Food Price and Diet and Health Outcomes

20 Years of the CARDIA Study

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Background: Despite surging interest in taxation as a policy to address poor food choice, US research directly examining the association of food prices with individual intake is scarce.

Methods: This 20-year longitudinal study included 12 123 respondent days from 5115 participants in the Coronary Artery Risk Development in Young Adults (CARDIA) Study. Associations between food price, dietary intake, overall energy intake, weight, and homeostatic model assessment insulin resistance (HOMA-IR) scores were assessed using conditional log-log and linear regression models.

Results: The real price (inflated to 2006 US dollars) of soda and pizza decreased over time; the price of whole milk increased. A 10% increase in the price of soda or pizza was associated with a −7.12% (95% confidence interval [CI], −63.50 to −10.71) or −11.5% (95% CI, −17.50 to −5.50) change in energy from these foods, respectively. A $1.00 increase in soda price was also associated with lower daily energy intake (−124 [95% CI, −198 to −50] kcal), lower weight (−1.05 [95% CI, −1.80 to −0.31] kg), and lower HOMA-IR score (0.42 [95% CI, −0.60 to −0.23]); similar trends were observed for pizza. A $1.00 increase in the price of *both* soda and pizza was associated with greater changes in total energy intake (−181.49 [95% CI, −247.79 to −115.18] kcal), body weight (−1.65 [95% CI, −2.34 to 0.96] kg), and HOMA-IR (−0.45 [95% CI, −0.59 to −0.31]).

Conclusion: Policies aimed at altering the price of soda or away-from-home pizza may be effective mechanisms to steer US adults toward a more healthful diet and help reduce long-term weight gain or insulin levels over time.

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Although price policies, such as taxation, are beginning to be used as a means of addressing obesity, diabetes, and other nutrition-related health concerns, minimal research has been done to study how these price changes would have an impact on health outcomes. To date, this research has focused on broad ecological relationships,[1-5] were conducted as small-scale experiments,[6-9] or used cross-sectional data[10,11] rather than examining the direct effects of price on food and beverage intake over a long period.

For editorial comment see page 405

To compensate for food environments where healthful foods (ie, fresh fruits and vegetables) tend to cost more,[12,13] public health professionals and politicians have suggested that foods high in calories, saturated fat, or added sugar be subject to added taxes and/or that healthier foods be subsidized.[1,14-17] Such manipulation of food prices has been a mainstay of global agricultural and food policy,[16,18] used as a means to increase availability of animal foods and basic commodities, but it has not been readily used as a mechanism to promote public health and chronic disease prevention efforts.[16,19,20]

To properly examine the total health effect of price changes, it is necessary to examine direct and indirect effects of price changes on dietary intake. This includes (1) the direct price elasticity of demand, defined as the measure of responsiveness in the quantity demanded for a commodity as a result of change in price of that same commodity, and (2) indirect effects on complements and substitutes, namely other foods for which consumption might be affected by price changes of a given food. For example, one could examine changes in consumption of fruit juice or milk in response to changes in the price of soft drinks.

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Using directly measured individual-level consumption and health-outcome data linked with community price data (specific to each individual's time-varying residential location at the time dietary data were collected), we investigated the secular trends in selected food and beverage prices and their association with consumption (price elasticity of demand), total energy intake, weight, and homeostasis model assessment of insulin resistance (HOMA-IR) score over a 20-year period in the Coronary Artery Risk Development in Young Adults (CARDIA) Study.

METHODS

STUDY POPULATION

The CARDIA Study is a multicenter, longitudinal study of the determinants and evolution of cardiovascular disease risk in black and white young adults. The CARDIA participants were drawn from 1 of 4 US cities, with recruitment procedures designed to create a balanced representation of age, sex, ethnicity, and education group in each location. The baseline survey was completed by 5115 young adults, aged 18 to 30 years. Follow-up examinations were conducted at 2, 5, 7, 10, 15, and 20 years after baseline, with retention rates of 91%, 86%, 81%, 79%, 74%, and 72%, respectively. Data from examination years 0 (1985-1986), 7 (1992-1993), and 20 (2005-2006) were used for this study, since these are the years in which dietary data were collected. Detailed descriptions of the sampling plan and cohort characteristics are described elsewhere.[21,22]

FOOD PRICES

Food price data were compiled by the Council for Community and Economic Research (C2ER, formerly known as the American Chamber of Commerce Research Association).[23] From the available price data, we selected the following beverage and food variables based on comparability with individual-level food consumption data in the CARDIA Study: soft drink (2-L bottle of soda), whole milk (one-half gallon [1.9 L]), hamburger (one-quarter pound [0.113 kg] burger, purchased away-from-home), and pizza (12-13 in [29.4-33.0 cm] cheese, thin crust purchased away from home). We also include a selection of prices of hypothesized complementary and replacement foods and beverages: beer (6 pack, 12–fl oz [360-mL] bottles), wine (1.5-L bottle), coffee (1-lb [0.45-kg] can of ground coffee), bananas (1 lb), steak (1 lb, US Department of Agriculture [USDA] choice), parmesan cheese (8 oz [224 g], grated), and fried chicken (pieces, thigh and drumstick, purchased away from home). To account for inflation, we used the consumer price index (CPI)[24] of year 2006, third quarter (CPI=100%) as the baseline to inflate the nominal values for all prices to 2006 dollars. We linked price data to CARDIA Study respondents temporally (based on the year and quarter of CARDIA Study examination dates) and spatially (based on the respondent's residential location at each time point). A more detailed description of price data and our imputation strategy is provided in the eAppendix (http://www.archinternmed.com).

