals, controlling for unmeasured individual determinants that affect food selection and food choices. Our approach based on a dynamic model allowed using lagged values of beverage consumption and instrumental variables, which helped to set up an adequate temporality for the main exposure while avoiding bias from reverse causality, unmeasured confounding and measurement error. The use of purchasing data from the *Homescan* dataset constitute an alternative way to characterize the population eating patterns [82]. Food purchasing and expenditure surveys have been previously used to measure household food availability. While these datasets do not capture individuals' actual dietary intake, they are useful to characterize the wide variability in food consumption patterns of the population [66, 80, 81]. Although the process of scanning and recording the purchases might be time-consuming and exposed to recording errors, *Homescan* has been validated using retailer's transaction and diary survey data, and its overall accuracy is in line with many other commonly used surveys of this type [83, 121]. One important advantage of using this dataset is the availability of ingredient information for each product that is purchased in the U.S. marketplace. Our approach also addressed issues related to measurement of sweeteners in the food supply that no other databases can achieve. Foods and beverages that contained sweeteners were objectively identified and classified, avoiding the potential misclassification error that likely affect self-reported data by individuals that might not be aware of the type sweetener in products.

The main limitation of using *Homescan* is that we are missing away-from-home eating patterns, with less than one third of the CS-and LCS-beverage consumption happening away from home [100]. In addition, we could be underestimating the effect on other foods that are usually consumed away from home (i.e. ice creams). Although single-person households were not that different in SES that other adults included in Homescan, adults living by themselves might not be representative of an average person and might have different dietary patterns and away-from-home eating patterns. Also, some of the purchases of single households might be used to share with others and they might waste food more, especially perishable products. Another source of measurement error might come from missing purchases of non-barcoded random-weight products that are not pre-bagged (i.e. loose fruits, nuts, etc).

In conclusion, as consumers appear to be turning to LCS for their sweet options, our study opens up new pathways that relate consumption of both LCS- and CS-beverages to increased purchases of overall energy, carbohydrates, sugar, and caloric desserts and sweeteners. While the current state of research on this topic is very incomplete and unclear, our results have significant public health implications especially regarding consumption of LCS-products. It is essential to understand if sweetener consumption translates into a better or worse dietary quality before continuing with more complex studies that relate sweetener intake to health outcomes. Our research combined an advanced statistical methodology and sweetener classification approach to contribute new evidence to understand the mechanisms potentially implicated in the association between sweetener consumption and lower nutritional quality. Our findings suggest that any type of sweetened beverage consumption might have a negative effect on diet, which can potentially inform future intervention strategies and nutrition policy recommendations aimed at improving diet and nutrition in the U.S.

Tables and Figures

Table 5.1. Sample sizes and demographic characteristics of the Homescan population from 2000-2010.

SAMPLE SIZES n=34,294 individuals	YEAR 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	TOTAL
T≥2 consecutive waves	N/A	6,595	7,073	7,817	8,004	8,847	10,518	11,727	12,122	12,032	11,632	96,367
T=1 consecutive waves	8,508	2,335	3,051	2,502	2,379	4,129	3,983	3,277	3,050	2,838	3,592	39,644
Total Sample	8,508	8,930	10,124	10,319	10,383	12,976	14,501	15,004	15,172	14,870	15,224	136,011
BEVERAGE CONSUMPTION *Servings per week [mean (SE)]*	**YEAR 2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	***P value***
LCS Beverages	2.4	2.4	2.6	2.8	2.9	3.0	2.9	2.7	2.7	2.6	2.7	0.034
	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	
CS Beverages	3.1	3.1	3.0	3.0	2.7	2.7	2.8	2.6	2.7	2.6	2.5	0.000
	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	
DEMOGRAPHIC CHARACTERISTICS												
Age [mean (SE)]	57.5	57.4	57.5	58.4	58.6	57.2	57.3	57.5	57.1	56.8	56.5	0.000
	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	
Gender [%]												
Male	49.8%	50.5%	51.4%	49.0%	49.6%	47.7%	49.2%	49.8%	50.2%	50.3%	51.4%	0.461
Race-ethnicity [%]												
Non-Hispanic White	86.1%	84.1%	84.9%	84.9%	83.3%	82.5%	81.6%	81.6%	80.1%	79.9%	78.2%	0.000
Non-Hispanic African-American	10.6%	11.1%	10.5%	10.5%	11.3%	11.1%	11.7%	11.5%	12.3%	11.9%	12.5%	0.000
Hispanic	2.1%	2.9%	2.6%	2.7%	3.2%	3.8%	4.1%	4.3%	4.6%	4.9%	5.3%	0.000
Other	1.1%	1.8%	2.0%	1.9%	2.3%	2.7%	2.7%	2.7%	3.0%	3.4%	4.1%	0.000
Education [%]												
Less or equal than high school	32.6%	32.8%	29.7%	33.0%	32.6%	36.9%	35.4%	35.1%	34.9%	34.0%	34.5%	0.000
More or equal than college	67.4%	67.2%	70.3%	67.0%	67.4%	63.1%	64.6%	64.9%	65.1%	66.0%	65.5%	0.000
Income [%]												
Lower income (<185%)	23.8%	22.7%	22.7%	22.3%	22.3%	33.3%	32.9%	32.7%	31.5%	30.0%	29.1%	0.000
Middle income (185-400 %)	43.9%	43.3%	42.4%	37.2%	37.8%	31.4%	31.3%	30.0%	29.7%	34.1%	34.6%	0.000
Higher income (>400 %)	32.2%	34.0%	34.9%	40.5%	39.9%	35.3%	35.8%	37.3%	38.8%	35.9%	36.3%	0.000

*Using sample weights to account for selection probability and sampling design;
**P for linear trend, *Wald test* $P<0.05$

Table 5.2. Dynamic modeling of the effect of increasing one daily serving of LCS- and CS-beverages on dietary quality and macronutrients

Key Explanatory Variables	***Outcome (t-1)***		***LCS-beverages (t-1)***		***CS-beverages (t-1)***		**Overall statistic**	**Sargan-Hansen test**	**Arellano-Bond test of autocorrelation**	
OUTCOMES (t)	**β**	**[SE]**	**β**	**[SE**	**β**	**[SE**	**χ^2(15)**	**χ^2 (25)**	**AR(1)**	**AR(2)**
Total Daily Energy (kcal/day)										
Total energy	0.39	0.18†	86.01	29.61†	112.95	55.31†	1383.19†	24.19	-4.91†	1.44
Total energy excluding LCS/CS-beverages	0.31	0.18	92.51	29.24†	73.03	37.23†	1139.45†	26.84	-4.58†	0.78
Total energy from food	0.23	0.15	99.41	27.96†	84.59	32.68†	903.96†	25.34	-4.64†	0.07
Total energy from all beverages	0.53	0.22†	-3.54	7.20	23.58	32.14	899.35†	21.79	-6.76†	0.91
Total energy from beverages excluding LCS/CS	0.74	0.11†	-2.17	4.77	-3.24	5.21	804.99†	32.71	-8.65†	1.34
Total Daily Macronutrients (kcal/day)										
Carbohydrates	0.34	0.17†	42.29	15.91†	85.94	38.29†	1107.54†	25.11	-5.50†	1.28
Sugar	0.26	0.20	19.41	9.65†	80.38	35.88†	1034.46†	19.55	-6.11†	0.83
Protein	0.37	0.17†	10.46	5.15†	8.88	5.06	363.40†	17.61	-3.10†	-1.36
Total fat	0.25	0.16	45.41	14.01†	38.54	17.31†	764.00†	23.04	-5.10†	0.28
Saturated fat	0.37	0.18†	14.10	5.57†	11.01	6.51	695.81†	21.93	-6.62†	0.94

