Cost Effectiveness of a Sugar-Sweetened Beverage Excise Tax in the U.S.

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Introduction: Reducing sugar-sweetened beverage consumption through taxation is a promising public health response to the obesity epidemic in the U.S. This study quantifies the expected health and economic benefits of a national sugar-sweetened beverage excise tax of $0.01/ounce over 10 years.

Methods: A cohort model was used to simulate the impact of the tax on BMI. Assuming ongoing implementation and effect maintenance, quality-adjusted life-years gained and disability-adjusted life-years and healthcare costs averted were estimated over the 2015–2025 period for the 2015 U.S. population. Costs and health gains were discounted at 3% annually. Data were analyzed in 2014.

Results: Implementing the tax nationally would cost $51 million in the first year. The tax would reduce sugar-sweetened beverage consumption by 20% and mean BMI by 0.16 (95% uncertainty interval [UI]=0.06, 0.37) units among youth and 0.08 (95% UI=0.03, 0.20) units among adults in the second year for a cost of $3.16 (95% UI=$1.24, $8.14) per BMI unit reduced. From 2015 to 2025, the policy would avert 101,000 disability-adjusted life-years (95% UI=34,800, 249,000); gain 871,000 quality-adjusted life-years (95% UI=342,000, 2,030,000); and result in $23.6 billion (95% UI=$9.33 billion, $54.9 billion) in healthcare cost savings. The tax would generate $12.5 billion in annual revenue (95% UI=$8.92, billion, $14.1 billion).

Conclusions: The proposed tax could substantially reduce BMI and healthcare expenditures and increase healthy life expectancy. Concerns regarding the potentially regressive tax may be addressed by reduced obesity disparities and progressive earmarking of tax revenue for health promotion.
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Introduction

Although consumption has declined in recent years, children and adults in the U.S. consume twice as many calories from sugar-sweetened beverages (SSBs) compared to 30 years ago.[1–4] Observational studies and RCTs have linked SSB consumption to excess weight gain, diabetes, and cardiovascular disease.[5] Consumption of SSBs increases the risk of chronic diseases through its impact on BMI and other mechanisms.[5,6] The *Dietary Guidelines for Americans, 2010*[7] recommend that individuals reduce intake of SSBs in order to manage their body weight.

Drawing on the success of tobacco taxation and decades of economic research,[8–10] public health experts have called for higher taxes on unhealthy food and beverages.[9,11] In 2009, the IOM recommended that local governments implement tax strategies to reduce consumption of "calorie-dense, nutrient-poor foods," emphasizing SSBs as an appropriate target for taxation.[12] As of January 2014, a total of 34 states applied a sales tax on carbonated beverages, with an average tax rate of 5.2%.[13] In 2013, one city and 12 states considered

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legislation to increase SSB taxes, although none passed.[14] The city of Berkeley, California, became the first city to pass a $0.01/ounce SSB excise tax in November 2014.[15] Although large SSB excise taxes have not been implemented in the U.S., other countries have implemented them, albeit generally of smaller size.[16] Mexico implemented a 1 peso/liter excise tax on SSBs in January 2014, which preliminary analyses suggest resulted in a 10% reduction in SSB purchases.[17]

Although evidence regarding the empirical associations among beverage prices, the current low tax rates, consumption, and BMI has been mixed,[9,18–20] a number of studies have found that higher beverage taxes and prices are linked to significantly lower BMI.[21–24] Moreover, recently proposed tax strategies differ in many ways from existing sales taxes. First, they would be implemented as per-volume, or specific excise taxes, which provide more visible and consistent price signals to consumers through incorporation into shelf prices. Excise taxes are generally imposed on the manufacturers, in contrast to sales taxes that are collected from the consumer at purchase.[25] Specific excise taxes, as opposed to ad valorem excise taxes, are imposed on the volume produced or distributed instead of on the sales price. Second, they exclude diet soft drinks included in many current sales taxes.[18] Third, current sales taxes often apply only to a subset of SSBs, such as carbonated sodas, which excludes important categories of SSB intake such as sports drinks and fruit drinks. Most importantly, the proposed excise tax of $0.01/ounce of SSBs would result in a 16% price increase, substantially higher than current tax rates.