DIETARY ASSESSMENT

Usual dietary intake was assessed using the CARDIA Study diet history followed by a comprehensive quantitative food frequency questionnaire. The CARDIA diet history is a valid and reliable[25] interviewer-administered questionnaire.[26] We used 2 beverage and 2 away-from-home food categories: whole milk (fluid milk only—not powdered, evaporated, or condensed or fluid milk used in recipes), soft drinks (sweetened), hamburgers (sandwich or fast food), and pizza (frozen or restaurant).

ANTHROPOMETRICS AND INSULIN RESISTANCE

Measured height (nearest 0.5 cm) and weight (nearest 0.1 kg) were collected by trained technicians. Fasting insulin and glucose levels were obtained by venous blood draw. Glucose was measured using hexokinase coupled to glucose-6-phosphate dehydrogenase. The HOMA-IR score, a measure of insulin resistance, was calculated as:

$$[\text{Fasting Glucose (in Millimoles per Liter)} \times \text{Fasting Insulin (in Microunits per Liter)}]/22.5.$$ [27]

Higher scores are indicative of increased insulin sensitivity.

COVARIATES

At each examination period, self-reported information on sociodemographic and selected health behaviors was collected using standardized questionnaires, including age, education (completed elementary school, ≤3 years of high school, 4 years of high school, ≤3 years of college, or ≥4 years of college), income (low [<$25 000], middle [$25 000 to <$50 000]), and high [≥$50 000]), and family structure (married, single, married with children, and single with children). Physical activity (in exercise units per week) was assessed using the CARDIA Study physical activity questionnaire.[28] All models also adjusted for the cost of living. A detailed description of cost of living data is provided in the eAppendix.

STATISTICAL ANALYSIS

All analyses were completed in Stata version 10 statistical software (StataCorp, College Station, Texas). Descriptive statistics of beverage prices, energy (measured in kilocalories) per person and per consumer from each food group, and percentage consuming each food group were compared across the 3 examination periods, with statistical significance set at the $P<.05$ level (2-tailed test).

For analysis of price elasticity (the ratio of a percentage change in consumption to percentage change in price), we used 2-step marginal effect models in which the resulting estimates are weighted means of the association between changes in price with changes in consumption. These models first estimate the association between price change on the probability of consuming a food or beverage (step 1) and then the association between price change and the quantity consumed among consumers (step 2).[29] Models were clustered on the individual (to correct standard errors for multiple observations and possible differences in variance), and estimates and standard errors were generated using 1000 replications.[30] We tested and did not find a statistically significant interaction between logged price values and income or logged price values and time (likelihood ratio test, $P>.10$). A more detailed description of the 2-step marginal effect method is available in the eAppendix.

We examined own-price and cross-price elasticities. Own-price elasticity is defined as the percentage change in consumption associated with a percentage change in price. Cross-price elasticity is the percentage change in consumption of the first good associated with a percentage change in the price of a second good; their inclusion is necessary for proper evaluation of the total effect of changes in food price on diet and health. For example, to fully understand how change in soda price is associated with change in total energy, we need to also under-

Table 1. Descriptive Statistics for Price and Energy Consumption From Selected Food and Beverage Groups at Examination Years 0, 7, and 20 of the Coronary Artery Risk Development in Young Adults (CARDIA) Study[a]

Food/Beverage	Year 0 No.	Year 0 Value	Year 7 No.	Year 7 Value	Year 20 No.	Year 20 Value
Soda						
Price, mean (SD), $	5115	2.71 (0.31)	5115	1.69 (0.17)	5115	1.42 (0.24)
Daily energy per person, mean (SE), kcal[b]	3943	100 (20)	3943	97 (22)	3943	64 (20)
Percentage consuming, mean (SE), %	3143	76.0 (7.8)	3143	66.7 (7.3)	3143	48.5 (8.4)
Daily energy per consumer, mean (SE), kcal[c]	3880	130 (13)	2591	143 (17)	1521	129 (19)
Whole milk						
Price, mean (SD), $	5115	2.00 (0.18)	5115	2.04 (0.12)	5115	2.24 (0.25)
Daily energy per person, mean (SE), kcal[b]	3943	100 (48)	3943	34 (16)	3943	16 (8)
Percentage consuming, mean (SE), %	3143	46.6 (7.8)	3143	25.8 (3.8)	3143	15.3 (2.3)
Daily energy per consumer, mean (SE), kcal[c]	2376	204 (69)	1002	129 (33)	481	101 (39)
Burger						
Price, mean (SD), $	5115	2.50 (0.18)	5115	2.65 (0.26)	5115	2.67 (0.22)
Daily energy per person, mean (SE), kcal[b]	3943	59 (25)	3943	49 (22)	3943	55 (21)
Percentage consuming, mean (SE), %	3143	52.1 (7.1)	3143	57.1 (7.7)	3143	57.1 (8.9)
Daily energy per consumer, mean (SE), kcal[c]	2660	110 (35)	2218	82 (27)	1792	57 (19)
Pizza						
Price, mean (SD), $	5115	13.48 (0.79)	5115	12.01 (1.23)	5115	10.80 (0.90)
Daily energy per person, mean (SE), kcal[b]	3943	95 (35)	3943	90 (32)	3943	48 (14)
Percentage consuming, mean (SE), %	3143	84.4 (1.8)	3143	84.6 (2.5)	3143	80.6 (3.0)
Daily energy per consumer, mean (SE), kcal[c]	4310	112 (39)	3285	105 (36)	2530	60 (16)