*Using a GMM 2-step system dynamic panel model with instrumental variables for the level and differenced equation;
**Instrumental variables: Average household grocery trips per year; Proportion of market sales (%): LCS beverage purchases, CS beverage purchases.
***Number of instruments = 41;
****Adjusted for age, gender, education, race/ethnicity, income and year;
† *P*<0.05

Table 5.3. Dynamic modeling of the effect of increasing one daily serving of LCS and CS sugar-sweetened beverages on dietary purchasing patterns

Key Explanatory Variables	*Outcomes (t-1)*		*LCS-beverages (t-1)*		*CS-beverages (t-1)*		Overall statistic	Sargan-Hansen test	Arellano-Bond test of autocorrelation	
OUTCOMES (t)	β	[SE]	β	[SE]	β	[SE]	χ²(16)	χ² (14)	AR(1)	AR(2)
Beverage groups (kcal/day)										
Juice, sweetened	0.73	0.23†	-2.28	2.07	-1.52	2.20	684.84†	15.58	-7.68†	0.70
Milk and milk drinks, sweetened	-0.07	0.18	-0.48	0.78	1.24	0.94	37.33†	24.60	-1.86	-3.76†
Milk, plain unsweetened	0.36	0.17†	1.82	2.33	2.22	2.57	583.93†	25.60	-3.72†	-0.65
Coffee/Tea, sweetened	-0.44	0.31	0.69	0.71	-1.08	0.98	28.51	19.73	-0.04	-2.82†
Coffee/Tea, unsweetened	0.76	0.17†	-0.73	0.65	0.40	0.81	263.13†	13.87	-4.91†	2.45†
Water and other beverages, unsweetened	-0.24	0.49	0.00	0.05	0.05	0.05	18.25	13.49	-1.08	-1.05
Alcohol	0.88	0.10†	-1.80	2.21	-2.83	1.98	579.87†	25.23	-8.89†	0.35
Food groups (kcal/day)										
Dairy, sweetened	0.39	0.20	1.76	1.55	0.98	1.43	82.09†	24.66	-4.71†	-0.52
Dairy, plain and unsweetened	0.76	0.14†	0.92	0.58	0.82	0.53	802.56†	38.23†	-7.79†	0.06
Fruit, processed and sweetened	-0.21	0.21	-0.36	0.57	0.41	0.56	44.59†	17.30	-1.51	-2.96†
Plain fruits and vegetables	0.28	0.21	0.85	1.53	0.27	1.50	292.18†	23.79	-3.32†	1.03
RTE Cereal, sweetened	0.05	0.15	8.13	3.39†	2.14	2.66	80.72†	22.92	-3.05†	-2.68†
Grains and breads	0.81	0.09†	-0.40	3.55	-1.40	3.52	1332.27†	27.96	-9.40†	4.41†
Desserts and sweeteners, LCS	0.39	0.13†	1.34	1.77	-1.29	1.23	186.39†	35.22	-6.45†	-0.55
Desserts and sweeteners, CS	0.24	0.19	40.18	14.04†	36.00	17.30†	601.28†	30.86	-4.51†	1.05
Salty Snacks	0.70	0.27†	1.66	2.74	0.04	2.57	158.59†	16.80	-5.04†	1.81
Cheese	0.45	0.20†	5.21	2.58†	3.92	2.85	202.39†	30.54	-8.16†	0.04
Cooking fats and dressings	0.89	0.22†	-2.22	7.00	-7.29	7.96	510.02†	27.80	-6.85†	4.12†
Nuts and seeds	0.53	0.23†	3.10	3.48	2.62	2.80	176.26†	17.11	-4.66†	-0.93
Meat, fish, poultry and eggs	0.80	0.08†	-1.71	3.15	-1.55	2.95	718.60†	17.66	-13.08†	2.99†
RTE mixed, frozen and fast food meals	0.69	0.17†	6.37	3.93	5.78	4.78	732.81†	20.68	-7.31†	2.07†

*Using a GMM 2-step system dynamic panel model with instrumental variables for the level and differenced equation;
**Instrumental variables: Average household grocery trips per year; Proportion of market sales (%): LCS beverage purchases, CS beverage purchases.
***Number of instruments = 41
****Adjusted for age, gender, education, race/ethnicity, income and year; † *P*<0.05

Supplemental Table 5.1. Population distributions by beverage consumer profile in the Homescan population from 2000-2010.

	2000-2010		YEAR										
	n	%	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Consumer profiles													
Neither LCS nor CS beverages	13,282	9.3%	8.9%	8.0%	8.1%	7.7%	8.1%	8.0%	9.0%	10.6%	11.0%	11.8%	11.1%
LCS beverages only	17,317	11.1%	9.1%	9.2%	8.0%	8.4%	10.7%	13.2%	11.5%	13.1%	12.0%	12.7%	13.2%
CS beverages only	35,410	28.3%	32.7%	32.7%	31.4%	31.4%	26.9%	24.3%	25.2%	25.4%	27.8%	26.7%	27.6%
Both LCS and CS beverages	70,002	51.3%	49.3%	50.1%	52.5%	52.6%	54.3%	54.5%	54.3%	51.0%	49.2%	48.8%	48.1%
LCS consumers													
0 servings/day	48,692	37.6%	41.5%	40.7%	39.5%	39.0%	34.9%	32.3%	34.2%	35.9%	38.9%	38.5%	38.7%
>0 to <1 servings/day	71,548	50.7%	48.1%	49.3%	49.3%	49.1%	52.5%	54.6%	53.3%	52.0%	49.5%	50.1%	49.3%
>=1 servings/day	15,771	11.7%	10.3%	10.0%	11.2%	11.9%	12.6%	13.1%	12.4%	12.1%	11.7%	11.4%	12.1%
CS consumers													
0 servings/day	30,599	20.4%	18.0%	17.2%	16.1%	16.0%	18.8%	21.2%	20.5%	23.7%	23.0%	24.5%	24.3%
>0 to <1 servings/day	92,835	68.0%	69.0%	69.5%	71.1%	71.5%	70.4%	67.2%	68.3%	65.9%	65.2%	64.9%	65.4%
>=1 servings/day	12,577	11.6%	13.0%	13.2%	12.9%	12.4%	10.8%	11.5%	11.2%	10.4%	11.8%	10.7%	10.4%

*Using sample weights to account for selection probability and sampling design

Supplemental Table 5.2. Changes in energy and macronutrients among individuals in the Homescan population, from 2000-2010.