Building on previous analyses,[26–29] this is the first study to estimate the cost effectiveness of implementing a $0.01/ounce SSB excise tax in the U.S. by estimating both the cost and impact of the change in BMI on reduction in healthcare expenditures; life-years lost; disability-adjusted life-years (DALYs) averted; and quality-adjusted life-years (QALYs) gained. The policy, political, and ethical implications of this economic evaluation are systematically situated within the broader debate in the U.S. over policy approaches to curb the obesity epidemic.

Methods

A national specific excise tax of $0.01/ounce of SSBs was modeled based on recent proposals under consideration by federal, state, and local governments (SSBs include all beverages with added caloric sweeteners as defined in the Appendix).[30–32] The intervention was modeled as an additional tax over and above existing sales and excise tax rates (adjusted for inflation annually). The excise tax does not apply to 100% juice, milk products, or artificially sweetened beverages. The comparator for this intervention was current practice. Baseline consumption of SSBs, milk, and juice was estimated by age group and gender from the 2011–2012 National Health and Nutrition Examination Survey (NHANES), taking into account sampling weights and the clustered sampling design (Table 1).[3] Average daily consumption of SSBs was 150 kcal/day.

Modeling Framework

This analysis was based on a modeling framework developed by collaborating researchers from the Harvard School of Public Health, Columbia Mailman School of Public Health, Deakin University, and University of Queensland in Australia. The current model adapted the Australian Assessing Cost-Effectiveness (ACE)-Obesity[33,34] and ACE-Prevention[35] framework to the U.S. context and followed the reporting recommendations from the U.S. Panel on Cost-Effectiveness in Health and Medicine.[36] Health gains expected from the tax, including changes in BMI, reductions in disease burden and healthcare expenditures, DALYs averted, and QALYs gained over 10 years were estimated using a Markov cohort model. The model was based on a spreadsheet developed for ACE-Prevention replicated in a compiled programming language (JAVA) using U.S. inputs for population characteristics, disease burden, and healthcare costs. The model simulated the 2015 U.S. population aged $\geq$2 years at baseline and followed them for 10 years until death or age 100 years. Based on estimated changes in population mean BMI and obesity rates for each 5-year age and gender group as a result of the intervention, the model predicted downstream changes in stroke, ischemic heart disease, hypertensive heart disease, diabetes mellitus, osteoarthritis, postmenopausal breast cancer, colon cancer, endometrial cancer, and kidney cancer—major diseases that have been linked to obesity. The model then estimated the resulting difference in life expectancy and disability-adjusted life expectancy of the cohort under the no-intervention and intervention scenario. QALYs gained were estimated based on shifts in overweight and obesity prevalence using published estimates of the relationship between BMI and QALYs by age and sex for adults.[37]

The model also estimated differences in healthcare expenditures with and without the intervention based on differences in healthcare costs among children and adults with and without obesity.[38] These healthcare costs were based on analyses of the Medical Expenditure Panel Survey and are reported as net present value discounted at 3% per year. Additional details on the modeling framework are reported in the overview paper by Gortmaker et al.[39]

In addition, key implementation and equity considerations[34] relevant to policymakers and consumers were qualitatively evaluated by a stakeholder group including U.S. policymakers, policy researchers, nutrition and physical activity researchers, and programmatic experts. The following implementation considerations were considered: level of evidence, equity, acceptability, feasibility, sustainability, side effects, and social and policy norms.