[a] Percentage consuming, per person, and per consumer estimates are age and sex adjusted and rounded to the nearest whole kilocalorie. Price data are real prices, in 2006 US dollars, for a 2-L bottle of soda ("soda"), a one-half gallon of whole milk ("whole milk"), a one-quarter pound hamburger purchased at a fast food restaurant ("burger"), and a 13-in cheese pizza, regular crust, purchased away from home ("pizza").

[b] "Per person" estimates apply to the entire sample and are derived from intake data of *both* consumers and nonconsumers of the specific food or beverage.

[c] "Per consumer" estimates apply *only* to those individuals who consumed the food or beverage.

stand how the change in soda price is associated with change in intake of whole milk (a potential substitute) or pizza (a potential complement).

Finally, we examined the association between daily total energy intake, body weight, and HOMA-IR with price using pooled ordinary least square regression models, clustered on the individual. For each model, the continuous food and beverage prices were regressed on the 3 outcomes variables, adjusting for sociodemographic (race, sex, age, income, education, and family structure) and lifestyle factors (total physical activity and smoking status) as well as logged values of hypothesized complementary and replacement foods, logged cost of living, and an indicator variable for time (year 0, year 7, and year 20 [reference]), and imputed price data (yes/no). The body weight models also adjusted for subjects' height.

EXCLUSIONS

In all models, participants' observations were excluded if price data were incomplete (n=3 observations) or the participant was pregnant (n=69 observations). This resulted in a final sample size for all marginal effect estimates of n=12 123 observations. In the HOMA-IR model, participants were further excluded if they were taking antidiabetic medication (n=182 observations), resulting in final sample sizes for the longitudinal repeated measures regression models of n=12 007 (for kilocalories), n=11 972 (for weight), and n=10 218 (for HOMA-IR score) observations.

RESULTS

The inflation-adjusted real price of soda and pizza steadily declined between examination year 0 (1985) and year 20 (2006), with the largest percentage decrease observed for soda, falling from $2.71 to $1.42 (a 48% decrease; **Table 1**). The price of an away-from-home hamburger and whole milk were relatively stable. It is important to note, however, that these prices ignore the total cost because they do not incorporate the time cost involved in preparing food.[31] Despite an average decline in prices, between 10% and 50% of our sample experienced price increases (depending on food group) between examination years 0 and 7 and years 7 and 20 (data not shown).

Age- and sex-adjusted estimates suggest, for most foods, an overall decline in intake (Table 1). For example, there was an overall decline in the percentage of the sample consuming soda, but among consumers, daily energy from soda remained relatively constant, resulting in an overall decline in estimates of daily energy intake per person.

Changes in the price of soda and pizza were associated with changes in the probability of consuming (model 1 vs model 2; **Table 2**), as well as the amount consumed (model 3). A 10% increase in the logged price of soda resulted in a 3% decline in the probability of consuming soda and a decrease in the log amount consumed (among consumers). A 10% increase in the price of soda is roughly equivalent to $0.20 per 1-L bottle.

Own-price elasticities were in the expected direction for soda and away-from-home pizza ($P<.05$; **Table 3**). Estimates for hamburgers and whole milk were in the opposite direction expected but were not statistically significant. Our results suggest that a 10% increase in the price of soda is associated with a mean (SE) 7.12% (1.83) decrease in daily energy from soda ($P<.001$) (accounting for nonconsumption).

Table 2. Estimated Model Coefficients[a] of the Association Between Price, the Probability of Consumption, and the Amount Consumed Among Consumers

	Model 1,[b] Estimated Probability	Model 2,[c] Probability With 10% Increase in Price	No.	Model 3,[d] Estimated Change in Amount Among Consumers
Soda	0.66 (0.18)	0.64 (0.18)[e]	7990	−0.19 (0.14)
Whole milk	0.32 (0.22)	0.32 (0.22)	3861	−0.07 (0.42)
Burger	0.55 (0.55)	0.55 (0.13)[e]	6669	0.07 (0.14)
Pizza	0.84 (0.09)	0.78 (0.10)[e]	10 123	−0.43 (0.18)