	YEAR											
Total Daily Energy, kcal/day [mean (SE)]	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Change2000-10**	***P* trend**
Total energy	1894.44	1890.31	1902.64	1882.26	1858.84	1822.45	1774.16	1724.13	1687.89	1657.94	1609.19	-285.26	0.000
	(8.08)	(7.81)	(7.46)	(7.31)	(7.21)	(6.79)	(6.56)	(6.47)	(6.44)	(6.48)	(6.50)		
Total energy excluding LCS/CS beverages	1835.45	1832.67	1842.51	1812.95	1795.35	1763.09	1724.05	1679.05	1644.57	1617.27	1573.23	-262.22	0.000
	(7.82)	(7.56)	(7.23)	(7.08)	(6.98)	(6.57)	(6.35)	(6.27)	(6.24)	(6.28)	(6.29)		
Total energy from LCS/CS beverages	57.55	56.56	59.18	68.64	62.89	58.64	49.82	44.97	43.60	40.97	36.46	-21.09	0.000
	(0.97)	(0.94)	(0.89)	(0.88)	(0.87)	(0.81)	(0.77)	(0.76)	(0.76)	(0.77)	(0.76)		
Total energy from food	1596.57	1598.59	1607.06	1587.96	1577.22	1552.08	1516.01	1481.20	1458.57	1437.27	1396.87	-199.71	0.000
	(7.14)	(6.91)	(6.60)	(6.47)	(6.38)	(6.01)	(5.80)	(5.73)	(5.70)	(5.74)	(5.75)		
Total energy from all beverages	297.03	291.05	294.98	293.97	281.33	270.00	258.00	242.91	229.58	220.96	212.81	-84.22	0.000
	(2.02)	(1.96)	(1.87)	(1.83)	(1.80)	(1.69)	(1.63)	(1.61)	(1.60)	(1.61)	(1.61)		
Total energy from beverages excluding LCS/CS	238.82	234.01	235.38	225.00	218.14	210.98	208.04	197.86	186.08	180.08	176.49	-62.33	0.000
	(1.67)	(1.61)	(1.54)	(1.51)	(1.49)	(1.39)	(1.34)	(1.33)	(1.32)	(1.33)	(1.33)		
Total Daily Macronutrients, kcal/day [mean (SE)]	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Change 2000-10**	***P* trend**
Carbohydrates (kcal/day)	1018.52	1008.50	1013.63	988.49	965.11	947.61	919.02	896.31	879.26	863.76	842.29	-176.24	0.000
	(4.58)	(4.43)	(4.23)	(4.14)	(4.08)	(3.84)	(3.71)	(3.66)	(3.64)	(3.67)	(3.68)		
Sugar (kcal/day)	529.24	519.90	525.90	512.55	497.18	486.09	468.49	444.97	438.84	423.60	412.15	-117.08	0.000
	(2.75)	(2.66)	(2.54)	(2.49)	(2.46)	(2.31)	(2.23)	(2.20)	(2.19)	(2.20)	(2.21)		
Protein (kcal/day)	182.00	186.04	188.63	190.43	193.04	189.15	187.94	184.91	180.73	179.64	175.75	-6.25	0.000
	(1.47)	(1.42)	(1.35)	(1.33)	(1.31)	(1.22)	(1.17)	(1.15)	(1.14)	(1.15)	(1.15)		
Total fat (kcal/day)	649.69	656.67	664.79	666.49	668.02	656.37	639.78	622.18	610.98	604.75	583.81	-65.88	0.000
	(3.20)	(3.10)	(2.96)	(2.90)	(2.86)	(2.69)	(2.60)	(2.56)	(2.55)	(2.57)	(2.57)		
Saturated fat (kcal/day)	213.69	214.45	219.43	221.06	220.12	215.57	213.56	206.05	201.33	199.89	193.85	-19.84	0.000
	(1.10)	(1.06)	(1.01)	(0.99)	(0.98)	(0.92)	(0.89)	(0.88)	(0.87)	(0.88)	(0.88)		

*Using random effects longitudinal linear models;
** Adjusted for gender, age, race/ethnicity, education and income;
****P* for linear trend, *Wald test P*<0.05

Supplemental Table 5.3. Changes in beverage groups (kcal and grams per day) among individuals in the Homescan population, from 2000-2010.

Beverage Groups [mean (SE)]	Units	YEAR												
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Change 2000-10	*P* trend
CS beverages	Kcal/day	57.2	56.2	58.8	68.3	62.2	58.1	49.4	44.5	43.1	40.5	35.9	-21.4	0.000
		(1.0)	(0.9)	(0.9)	(0.9)	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)		
	Grams/day	151.1	149.1	149.6	149.3	138.4	126.6	120.9	112.9	109.5	104.5	98.4	-52.7	0.000
		(2.0)	(2.0)	(1.9)	(1.8)	(1.8)	(1.7)	(1.6)	(1.6)	(1.6)	(1.6)	(1.6)		
LCS-beverages	Kcal/day	0.3	0.3	0.3	0.3	0.7	0.6	0.4	0.5	0.5	0.5	0.6	0.3	0.000
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		(0.0)		
	Grams/day	124.6	126.2	135.1	143.3	147.9	150.8	146.9	136.1	127.1	125.7	126.9	2.4	0.003
		(2.4)	(2.3)	(2.2)	(2.1)	(2.1)	(2.0)	(1.9)	(1.9)	(1.9)	(1.9)	(1.9)		
Juice, sweetened	Kcal/day	63.6	61.3	59.8	57.8	55.5	53.1	49.6	46.7	43.9	42.5	40.3	-23.3	0.000
		(0.6)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)		
	Grams/day	134.8	131.1	129.6	126.1	124.2	121.1	113.9	108.2	104.8	101.4	99.4	-35.4	0.000
		(1.2)	(1.2)	(1.1)	(1.1)	(1.1)	(1.0)	(1.0)	(0.9)	(0.9)	(0.9)	(0.9)		
Milk and milk drinks, sweetened	Kcal/day	8.1	8.8	9.2	9.5	9.5	9.1	9.0	8.6	8.8	8.8	8.5	0.39	0.132
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)		
	Grams/day	11.5	12.9	13.2	13.7	14.3	13.7	13.7	13.7	13.9	14.1	14.1	2.6	0.000
		(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)		
Milk, plain unsweetened	Kcal/day	83.6	85.7	83.8	82.8	79.9	78.0	79.3	74.3	66.7	66.1	62.8	-20.8	0.000
		(0.8)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)		
	Grams/day	175.5	170.0	166.7	161.8	157.9	154.4	152.9	145.3	139.1	137.8	130.4	-45.0	0.000
		(1.3)	(1.3)	(1.2)	(1.2)	(1.2)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)		
Coffee/Tea, sweetened	Kcal/day	5.0	5.7	5.9	5.8	5.5	5.7	6.5	6.8	6.6	6.8	7.1	2.0	0.000
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)		
	Grams/day	31.5	33.3	36.2	36.7	36.5	37.4	43.1	47.1	46.2	53.2	52.5	21.0	0.000
		(1.5)	(1.5)	(1.4)	(1.4)	(1.4)	(1.3)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)		
Coffee/Tea, unsweetened	Kcal/day	5.1	5.1	4.9	4.3	4.7	4.6	4.5	3.9	4.4	3.5	3.4	-1.8	0.000
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)		
	Grams/day	320.2	313.7	310.8	311.6	308.0	289.7	284.3	276.8	268.4	255.2	252.7	-67.5	0.000
		(3.2)	(3.1)	(3.0)	(2.9)	(2.9)	(2.7)	(2.6)	(2.6)	(2.5)	(2.6)	(2.6)		
Water and other flavored beverages, unsweetened	Kcal/day	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.000
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)		
	Grams/day	38.1	43.4	48.6	55.2	56.9	65.0	69.2	69.0	65.6	59.9	59.2	21.1	0.000
		(1.5)	(1.5)	(1.4)	(1.4)	(1.3)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)		
Alcohol	Kcal/day	54.1	53.7	53.0	53.1	51.2	49.3	49.1	48.0	46.3	44.0	43.6	-10.6	0.000
		(1.1)	(1.0)	(1.0)	(1.0)	(1.0)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)		
	Grams/day	89.4	89.0	87.3	87.3	83.5	79.5	78.5	76.5	72.7	69.9	68.6	-20.8	0.000
		(2.1)	(2.0)	(1.9)	(1.9)	(1.9)	(1.8)	(1.7)	(1.7)	(1.7)	(1.7)	(1.7)		

*Using random effects longitudinal linear models; ** Adjusted for gender, age, race/ethnicity, education and income; ****P* for linear trend, *Wald test P*<0.05

Supplemental Table 5.4. Changes in food groups (kcal and grams per day) among individuals in the Homescan population, from 2000-2010.