Assessment of Benefit

Based on beverage price data from Powell and colleagues,[40] the proposed tax of $0.01/ounce in 2014 dollars would increase prices by approximately 16% (Appendix). The price-induced change in SSB consumption was calculated based on a review of beverage demand elasticity by Powell et al.,[41] which reported an average soft drink own-price elasticity of –1.21 (range, –0.69 to –3.87). Change

Table 1. U.S. Beverage Consumption (kcal/day) and Expected Changes From an SSB Excise Tax

	2011–2012 beverage consumption (kcal/day)						Expected change in consumption (kcal/day) in response to SSB excise tax[a]							
	Male			Female			Male				Female			
Age (years)	SSB	Milk	Juice	SSB	Milk	Juice	SSB	Milk	Juice	Net change[b]	SSB	Milk	Juice	Net change[b]
2–4	58	231	89	66	191	64	−11	6	10	4	−13	5	7	−1
5–9	136	194	51	104	152	38	−27	5	6	−16	−21	4	4	−13
10–14	188	170	29	149	123	30	−37	4	3	−30	−30	3	3	−23
15–19	266	150	53	197	75	35	−53	4	6	−43	−39	2	4	−33
20–29	273	59	36	182	45	36	−54	1	4	−49	−36	1	4	−31
30–39	235	71	42	152	63	23	−47	2	5	−40	−30	2	3	−26
40–49	201	80	19	151	52	26	−40	2	2	−36	−30	1	3	−26
50–59	160	79	39	95	48	19	−32	2	4	−25	−19	1	2	−15
60–69	106	84	51	59	56	20	−21	2	6	−13	−12	1	2	−8
70–79	74	75	31	65	77	29	−15	2	4	−9	−13	2	3	−8
≥80	68	89	38	29	92	37	−14	2	4	−7	−6	2	4	1

[a]Mean change from Scenario 3 in SSB, juice, milk, and total energy intake from model simulation based on NHANES 2011–2012 consumption data,16% SSB price increase resulting from excise tax, own-price elasticity for SSBs, and cross-price elasticities for milk and juice. Rows may not sum as a result of rounding.
[b]Net change indicates change in total calorie intake from beverages per day.
NHANES, National Health and Nutrition Examination Survey; SSB, sugar-sweetened beverage.

in BMI from reducing SSB consumption in response to the estimated tax-induced price change was based on four large studies in adults[42–45] (0.21–0.57 BMI units/12-ounce serving), and a recent double-blind, placebo-controlled trial in youth[46] (1.01 kg/8-ounce serving). Using observed change in BMI from reductions in SSB intake inclusive of all dietary and physical activity changes, these studies incorporated substitution for all other foods and beverages as well as any changes in physical activity. To account for the time lag in weight change following changes in energy balance,[47] no benefits of BMI reduction were estimated during the first year of intervention. The benefits of the full effect of the intervention on BMI were modeled in Years 2–10. With sustained tax implementation over the 10-year period, the tax was assumed to result in sustained reductions in SSB intake and BMI at the population level. Additional detail on the logic model linking the tax to changes in BMI is in the Appendix.

Costs of Intervention

The cost of implementing the proposed tax was estimated from a societal perspective (i.e., taking into account costs and benefits for all members of society) for the 2015–2025 period for the 2015 U.S. population using administrative data from two states operating soft drink excise taxes (West Virginia and Washington) (Appendix Table 5). The costs and labor associated with tax compliance by the beverage industry were assumed to be equal to the cost of administration reported by the government. We did not identify any literature on the cost of compliance with excise taxes. However, parallel evidence regarding costs of administration and compliance with sales taxes, which are expected to be more expensive to administer than the SSB excise tax given the limited number of bottlers and distributors in each state, supports the assumption that costs of administration and compliance are equivalent. A 2006 study found that large retailers (similar to bottlers and distributors subject to the proposed excise tax) reported compliance costs for sales taxes equal to 1% of tax collected excluding credit card fees and unrecovered taxes.[48] As a comparison, the California State Board of Equalization responsible for collecting sales taxes reported administrative costs of 0.95% of sales tax revenue in 2012–2013.[49] Although tax revenues were not part of the economic analysis because they are transfer payments with no net impact on societal costs,[50] expected annual revenue was calculated from the tax to inform the ongoing policy debate.