[a] Values are estimated model coefficients (SE). Models 1 and 2, n = 12 123; model 3, sample sizes vary as listed.
[b] Probit model of probability of consumption on logged price of each food or beverage. All models adjusted for the following covariates: logged values for the price of soda, whole milk, hamburgers, and pizza, as well as Coronary Artery Risk Development in Young Adults (CARDIA) Study center; age (continuous); race; sex; education (completed elementary school, ≤3 years of high school, completed high school, ≤3 years of college, and completed college [reference]); family structure (single, married [reference], single with children, and married with children); annual household income (low [<$25 000], middle [$25 000 to <$50 000], and high [>$50 000] [reference]); logged cost of living index; imputed price (indicator, yes/no); and time (year 0, year 7, and year 20 [reference]). The model is clustered on the individual. Individual food models also include the following: "soda," logged price of wine; "whole milk," logged price of coffee; "burger," logged price of fried chicken, parmesan cheese, and steak; and "pizza," logged price of fried chicken.
[c] Same probit models described in footnote b, with probabilities predicted for a 10% change in the price of the selected food or beverage using the Stata predict command in Stata version 10 (StataCorp, College Station, Texas).
[d] Coefficients derived from linear regression model estimated for consumers of the selected food or beverage. All food models include the same covariates listed for Model 1.
[e] Estimates are statistically significantly different from one another using a 2-tailed χ^2 test ($P < .05$).

Table 3. Price Elasticity of Percentage Change in Energy From Foods Associated With a 10% Change in the Price[a]

	Change in Energy, %			
10% Increase in the Price	Soda	Whole Milk	Burger	Pizza
Soda	−7.12 (1.83)[b]	4.11 (3.02)	−4.21 (2.61)	9.95 (3.95)[b]
Whole milk	−0.38 (1.85)	2.38 (3.24)	2.98 (2.56)	6.87 (3.72)
Burger	2.95 (1.74)	−0.39 (2.87)	2.03 (2.50)	−6.07 (3.72)
Pizza	3.11 (1.42)[b]	−1.71 (2.46)	1.47 (1.97)	−11.50 (3.06)[b]

[a] Values are given as elasticity (SE) derived from conditional log-log marginal effect models of percentage daily energy (kilocalories) from food or beverage groups on percentage change in price of food or beverage. All models adjusted for the following covariates: logged values for the price of soda, whole milk, orange juice, hamburgers, and pizza, as well as Coronary Artery Risk Development in Young Adults (CARDIA) Study center; age (continuous); race; sex; education (completed elementary school, ≤3 years of high school, completed high school, ≤3 years of college, and completed college [reference]); family structure (single, married [reference], single with children, and married with children); annual household income (low [<$25 000], middle [$25 000 to <$50 000], high [>$50 000] [reference]); logged cost of living index; imputed price (indicator, yes/no); and time (year 0, year 7, and year 20 [reference]). Standard error estimates were calculated using 1000 replications (n = 12 123 observations). Specific food and beverage models also adjusted for the following covariates (these estimated coefficients [cross-price elasticities] are not shown): "soda," logged price of wine; "whole milk," logged price of coffee; "burger," logged price of fried chicken, parmesan cheese, and steak; "pizza," logged price of fried chicken.
[b] Estimate is significantly different from zero ($P < .05$).

Cross-price elasticities tended to be smaller than own-price elasticities. For example, a 10% increase in the price of pizza was associated with a mean (SE) 3.11% (1.42) increase in the daily energy from soda ($P = .01$) (cross-price elasticity; Table 3) compared with an 11.5% (3.06) decrease in daily energy from pizza ($P < .001$) (own-price elasticity; Table 3).

Price was also associated with total energy intake, body weight, and HOMA-IR scores (**Figure 1**). A $1.00 increase in the price of soda was associated with a mean (SE) of 124 (38) fewer total daily kilocalories ($P = .001$), a 2.34 (0.85)-lb (1.05 [0.38]-kg) lower weight ($P = .006$), and a 0.42 (0.10) lower HOMA-IR score (improved insulin resistance) ($P < .001$). The associations between price and the 3 outcomes were consistent (ie, the 3 dependent variables were in the same direction) for both away-from-home hamburgers and pizza, although the estimates only reached statistical significance for pizza.

Because of their strong cross-price elasticities, we also estimated the additive association of changing the price of soda, pizza, or soda and pizza on total daily energy intake, body weight, and HOMA-IR. A $1.00 increase in the price of *both* soda and pizza was associated with an additively greater change in total energy intake compared with increasing the price of just 1 of these foods. For example, increasing the price of soda or pizza alone resulted in a mean (SE) of 124 (38) ($P = .001$) and 58 (19) ($P = .002$) fewer total daily kilocalories, while a $1.00 increase in the price of *both* soda and pizza resulted in a mean (SE) of 181 (34) ($P < .001$) fewer total daily kilocalories. Similar patterns were observed for body weight and HOMA-IR scores (**Figure 2**).