Food Groups [mean (SE)]	Units	YEAR 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Change 2000-10	*P* trend
Dairy, sweetened	Kcal/day	36.6	37.3	38.3	38.8	38.9	39.4	40.3	40.0	39.6	39.8	42.6	6.0	0.000
		(0.6)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)		
	Grams/day	22.3	22.8	23.5	24.2	24.9	26.4	27.6	27.7	27.8	28.6	30.0	7.6	0.000
		(0.4)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)		
Dairy, plain and unsweetened	Kcal/day	9.1	8.8	9.3	10.1	10.2	10.0	10.1	9.8	9.8	10.2	10.3	1.2	0.000
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)		
	Grams/day	6.1	5.9	6.2	6.7	6.9	6.9	7.0	6.8	6.9	7.2	7.3	1.2	0.000
		(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)		
Fruit, processed and sweetened	Kcal/day	9.9	10.0	10.2	10.4	10.4	10.6	10.5	10.6	10.3	9.9	9.6	-0.3	0.058
		(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)		
	Grams/day	11.5	11.6	11.9	12.0	11.7	11.8	11.4	11.2	11.1	10.5	9.8	-1.6	0.000
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)		
Plain fruits and vegetables	Kcal/day	48.3	47.8	58.8	57.0	56.6	49.9	48.9	53.0	53.2	51.2	50.9	2.6	0.018
		(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)		
	Grams/day	97.0	96.7	98.5	100.4	100.2	101.3	100.7	97.1	96.7	98.2	97.5	0.5	0.174
		(0.8)	(0.8)	(0.7)	(0.7)	(0.7)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)		
RTE Cereal, sweetened	Kcal/day	83.6	79.2	79.9	80.5	79.6	80.0	81.3	80.8	81.3	80.1	77.5	-6.0	0.004
		(0.8)	(0.8)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)	(0.6)	(0.6)	(0.7)	(0.7)		
	Grams/day	21.0	20.8	21.1	21.3	21.1	21.6	22.0	21.9	22.1	22.1	21.2	0.2	0.000
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)		
Grains and breads	Kcal/day	118.6	115.6	112.9	106.2	100.8	98.1	93.0	90.9	88.8	86.7	87.6	-30.9	0.000
		(1.0)	(1.0)	(0.9)	(0.9)	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)		
	Grams/day	37.0	36.2	34.6	32.3	30.6	29.5	27.9	27.2	26.8	26.0	25.3	-11.7	0.000
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)		
Desserts and sweeteners, LCS	Kcal/day	7.6	10.0	11.2	12.8	17.3	17.9	14.6	15.7	14.7	14.8	15.5	8.0	0.000
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)		
	Grams/day	4.4	5.4	6.3	7.4	9.9	10.6	9.2	9.8	9.3	9.4	9.5	5.0	0.000
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)		
Desserts and sweeteners, CS	Kcal/day	656.1	653.9	649.2	627.5	608.8	595.4	584.3	567.1	558.7	542.0	522.8	-133.3	0.000
		(3.6)	(3.5)	(3.3)	(3.3)	(3.2)	(3.0)	(2.9)	(2.9)	(2.9)	(2.9)	(2.9)		
	Grams/day	199.1	197.2	195.6	191.8	186.2	182.1	180.5	174.3	170.9	167.0	161.7	-37.4	0.000
		(1.0)	(1.0)	(0.9)	(0.9)	(0.9)	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)		
Salty Snacks	Kcal/day	40.5	43.9	45.6	44.9	45.9	48.3	46.7	44.8	44.0	44.2	47.5	7.0	0.000
		(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)		
	Grams/day	9.5	10.0	10.4	10.4	10.9	11.3	11.2	10.8	10.6	10.6	11.1	1.6	0.000
		(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)		
Cheese	Kcal/day	53.9	53.5	54.4	57.2	58.7	58.5	58.5	56.2	54.8	58.9	56.9	3.1	0.000
		(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)		
	Grams/day	20.6	20.5	20.7	21.5	22.0	21.9	21.8	20.8	20.2	21.7	20.8	0.2	0.590
		(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)		
Cooking fats and dressings	Kcal/day	208.3	209.2	207.0	203.4	199.5	200.0	192.0	185.3	180.4	183.7	171.5	-36.8	0.000
		(1.5)	(1.4)	(1.4)	(1.3)	(1.3)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)		
	Grams/day	62.8	62.8	62.5	61.0	61.0	60.8	58.8	57.0	55.8	56.8	54.5	-8.3	0.000
		(0.4)	(0.4)	(0.4)	(0.4)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)		
Nuts and seeds	Kcal/day	36.3	36.0	38.5	44.2	50.4	47.6	46.7	47.3	46.2	46.2	44.6	8.3	0.000
		(0.8)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)		

	Grams/day	6.5	6.6	7.0	8.1	9.0	8.6	8.2	8.3	8.1	8.2	8.0	1.6	0.000
		(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)		
Meat, fish, poultry and eggs	Kcal/day	97.5	103.7	106.3	109.4	110.6	107.8	104.5	99.3	99.8	96.5	94.1	-3.4	0.000
		(0.8)	(0.8)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)		
	Grams/day	56.8	57.5	59.2	60.8	61.0	59.1	57.7	55.2	55.1	54.4	52.8	-4.0	0.000
		(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.3)	(0.3)	(0.3)	(0.3)		
RTE mixed, frozen and fast food meals	Kcal/day	159.1	161.0	158.0	161.2	164.6	165.2	163.6	161.7	159.0	156.9	154.0	-5.1	0.000
		(1.1)	(1.1)	(1.1)	(1.0)	(1.0)	(1.0)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)		
	Grams/day	132.8	133.4	130.9	132.2	133.3	132.2	130.6	130.2	129.1	127.7	126.1	-6.7	0.000
		(0.9)	(0.9)	(0.8)	(0.8)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)		

*Using random effects longitudinal linear models;
** Adjusted for gender, age, race/ethnicity, education and income;
***P for linear trend, *Wald test* $P<0.05$

Supplemental Table 5.5. Changes in market-level instrumental variables in the Homescan population, from 2000-2010.