Cost-Effectiveness Analysis

Short-term cost effectiveness was estimated in terms of cost per BMI unit reduced over 2 years. We estimated cost per BMI based on the national cost of implementation over 2 years divided by either total BMI units reduced for the overall population or by only the effects in youth. BMI-related health benefits and healthcare cost reductions were also estimated over 10 years, with no benefits estimated during the first year of implementation. The incremental cost-effectiveness ratios were calculated by dividing the difference in net costs by the difference in net effectiveness, comparing the intervention with the control scenarios using cost per BMI unit reduced; cost per life-year (LY) saved; cost per DALY averted; and cost per QALY gained.

Table 2. Key Model Variables: Mean Values and 95% Uncertainty Intervals[a]

Parameters	Mean value	95% uncertainty interval	Sources and modeling parameters
Change in SSB consumption and BMI			
Daily intake of SSB, juice, and milk	See Appendix Table 2	See Appendix Table 2 for SE of the mean	Samples drawn from a normal distribution based on age- and gender-specific mean and SE from NHANES 2011–2012
Own-price elasticity of demand for SSB	1.22	(0.70, 2.63)	Samples drawn from an exponential distribution (β=0.5251, shift=0.6892) fitted to absolute value of weighted frequency of 12 estimates included in a review by Powell et al.[41] with M=1.21 and range=0.69–3.87
Δ in SSB consumption (8 oz/day) to Δweight (kg) in youth (2–19 years of age)	1.01	(0.48, 1.54)	Samples drawn from a normal distribution (M=1.01, SD=0.27) based on the mean and SE from an RCT by de Ruyter et al.[46]
Δ in SSB consumption (12 oz/day) to ΔBMI in adults (>19 years of age)	0.39	(0.22, 0.56)	Samples drawn from a uniform distribution (min=0.21, max=0.57) based on four studies[42–45]
Cost of implementing SSB excise tax			
Government/industry administration and compliance time costs per million people per year (FTE)	0.32	(0.10, 0.54)	Samples drawn from a uniform distribution (min=0.09, max=0.55) based on data from personal communications with Washington and West Virginia State Departments of Revenue; see Appendix for more detail.
Government/industry field audit time costs per million people per year (FTE)	0.30	(0.24, 0.35)	Samples drawn from a beta distribution (min=0.223, most likely=0.297, max=0.371) based on an estimate of field audit time (±25%) from a personal communication with West Virginia State Department of Revenue
Fied audit direct costs per million people per year ($)	9,170	(6,450, 11,900)	Samples drawn from a gamma distribution (5th percentile=$6,871; 50th percentile=$9,161; 95th percentile=$11,460) based on an estimate of field audit direct cost (±25%) from a personal communication with West Virginia State Department of Revenue
Tax certification system operating costs per million people per year ($)	11,900	(8,360, 15,400)	Samples drawn from a gamma distribution (5th percentile=$8,899; 50th percentile=$11,865; 95th percentile =$14,844) based on an estimate of tax certification operating costs (±25%) from a personal communication with West Virginia State Department of Revenue
Department of Revenue Officer salary ($) (+56% non-salary benefits)	89,500	N/A	Mean annual salaries from the U.S. Bureau of Labor Statistics 2013 salary for Occupation 13-2081: Tax examiners, collectors, and revenue agents plus 56% non-salary benefits
Industry Auditor salary ($) (+43% non-salary benefits)	106,000	N/A	Mean annual salaries from the U.S. Bureau of Labor Statistics 2013 salary for Occupation 13-2011: Accountants and auditors plus 43% non-salary benefits

[a]95% uncertainty interval based on 10,000 simulations drawn from parameter-specific distributions.
FTE, full-time equivalent; NHANES, National Health and Nutrition Examination Survey; SSB, sugar-sweetened beverage.

Sensitivity Analyses

Probabilistic sensitivity analyses were conducted by simultaneously sampling all parameter values from predetermined distributions using Monte Carlo simulations (Table 2). Means and 95% uncertainty intervals (UIs) for BMI effects and implementation costs were reported based on 10,000 iterations of the model using @Risk, version 6. Impacts on healthcare cost savings, LYs, DALYs, and QALYs were estimated based on 1 million iterations of the model developed in a compiled programming language. Data were analyzed in 2014.