COMMENT

Price manipulations on unhealthful foods and beverages have been proposed as a potential mechanism for improving the diet and health outcomes of Americans.[1,14,16] While some argue that there is little evidence

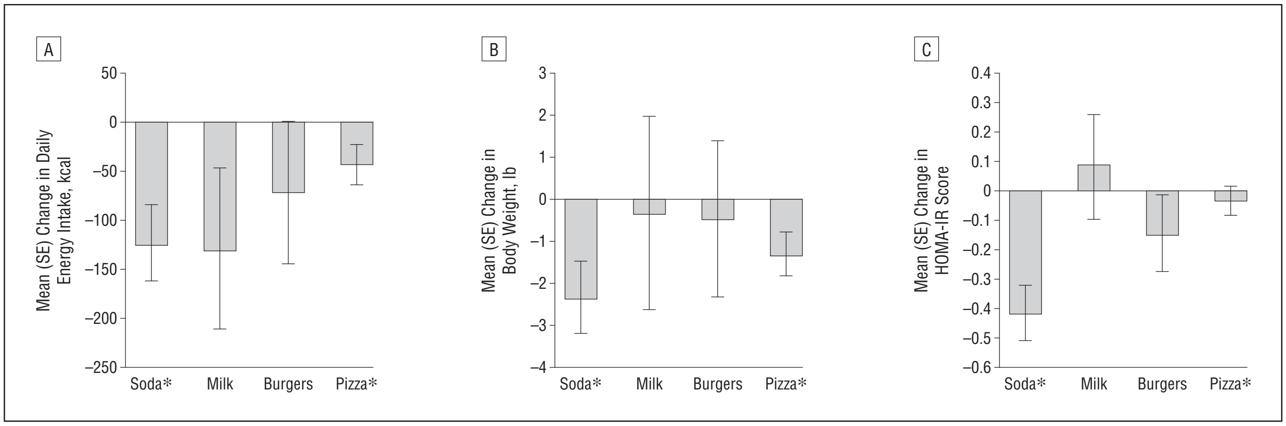

Figure 1. Association between a $1.00 increase in the price of selected foods and beverages with change in total energy intake (A), body weight (B), and homeostasis model assessment of insulin resistance (HOMA-IR) (C). Each food/beverage and outcome variable was modeled independently (n=12 models) as linear regression models of outcome (total energy intake [in kilocalories, n=12 007 observations], weight [in pounds, n=11 972 observations; to convert to kilograms, multiply by 0.45], and HOMA-IR [n=10 218 observations]) on the price (in dollars) of soda, whole milk, hamburgers, and pizza. All models adjusted for the following covariates: age (continuous); race; sex; income (low [<$25 000], middle [$25 000 to <$50 000], high [≥$50 000] [reference], and missing income); education (<high school, completed high school [reference], 3 years college, and ≥4 years college); family structure (single, married [reference], single with children, and married with children); logged cost of living; imputed price (indicator variable, yes/no); and Coronary Artery Risk Development in Young Adults (CARDIA) Study center. Models adjusted for clustering at the individual level. Models with weight as the dependent variable also adjusted for participants' height. Specific food and beverage models also adjusted for the following covariates: "soda," logged price of wine; "whole milk," logged price of coffee; "burger," logged price of fried chicken, steak, and parmesan cheese; and "pizza," logged price of fried chicken. *Estimate is significantly different from zero ($P<.05$).