INSTRUMENTAL VARIABLES Market Level [mean (SE)]	YEAR											Change 2000-10	P trend
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010		
Average prices ($/100 gr or mL)													
Food price index	98.29	97.72	98.71	100.85	101.03	103.85	105.87	110.52	114.72	119.08	118.17	19.88	0.000
	(0.46)	(0.46)	(0.46)	(0.46)	(0.46)	(0.46)	(0.46)	(0.46)	(0.46)	(0.46)	(0.46)		
LCS-beverage prices	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.09	0.10	0.03	0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
CS-beverage prices	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.02	0.000
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Average household purchases per year ($)													
Total Food	1882.51	1879.97	1910.63	1972.18	2017.68	2066.70	2190.43	2243.57	2353.50	2377.08	2354.14	471.63	0.000
	(8.56)	(8.56)	(8.56)	(8.50)	(8.50)	(8.50)	(8.50)	(8.50)	(8.50)	(8.50)	(8.50)		
Total Beverages	490.47	481.85	479.66	493.63	500.55	520.62	547.13	567.60	577.97	562.84	559.30	68.83	0.000
	(2.80)	(2.80)	(2.80)	(2.78)	(2.78)	(2.78)	(2.78)	(2.78)	(2.78)	(2.78)	(2.78)		
Total LCS/CS beverages	130.87	129.20	134.41	140.31	140.11	149.66	159.09	158.61	155.64	155.96	151.06	20.19	0.000
	(1.14)	(1.14)	(1.14)	(1.13)	(1.13)	(1.13)	(1.13)	(1.13)	(1.13)	(1.13)	(1.13)		
Average household grocery trips per year													
Number of trips/year	115.61	113.95	113.79	113.63	112.03	107.57	105.10	102.50	101.99	101.97	100.80	-14.80	0.000
	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)		
Proportion of market sales (%)													
LCS-beverage purchases	33.97	33.79	35.19	36.98	40.07	41.04	40.47	40.13	39.26	40.22	41.48	7.52	0.000
	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)		
CS-beverage purchases	57.98	56.57	54.21	51.13	46.90	43.37	41.82	40.19	40.98	40.90	39.81	-18.16	0.000
	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)	(0.29)		

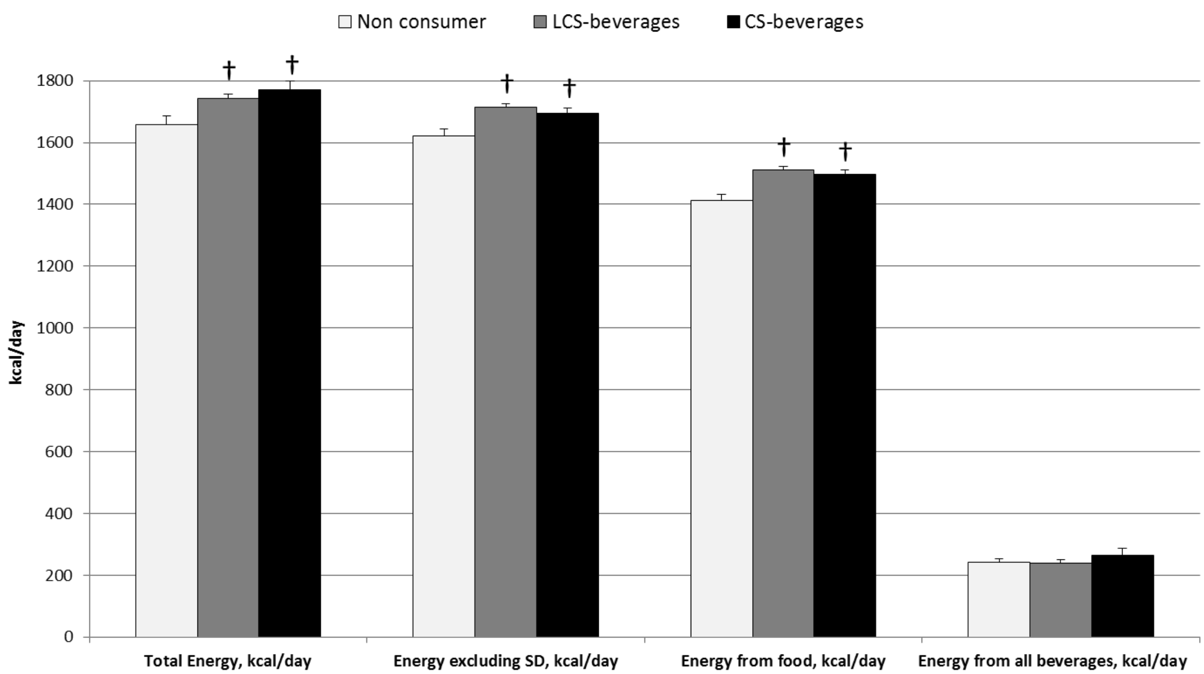
** Adjusted for market;
***P for linear trend, Wald test P<0.05

Supplemental Table 5.6. Associations between lagged instrumental variables and lagged outcomes and exposures in the Homescan population, from 2000-2010.

	INDEPENDENT VARIABLES (servings/day)				DEPENDENT VARIABLES (kcal/day)							
INSTRUMENTAL VARIABLES Market Level	LCS-beverages		CS-beverages		Total energy		Total energy excluding LCS/CS bev.		Total beverages excluding LCS/CS bev.		Total energy from food	
	β	(SE)	β	(SE)	β	(SE)	β	(SE)	β	(SE)	β	(SE)
Average prices ($/100 gr or mL)												
Food price index	-0.00090	(0.00087)	-0.00080	(0.00077)	-1.46138	(0.99770)	-1.37329	(0.96991)	-0.75704	(0.22817) †	-0.61481	(0.89496)
LCS bev. prices	0.52942	(0.34428)	0.14600	(0.30687)	333.84320	(395.64580)	219.28940	(384.62350)	109.74910	(90.48177)	110.63400	(354.90260)
CS bev. prices	-0.29223	(0.96174)	0.61266	(0.85719)	1506.79700	(1105.16800)	1167.58100	(1074.37500)	657.44210	(252.73670) †	504.60710	(991.35250)
Average household purchases per year ($)												
Total Food	-0.00004	(0.00003)	-0.00010	(0.00003) †	0.08474	(0.03846) †	0.09587	(0.03738) †	-0.01517	(0.00879)	0.11114	(0.03449) †
Total Beverages	-0.00022	(0.00011) †	0.00012	(0.00010)	-0.22801	(0.12904)	-0.21344	(0.12542)	0.11441	(0.02947) †	-0.32580	(0.11572) †
Total LCS/CS bev.	0.00117	(0.00025) †	0.00047	(0.00022) †	0.14505	(0.28738)	0.12068	(0.27935)	-0.18146	(0.06566) †	0.30224	(0.25774)
Average household grocery trips per year												
Number of trips/year	0.00126	(0.00067)	-0.00019	(0.00060)	3.46010	(0.76735) †	3.44305	(0.74592) †	1.03024	(0.17536) †	2.41165	(0.68824) †
Proportion of market sales (%)												
LCS bev. purchases	0.00565	(0.00108) †	-0.00064	(0.00096)	0.53795	(1.24340)	0.69859	(1.20873)	-0.17449	(0.28431)	0.87125	(1.11531)
CS bev. purchases	0.00071	(0.00110)	0.00261	(0.00098) †	0.79737	(1.26644)	0.51711	(1.23114)	0.44346	(0.28957)	0.07739	(1.13599)