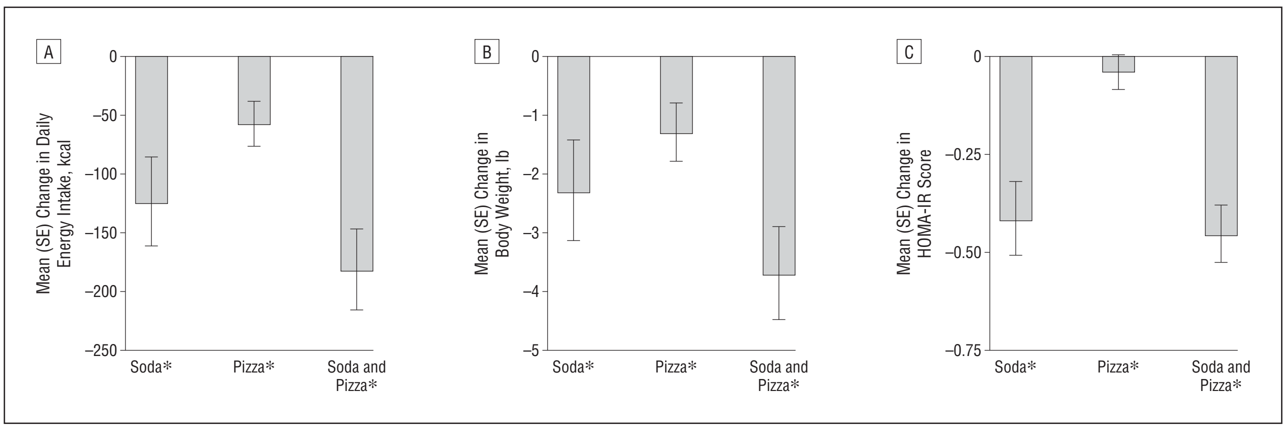

Figure 2. Association between a $1.00 increase in the price of soda alone, pizza alone, or both soda and pizza with change in total energy intake (A), body weight (B), and homeostasis model assessment of insulin resistance (HOMA-IR) score (C). Estimates were derived from linear regression model of outcome (total energy intake [in kilocalories, n=12 007 observations], body weight [in pounds, n=11 972 observations; to convert to kilograms, multiply by 0.45], and HOMA-IR [n=10 218 observations]) on the prices (in dollars) of soda, whole milk, hamburgers, and pizza. All models adjusted for age (continuous); race; sex; income (low [<$25 000], middle [$25 000 to <$50 000], high [≥$50 000] [reference], and missing income); education (<high school, completed high school [reference], 3 years college, and ≥4 years college); family structure (single, married [reference], single with children, and married with children); logged price of the replacement beverage wine and orange juice; the logged cost of living index; having imputed prices (indicator variable, yes/no); and Coronary Artery Risk Development in Young Adults (CARDIA) Study center. Models adjusted for clustering at the individual level. Models with weight as the dependent variable also adjusted for participants' height. *Estimate is significantly different from zero ($P<.05$).

such a tax would improve health or have a positive impact on obesity rates,[32] to our knowledge, no research has examined the direct and indirect total effects of such taxes on energy intake and subsequent changes in weight and other metabolic outcomes. Similar taxation policies have proven a successful means of effectively reducing adult and teenage smoking.[33,34]

Our results provide stronger evidence to support the potential health benefits of taxing selected foods and beverages. We report that an increase in the price of soda and pizza is associated with a significant decrease in daily energy intake from these foods. Price increases in soda and pizza were also associated with significant declines in overall daily energy intake, lower weight, and lower HOMA-IR scores over the 20-year study period. Furthermore, we report declines in the real (inflation-adjusted) prices of soda and away-from-home foods (foods that are commonly associated with increased caloric consumption and adverse health outcomes).[35-39]

Using our price elasticities and the sample's mean daily energy, body weight, and HOMA-IR values, we estimate that an 18% tax, which is the level that was unsuccessfully proposed by the state of New York and is considered by others as a minimal tax, would result in a roughly 56-kcal decline in daily total energy intake among young to middle-aged adults (18 [proposed tax] $\times$ –0.1116978 [estimated elasticity] $\times$ 2811.9 kcal [mean daily kilocalories in our sample]). At the population level, declines of 56 kcal per day would be associated with a reduction of roughly 5 lb (2.25 kg) per person per year and significant reductions in the risks of most obesity-related chronic diseases.[40-42] With respect to smoking, price elasticities were typically higher for children, teenagers, and elderly persons.[33,34,43,44] If this is also true for beverages, the overall impact of this tax on all its citizens might be greater than that found herein among adults aged 20 to 54 years.

Our results are in the same direction as those reported elsewhere. In France and Italy, demand elasticity was negative and relatively small for fluid milk.[45] Similar in direction but of greater magnitude, Barquera et al[46] reported that 10% price increases were associated with a decline of roughly 7 and 23 kcal/d from whole milk and soda, respectively, in a sample of Mexican adolescents and adults. The difference in magnitude of effects between the US and Mexican sample may indicate that US adults are less price sensitive; however, a direct comparison is not possible owing to differences in dietary methodology (direct weighing and recipe collection vs food frequency questionnaire) and study design (cross-sectional vs longitudinal).

While there are many strengths as a result of using the CARDIA data, our analysis is limited by its focus on a small number of food and beverage groups. Additional and important substitution and complementary foods and beverages may exist and should be examined in future studies. The relationship between price and consumption of "healthful" food items (ie, raw fruits and vegetables) should also be examined; our price data did not allow for evaluation of these relationships. Furthermore, we were not able to capture the full range of substitutability for the foods and beverages examined (ie, using low-fat or skim milk if the price of whole milk increases or choosing another fast food sandwich if hamburger prices rise), and thus we might have failed to take into account important explanations for our outcomes. Ideally, a full set of prices and food groups would have been used and the association between price and overall health would have been examined with the demand approach frequently used by economists, the Almost Ideal Demand System.[47-49] Finally, it is possible that some of these paired changes, ie, the price and consumption of soda, are parallel trends over time, which are associated with other unobserved factors and are not necessarily causally related. However, given that over a fifth of our sample experienced increased soft drink price, this is unlikely.

In our sample, income did not modify the relationship between price and consumption. Deeper exploration of the interactions between food price and income may be crucial in other samples. Finally, this study has limited generalizability to non-US and younger populations. However, adolescents have been observed to be much more responsive to price changes in cigarettes than adults.[33,34,43] We expect the relationship for price changes in foods and beverages to be similar.

Despite these limitations, to our knowledge, ours is the first dietary behavior study in the United States to examine both the *direct* effects of a price change on intake of a particular food (own-price elasticity) and the *indirect* effects on substitutes and complementary foods (cross-price elasticities). Furthermore, by doing this over a long-term period, we adjust for individual heterogeneity and are able to draw conclusions about how an individual's dietary behaviors would respond to changes in food price over a 20-year period. Finally, our findings highlight the substantial disparities between the fields of smoking and dietary behavior research; while there are extensive data sets on tobacco price and smoking behavior, there is a palpable scarcity of comparable data sets related to food price and dietary intake in the United States.