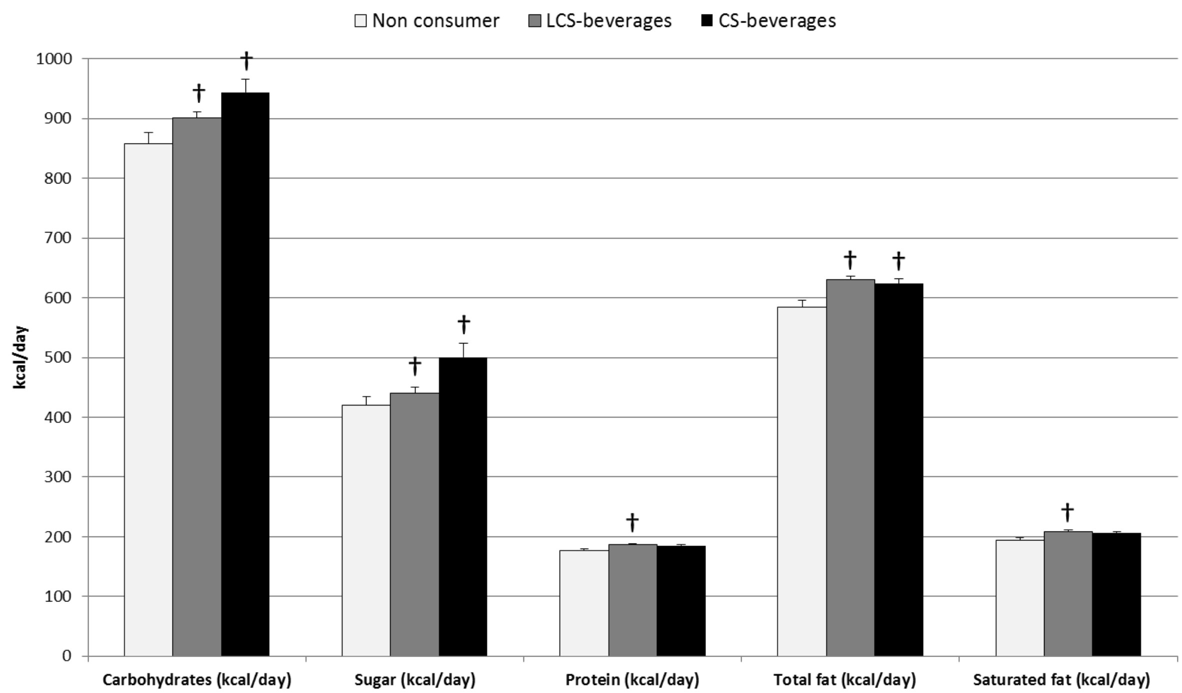
*Using longitudinal random effects models;
** Adjusted for year, market, gender, age, race/ethnicity, education and income;
† *P*<0.05

Figure 5.1. Effect of increasing one serving of LCS- or CS-beverages compared to non-consumers on total daily energy*



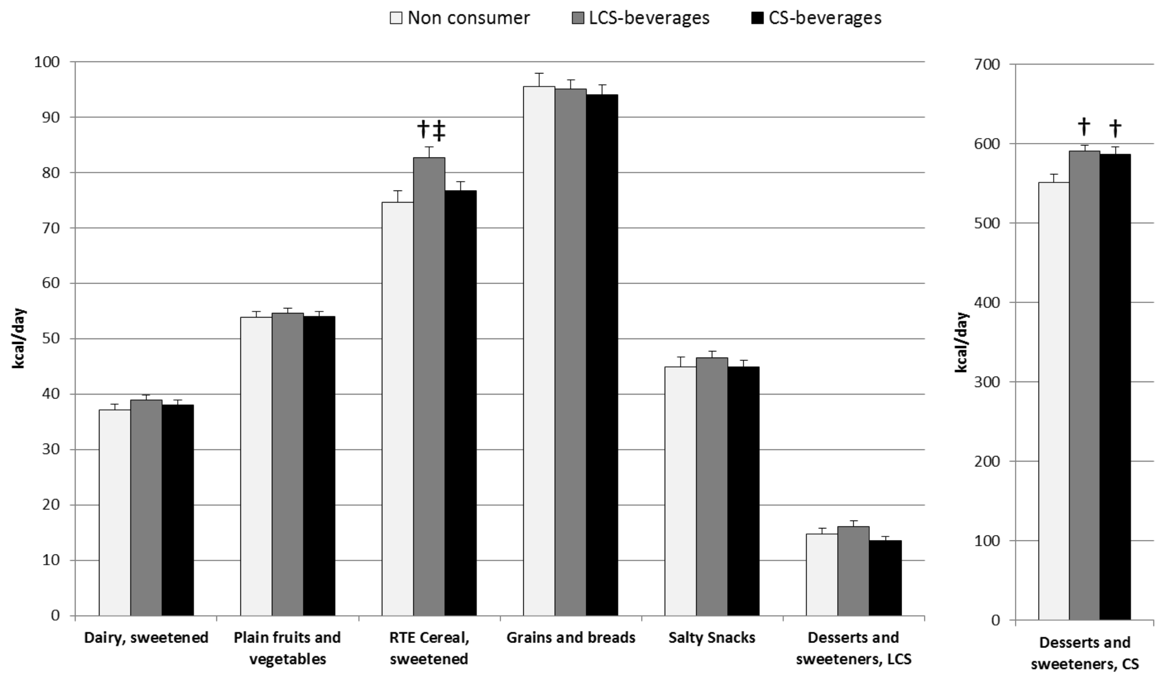
*Using a GMM 2-step system dynamic panel model with instrumental variables for the differenced equation. The coefficients obtained from the model represent the predicted increase in the outcome variable in relation to an increase in one serving of each type of beverage. For each outcome, margins commands were used after the fully adjusted models to predict the mean energy purchased (kcal/day) for every serving purchased of LCS-, CS- and for non-beverage consumers. LCS-beverage consumers are considered those with an increase in 1 serving per day of LCS-beverages but zero servings of CS-beverages and vice-versa for CS-beverage consumers. Non-consumers are considered those with zero servings per day of both LCS- and CS-beverages.
**Instrumental variables (lagged difference): Average household grocery trips per year; Proportion of market sales (%): LCS-beverage purchases, CS-beverage purchases.
***Number of instruments = 46; Number of observations = 71,084; Number of individuals = 17,799
****Adjusted for age, gender, education, race/ethnicity, income and year;
†Significantly different from non-consumer P<0.05; ‡Significantly different from LCS-beverage consumer P<0.05

Figure 5.2. Effect of increasing one serving of LCS- or CS-beverages compared to non-consumers on energy from macronutrients*



*Using a GMM 2-step system dynamic panel model with instrumental variables for the differenced equation. The coefficients obtained from the model represent the predicted increase in the outcome variable in relation to an increase in one serving of each type of beverage. For each outcome, margins commands were used after the fully adjusted models to predict the mean energy purchased (kcal/day) for every serving purchased of LCS-, CS- and for non-beverage consumers. LCS-beverage consumers are considered those with an increase in 1 serving per day of LCS-beverages but zero servings of CS-beverages and vice-versa for CS-beverage consumers. Non-consumers are considered those with zero servings per day of both LCS- and CS-beverages.
**Instrumental variables (lagged difference): Average household grocery trips per year; Proportion of market sales (%): LCS-beverage purchases, CS-beverage purchases.
***Number of instruments = 46; Number of observations = 71,084; Number of individuals = 17,799
****Adjusted for age, gender, education, race/ethnicity, income and year;
†Significantly different from non-consumer $P<0.05$; ‡Significantly different from LCS-beverage consumer $P<0.05$

Figure 5.3. Effect of increasing one serving of LCS- or CS-beverages compared to non-consumers on energy from food groups*



*Using a GMM 2-step system dynamic panel model with instrumental variables for the differenced equation. The coefficients obtained from the model represent the predicted increase in the outcome variable in relation to an increase in one serving of each type of beverage. For each outcome, margins commands were used after the fully adjusted models to predict the mean energy purchased (kcal/day) for every serving purchased of LCS-, CS- and for non-beverage consumers. LCS-beverage consumers are considered those with an increase in 1 serving per day of LCS-beverages but zero servings of CS-beverages and vice-versa for CS-beverage consumers. Non-consumers are considered those with zero servings per day of both LCS- and CS-beverages.
**Instrumental variables (lagged difference): Average household grocery trips per year; Proportion of market sales (%):LCS-beverage purchases, CS-beverage purchases.
***Number of instruments = 46
****Adjusted for age, gender, education, race/ethnicity, income and year;
†Significantly different from non consumer $P<0.05$; ‡Significantly different from LCS-beverage consumer $P<0.05$

Chapter 6. Synthesis

Overview of findings

This research investigated the consumption of low-calorie and caloric sweeteners in association with dietary quality and dietary patterns. First, this study used a novel approach to identify and classify sweeteners in food products by using information on ingredients for each product that was purchased. Secondly, we identified dietary patterns that were associated with different profiles of LCS and CS-beverage consumption. Finally, we implemented a dynamic panel model with instrumental variables to investigate the effect of LCS and CS-beverage consumption on dietary quality and food patterns over the last decade in the U.S.