In conclusion, our findings suggest that national, state, or local policies to alter the price of less healthful foods and beverages may be one possible mechanism for steering US adults toward a more healthful diet. While such policies will not solve the obesity epidemic in its entirety and may face considerable opposition from food manufacturers and sellers, they could prove an important strategy to address overconsumption, help reduce energy intake, and potentially aid in weight loss and reduced rates of diabetes among US adults.

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REFERENCES

1. Cash S, Sunding D, Zilberman D. Fat taxes and thin subsidies: prices, diet, and health outcomes. *Acta Agric Scand C Food Econ*. 2005;2(3-4):167-174.
2. Schroeter C, Lusk J, Tyner W. Determining the impact of food price and income changes on body weight. *J Health Econ*. 2008;27(1):45-68.
3. Finkelstein DM, Hill EL, Whitaker RC. School food environments and policies in US public schools. *Pediatrics*. 2008;122(1):e251-e259.
4. Powell LM, Chriqui J, Chaloupka FJ. Associations between state-level soda taxes and adolescent body mass index. *J Adolesc Health*. 2009;45(3)(suppl):S57-S63.
5. Fletcher JM, Frisvold DE, Tefft N. The effects of soft drink taxes on child and adolescent consumption and weight outcomes. August 26, 2009. http://ssrn.com/abstract=1464542. Accessed December 4, 2009.
6. Epstein LH, Dearing KK, Paluch RA, Roemmich JN, Cho D. Price and maternal obesity influence purchasing of low- and high-energy-dense foods. *Am J Clin Nutr*. 2007;86(4):914-922.
7. Epstein LH, Handley EA, Dearing KK, et al. Purchases of food in youth: influence of price and income. *Psychol Sci*. 2006;17(1):82-89.
8. French SA. Pricing effects on food choices. *J Nutr*. 2003;133(3):841S-843S.
9. French SA, Jeffery R, Story M, et al. Pricing and promotion effects on low-fat vending snack purchases: the CHIPS Study. *Am J Public Health*. 2001;91(1):112-117.
10. Mytton O, Gray A, Rayner M, Rutter H. Could targeted food taxes improve health? *J Epidemiol Community Health*. 2007;61(8):689-694.
11. McColl K. "Fat taxes" and the financial crisis. *Lancet*. 2009;373(9666):797-798.
12. Drewnowski A, Darmon N. The economics of obesity: dietary energy density and energy cost. *Am J Clin Nutr*. 2005;82(1)(suppl):265S-273S.
13. Drewnowski A, Darmon N. Food choices and diet costs: an economic analysis. *J Nutr*. 2005;135(4):900-904.
14. Chouinard H, Davis D, LaFrance J, Perloff J. Fat taxes: big money for small change. *Forum Health Econ Policy*. 2007;10(2)(article 2). http://www.bepress.com/fhep/10/2/2. Accessed December 4, 2009.
15. Jacobson MF, Brownell KD. Small taxes on soft drinks and snack foods to promote health. *Am J Public Health*. 2000;90(6):854-857.
16. Popkin BM. *The World Is Fat—The Fads, Trends, Policies, and Products That Are Fattening the Human Race.* New York, NY: Avery-Penguin Group; 2008.
17. Brownell J, Farley T, Willett W, et al. The public health and economic benefits of taxing sugar-sweetened beverages. *N Engl J Med*. 2009;361(16):1599-1605.
18. von Braun J, Ahmed A, Asenso-Okyere K, et al. *High Food Prices: The What, Who, and How of Proposed Policy Actions.* Washington, DC: International Food Policy Research Institute; 2008.
19. World Health Organizatin. *Obesity: Preventing and Managing the Global Epidemic: Report of a WHO Consultation.* Geneva, Switzerland: World Health Organization; 2000. WHO Technical Report Series 894.
20. World Health Organization/Food and Agriculture Organization. *Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases: Report of the Joint WHO/FAO Expert Consultation*. Geneva, Switzerland: World Health Organization; 2003.
21. Friedman GD, Cutter GR, Donahue RP, et al. CARDIA: study design, recruitment, and some characteristics of the examined subjects. *J Clin Epidemiol*. 1988;41(11):1105-1116.
22. Hughes GH, Cutter G, Donahue R, et al. Recruitment in the coronary artery disease risk development in young adults (CARDIA) study. *Control Clin Trials*. 1987;8(4)(suppl):68S-73S.
23. Council for Community and Economic Research Web site. http://www.c2er.org/. Accessed September 24, 2008.
24. Bureau of Labor Statistics. Consumer price index. Last modified October 16, 2001. http://www.bls.gov/cpi/cpiovrvw.htm. Accessed January 24, 2009.
25. Liu K, Slattery ML, Jacobs DR Jr, et al. A study of the reliability and comparative validity of the CARDIA dietary history. *Ethn Dis*. 1994;4(1):15-27.
26. McDonald A, Van Horn L, Slattery M, et al. The CARDIA dietary history: development, implementation, and evaluation. *J Am Diet Assoc*. 1991;91(9):1104-1112.
27. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia*. 1985;28(7):412-419.
28. Jacobs DR, Hahn LP, Haskell WL, Pirie P, Sidney S. Validity and reliability of short physical activity history: CARDIA and the Minnesota Heart Healthy Program. *J Cardiopulmonary Rehab*. 1989;9:448-459.
29. Haines P, Guilkey DK, Popkin BM. Modeling food consumption decisions as a two-step process *Am J Agric Econ*. 1988;70(3):543-552.
30. Davidson A, Hinkley DV. *Bootstrap Methods and Their Application.* Cambridge, England: Cambridge University Press; 1997.
31. Mincer J. Market prices, opportunity costs, and income effects. In: Christ CF, Friedman M, Goodman LA, eds, et al. *Measurement in Economics: Studies in Mathematical Economics and Econometrics in Memory of Yehuda Grunfeld.* Stanford, CA: Stanford University Press; 1963.
32. Finkelstein E, French S, Variyam JN, Haines PS. Pros and cons of proposed interventions to promote healthy eating. *Am J Prev Med*. 2004;27(3)(suppl):163-171.
33. Chaloupka FJ, Cummings KM, Morley CP, Horan JK. Tax, price and cigarette smoking: evidence from the tobacco documents and implications for tobacco company marketing strategies. *Tob Control*. 2002;11(suppl 1):I62-I72.
34. Grossman M, Chaloupka FJ. Cigarette taxes: the straw to break the camel's back. *Public Health Rep*. 1997;112(4):290-297.
35. Vartanian LR, Schwartz MB, Brownell KD. Effects of soft drink consumption on nutrition and health: a systematic review and meta-analysis. *Am J Public Health*. 2007;97(4):667-675.
36. Dhingra R, Sullivan L, Jacques PF, et al. Soft drink consumption and risk of developing cardiometabolic risk factors and the metabolic syndrome in middle-aged adults in the community. *Circulation*. 2007;116(5):480-488.
37. Schulze MB, Manson JE, Ludwig DS, et al. Sugar-sweetened beverages, weight gain, and incidence of type 2 diabetes in young and middle-aged women. *JAMA*. 2004;292(8):927-934.
38. Duffey KJ, Gordon-Larsen P, Jacobs DRJ Jr, Williams OD, Popkin BM. Differential associations of fast food and restaurant food consumption with 3-y change in body mass index: the Coronary Artery Risk Development in Young Adults Study. *Am J Clin Nutr*. 2007;85(1):201-208.
39. Rosenheck R. Fast food consumption and increased caloric intake: a systematic review of a trajectory towards weight gain and obesity risk. *Obes Rev*. 2008;9(6):535-547.
40. Wood PD, Stefanick ML, Dreon DM, et al. Changes in plasma lipids and lipoproteins in overweight men during weight loss through dieting as compared with exercise. *N Engl J Med*. 1988;319(18):1173-1179.
41. Wing RR, Koeske R, Epstein LH, Nowalk MP, Gooding W, Becker D. Long-term effects of modest weight loss in type II diabetic patients. *Arch Intern Med*. 1987;147(10):1749-1753.
42. Goldstein DJ. Beneficial health effects of modest weight loss. *Int J Obes Relat Metab Disord*. 1992;16(6):397-415.
43. Liang L, Chaloupka F, Nichter M, Clayton R. Prices, policies and youth smoking, May 2001. *Addiction*. 2003;98(suppl 1):105-122.
44. Warner K. Tobacco policy in the United States: lessons for the obesity epidemic. In: Mechanic D, Rogut L, Colby D, Knickman J, eds. *Policy Challenges in Modern Health Care*. New Brunswick, NJ: Rutgers University Press; 2005:99-114.
45. Bouamra-Mechemache Z, Réquillart V, Soregaroli C, Trévisiol A. Demand for dairy products in the EU. *Food Policy*. 2008;33:644-656.
46. Barquera S, Hernandez-Barrera L, Tolentino M, et al. Energy intake from beverages is increasing among Mexican adolescents and adults. *J Nutr*. 2008;138(12):2454-2461.
47. Huang KS. Nutrient elasticities in a complete food demand system. *Am J Agric Econ*. 1996;78(1):21-29.
48. Huang K, Bouis H. *Structural Changes in the Demand for Food in Asia*. Washington, DC: International Food Policy Research Institute; 1996. Food, Agriculture, and the Environment Discussion Paper 11.
49. Wu Y, Li E, Samuel S. Food consumption in urban China: an empirical analysis. *Applied Econ*. 1995;27(6):509-515.
50. Burns C, Sacks G, Gold L. Longitudinal study of Consumer Price Index (CPI) trends in core and non-core foods in Australia. *Aust N Z J Public Health*. 2008;32(5):450-453.
51. Christian T, Rashad I. Trends in US food prices, 1950-2007. *Econ Hum Biol*. 2009;7(1):113-120.