We used commercial datasets that capture measures of foods as purchased, and national surveys of dietary intake that capture measures of foods as consumed. The Nielsen Homescan Consumer Panel is a unique longitudinal dataset that collects daily grocery purchases made by U.S. households from 2000 to 2010. This dataset captures over 600,000 products purchased from the U.S. marketplace, and all purchased food items were linked to detailed food descriptions and ingredient lists that facilitated classification of products with sweeteners. We also used the National Health and Nutrition Examination Surveys (NHANES) 2003-2010 that collect dietary intake data for a representative sample of the U.S. population.

1. *Trends in purchases and intake of foods and beverages containing caloric and low-calorie sweeteners over the last decade in the U.S.*

   Over the last 30 years, there have been important changes in consumption of caloric- and low-calorie sweetened foods and beverages among children and adults in the U.S. However, current food databases might not capture rapidly occurring changes in the U.S. food supply, such as the increased use of caloric (CS) combined with low-calorie sweeteners (LCS) in newly introduced or reformulated food products. We analyzed the Homescan dataset (foods as purchased) and NHANES surveys of dietary intake (foods as consumed) to explore recent time trends in foods and beverages containing LCS, CS or both sweeteners in the U.S.

   In terms of purchases (Homescan 2000-10), although CS food and beverages continue declining, they remained high. We showed an important but previously unexplored trend in purchases of products that contain both LCS and CS, especially among households with children. In terms of intake (NHANES 2003-10), children (2-18 y-old) increased their consumption of LCS beverages and decreased intake of CS beverages. In summary, during a period of declining purchases and consumption of CS products, we have documented an increasing trend in products that contain LCS and a previously unexplored trend in products with both LCS and CS, especially important among households with children.

2. *Diet quality, food intake and purchase patterns of consumers of LCS and CS-beverages.*

To date few studies have explored in depth what dietary patterns and behaviors are followed by consumers of LCS- and CS-beverages. Such dietary patterns may be one pathway linking consumption of sweetened beverages to health outcomes such as cardio-metabolic disorders. Using a novel approach that uses ingredient lists of each product to classify sweetened beverages with low-calorie- (LCS) and caloric-sweeteners (CS), we examined the dietary quality and food patterns of consumers of LCS-beverages; CS-beverages; LCS&CS-beverages; and non/low-consumers. We performed factor analyses and applied factor scores to derive longitudinal dietary patterns (only in Homescan) to investigate the association between each beverage consumption profile and the different dietary patterns that emerged.

Compared to non/low-consumers of beverages, all other profiles had significantly higher total daily energy, energy from carbohydrates and sugars, and a lower probability of adherence to a "Prudent" dietary pattern. LCS-beverage consumers had a higher probability of being associated with two distinct diet patterns, those who followed a "Prudent+snacks/desserts LCS" pattern of purchases, and those who followed the "Ready-to-eat meals/Fast food" pattern. In conclusion, as LCS-beverages appear to be displacing those with CS over the last 10 years, our findings suggest that overall dietary quality is lower in LCS-, CS- and LCS&CS-beverage consumers relative to individuals who do not consume any type of sweetened beverages.

3. *Estimation of a dynamic model to examine the impact of low calorie- and caloric-sweetened beverages on dietary quality and food purchasing patterns of U.S. household consumers*. Investigating the prospective relationship between CS- and LCS-beverages and dietary quality is challenging because it is difficult to disentangle if there is a particular dietary pattern that is linked to a particular beverage pattern or if specific beverage patterns could explain adherence to a particular diet pattern. In addition, there might be unobserved common factors (i.e. obesity, diabetes, or individual preferences) that drive

beverage and dietary patterns in the same direction. For this study, we implemented a dynamic panel model using longitudinal measures of yearly purchases by households included in the Nielsen Homescan Longitudinal dataset 2000-2010 to investigate the effect of beverage consumption on diet quality over time. This model includes market level variables as instrumental variables to control for bias due to unobserved heterogeneity and also includes a lag structure for several dependent variables that is selected on the basis of specification tests and supported by the data. Despite secular declines in calories from all sources, we found that increasing one daily serving of either CS- or LCS-beverages was associated with significantly higher total daily energy, energy from food, and higher daily energy from carbohydrates, total sugar, and total fat. We also found that increasing one serving of either beverage per day was predominantly associated with higher purchases of caloric desserts and sweeteners. As consumers appear to be turning to LCS for their sweet options, our study opened up new pathways that relate consumption of both LCS- and CS-beverages to poorer dietary quality and increased consumption of sugar and caloric desserts and sweeteners.

Strengths and Limitations

The use of purchasing data from the Homescan Consumer Panel dataset constitute an alternative way to characterize the population eating patterns [82]. Food purchasing and expenditure surveys have been previously used to measure household food availability, and although these datasets do not provide measures of individuals' actual consumption and dietary intake, they are useful to characterize the wide variability in food consumption patterns at the population level [66, 80, 81]. Another main advantage of using rapidly updated commercial datasets, such as Homescan, in public health research is that these longitudinal datasets provide accurate and reliable measures of usual food consumption, and might be potential sources of information for the nutrition field. However, since Homescan data is self-reported and the recording time-consuming, several reports have investigated the validity of Homescan against retailer's transaction data and diary survey data [83-85]. Although there is potential for recording errors in Homescan (i.e. missing trips, missing purchases), its overall accuracy is in line with many other commonly used surveys of this type [83, 121].

Our research was able to address issues related to measurement of sweeteners in the food supply that no other databases can offer. Because detailed ingredient lists and label information is available, we were able to accurately identify and classify all LCS and CS sources and also to capture newly introduced or reformulated products containing them. Importantly, we captured a new set of foods and beverages that include both CS and LCS sweeteners in the same product, which were missed in the NHANES surveys and the underlying USDA food composition tables developed to provide nutrient measures for each of those surveys. Overall, it takes long periods of time between the USDA finds new products and these products are incorporated in the FNDDS food composition tables used for each survey [122]. Finally, the longitudinal nature of Homescan also allowed for studying long-term dynamics in LCS and CS purchasing patterns and usual dietary patterns, and also allowed to control for individual determinants that affect food selection and food choices.

The main limitation of using the Homescan longitudinal dataset is that we are missing away-from-home eating. However, we are still capturing the greatest source of kcal for the average American. For the period covered in this research, about 77% of the total daily energy intake per capita was coming from store-bought foods for the average American adult. In addition, approximately ~ 85% of the LCS beverage intake was coming from store-bought beverages. We could also miss other sources of LCS or CS that are usually consumed away from home (i.e. gum, candy) and we also miss non-barcoded items such as random-weight fruits and vegetables or tap water.

On the other hand, there are limitations by using household level data from Homescan. First, when using multi-person households we are assuming that every person in the household is consuming everything that is purchased, when this assumption might not be always true. We overcome this limitation by using single-person households in the third aim, although these households might not represent all types of households and might be different to adults living in a family in terms of dietary patterns. For example, some of the purchases might be used to share with others and they might also waste food more, especially perishable products. In either case, we cannot account for wastage and storage of foods. Wastage might be more frequent for foods or beverages with short shelf life, such as fruits, vegetables; whereas storage might be frequently done with foods that, on the contrary, have very long shelf life, such as canned, dry, bottled foods and beverages.

Another limitation of using Homescan is the lack of information on health outcomes and other health-related behaviors. Particularly, obesity, diabetes and cardiovascular disease are unmeasured confounders in some of the statistical models. Households affected by any of these conditions (i.e. a diabetic following a low sugar diet; an obese person following a low calorie diet) might have a particular dietary pattern and also a particular association with consumption of LCS. For example, unhealthy dietary patterns (i.e.

high sugar diet) might lead to a particular condition (i.e. obesity), and those suffering that condition might change their patterns to consume more LCS products but might or might not change the rest of their eating patterns. Despite the potential bias introduced by unmeasured confounders and reverse causality, the use of instrumental variables in the third aim allowed to control for this heterogeneity in order to obtain correct measures of association.

When using NHANES data, the main limitation is that the dietary intake data is coming from one day of intake, reflecting current intake rather than usual intake, a problem that affected the comparability between NHANES and Homescan. Both NHANES and Homescan data might be affected by random and systematic error. Random error might be very high for NHANES because we are not accounting for day-to-day variation and within-person variation, but for Homescan we expect a negligible amount of random variation since we have at least 10 months of purchases per household. Measurement error might occur in NHANES because of recall bias and differential misreporting (i.e. underreporting of unhealthier foods); and in Homescan if people do not scan their purchases correctly or if the fail to scan certain foods or beverages deliberately. Given the widespread perception that beverages, desserts and other junk foods are things to reduce in our diets, these food groups could potentially be under-reported by both Homescan and NHANES participants.

Significance and public health impact

This research is the first effort to specifically design a more accurate approach to identify LCS and CS in products; explore consumption of LCS and CS-foods and beverages and investigate the effects of LCS and CS-beverages on food patterns and nutritional quality in the U.S. population. Our study can inform future research of the great advantage of using detailed information on ingredient lists, which is essential to improve the current system of classification of LCS products and to capture newly introduced or reformulated products containing sweeteners. Also, the use of scanned purchases constitute an objective measure that minimize reporting errors, which also allows capturing the usual dietary patterns by collecting all household purchases over a year. Finally, the longitudinal nature of our database allowed for studying long-term effects of LCS and CS on purchasing patterns and dietary quality using advanced econometric models that controlled for individual determinants that affect food selection and food choices. Although instrumental variables are not widely used in the epidemiological research, these new techniques help to control for unmeasured and residual confounding that always limit the validity of observational studies.

Our results have also important public health and nutritional implications, particularly given the controversy surrounding consumption of LCS-beverages. Despite the common perception that sweetened beverages, particularly CS-beverages and more recently LCS-beverages, can have a direct effect in the risk of obesity and other cardio-metabolic outcomes, this study used novel methods to open up new ways to indirectly link consumption of LCS- and CS-beverages with poor diet quality and adverse health outcomes. We found that consumption of any sweetened beverage -- with either CS or LCS -- was associated with poorer dietary purchasing and dietary intake patterns. LCS-beverage consumers seem to follow two different directions, one pattern of purchases consisting in fruits, vegetables, nuts but also snacks and desserts; and another pattern characterized by more convenient food groups such as RTE meals and fast foods. Our results are in line with other recent studies that highlight the complexity of studying the effect of LCS beverage intake on cardiometabolic outcomes when dietary patterns of LCS beverage consumers are ignored [36, 37]. Although causal associations need to be further studied, this study highlights the importance of other food groups that appear to be eaten in combination with sweetened beverages.

In summary, the complicated and multi-factorial etiology of many nutrition-related diseases such as obesity or cardio-metabolic risk cannot be explained by just studying the direct effect of a single food component, but with a comprehensive understanding of the multiple pathways that can ultimately link the use of LCS and CS with health. This research provided a better understanding of the context in which LCS and CS are used and the long terms effects of its consumption, which have the potential to inform future intervention strategies and nutrition policy recommendations aimed at improving nutrition and diet in the U.S.

Future directions

Consumption of caloric and low-calorie sweeteners constitute an important part of our diets. Although CS have been often related to poor diet and higher risk of health outcomes, clearly more research is needed to establish the biochemical pathways that can relate LCS with health. The present dissertation helped to identify several dietary patterns that link LCS and CS consumption to increased energy intake and poor dietary quality, which could potentially mediate the effects on overall health. However, our results are based on observational data, with limited ability to establish a causal relationship. Further intervention studies are needed to elucidate if those who change to consume larger doses of LCS in foods, liquids or both also change their dietary patterns in the long-term, which will reflect a potential effect of LCS on sweetness preferences and intake.

In addition, we studied dietary quality and food patterns of consumers of LCS and CS beverages. Overall, consumers of sweetened beverages might be prone to unhealthier habits compared to consumers of water or other unsweetened beverages. In relation to sweetener consumption, another future direction could be to study the dietary quality and patterns of consumers of LCS and CS sweetener packets, compared to people that consume little or no sweeteners. However, consumers of LCS and CS beverages constitute an important proportion of the populations studied, whereas the amount of consumers of LCS and CS sweeteners might still not be sufficient to attempt such a complex effort.

On the other hand, this study highlighted the importance of an adequate identification and classification of foods and beverages with sweeteners. Most studies that collect self-reported dietary intake data have to rely on the subjects' knowledge and awareness to determine if a product has LCS, CS or both. Future efforts that aim to improve dietary recall should consider different ways to collect the data to minimize the potential for misclassification and measurement error in the dietary recalls. For example, a food diary that can be completed by scanning the food products that people eat would be one way to collect more objective measures of intake, although it can introduce other sources of bias and would be very difficult for home-prepared meals.

In order to analyze food demand, consumption and sale strategies, home expenditure surveys such as Homescan are specifically designed to capture food purchasing patterns. However, when analyzing dietary patterns, we are missing an important part of the dietary intake that comes from away-from-home sources. Household expenditure surveys could be much improved by collecting information about weekly expenses that are not coming from stores. In addition, household food surveys are not designed to collect the amount of calories that each member of the household eats or which foods or beverages each member consumes. In our study, we investigated household-level dietary patterns to which each member is exposed to in relation to LCS and CS beverage purchases. However, we were not able to study individual level dietary patterns for those households that have multiple members.

Finally, one of the major limitations of this study was the inability to relate our results to health outcomes. It would be useful for home expenditure surveys such as Homescan to collect health information for each member of the household, so that our analysis of dietary patterns can be interpreted in the appropriate context. From this perspective, it is critical to understand how adherence to LCS or CS-beverages in the context of different dietary patterns affect the risk of nutrition related diseases such as obesity, diabetes or cardiovascular disease.

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