Model uncertainty was assessed by modifying the primary scenario with alternative logic pathways. In the primary scenario, BMI changes from reduced SSB consumption were modeled directly based on a review of the literature. In secondary and tertiary scenarios, expected BMI effects were estimated through change in total energy intake based on work by Hall and colleagues.[47,51] In the secondary scenario, change in total energy intake from a reduction in SSB consumption was estimated based on crossover feeding trials and observational studies of diet and energy intake, which accounted for any substitution to other foods and beverages but did not incorporate changes in physical activity or longer-term substitution patterns captured in the primary scenario. In the tertiary scenario, changes in total energy intake were estimated based on cross-price elasticities for milk and juice identified in a recent review.[41] This approach explicitly modeled potential substitution to other caloric beverages. Inputs for the two alternative scenarios are discussed in the Appendix.

Additional sensitivity analyses were conducted (Appendix). The assumed tax "pass-through" rates varied from 50% to 150%, in which beverage companies may decide to raise the price of SSBs by less or more than the cost of the imposed tax. The lowest own-price elasticity from the systematic review by Powell et al.[41] was used (–0.69) to estimate the lower bound of predicted change in consumption. An alternative program cost assumption was tested based on previous tobacco excise tax implementation (3% of tax revenue).[52]

Results

Implementing a national excise tax of $0.01/ounce of SSBs was estimated to cause a 20% (95% UI=11%, 43%) reduction in baseline consumption. For men aged 20–29 years, the group with the highest consumption level, consumption of SSBs would decrease from 273 kcal/day to 219 kcal/day (Table 1). At full effect, this change would reduce BMI by an average of 0.08 (95% UI=0.03, 0.20) among adults and 0.16 (95% UI=0.06, 0.37) among youth, and lead to an estimated 0.99% decrease in obesity prevalence among adults (obesity defined as BMI $\geq$30) and a 1.38% decrease among youth (obesity defined as $\geq$95th percentile of age- and sex-specific BMI).[53,54] The intervention would cost $51 million the first year and $430 million (95% UI=307 million, 552 million) over 10 years of implementation. Over the first 2 years, the intervention would cost $3.16 (95% UI=$1.24, $8.14) per BMI unit reduced across the entire population, or $8.54 (95% UI=$3.33, $24.2) per BMI unit reduced among youth, assuming full costs of implementation but only considering benefits in youth (Table 3).[55]

Over the 2015–2025 period, for the 2015 U.S. population the intervention would save 32,300 (95% UI=11,100, 80,100) LYs, avert 101,000 (95% UI=34,800, 249,000) DALYs, and lead to 871,000 (95% UI=342,000, 2,030,000) QALYs gained. The reductions in BMI would result in a mean estimated $23.6 billion (95% UI=$9.33 billion, $54.9 billion) reduction in total healthcare costs over 10 years for the 2015 cohort. For every dollar invested, the intervention would result in $55.0 (95% UI=$21.0, $140.0) in healthcare cost savings. The intervention was "cost saving," as it would result in both savings in DALYs or increase in QALYs and reduction in total costs compared to current practice. The proposed intervention would remain cost saving across a wide range of input parameter values (Table 4). The tax was estimated to be cost saving across all scenarios beginning in Year 2.

Although not considered a benefit in our cost-effectiveness analyses, from the government's perspective, the national excise tax would generate an estimated $12.5 billion (95% UI=$8.92 billion, $14.1 billion) in annual revenue in 2014 dollars, or $12.48 billion net revenue.

A summary of stakeholder discussions regarding implementation and equity considerations is presented in Table 5.[57–60] The stakeholders placed significant weight on the potential of the intervention to shift public awareness and social and policy norms leading to healthier beverage intake. Stakeholders emphasized that the proposed intervention would also lead to substantial additional reductions in diabetes, heart disease, and dental disease not modeled in this study.[6,61–63] However, the tax could lead to a backlash against public health intervention because of the current anti-tax sentiment in the U.S.[64]

Discussion

This is the first cost-effectiveness analysis of an excise tax on SSBs as a tool for reducing BMI, healthcare costs, health burden, and excess mortality in the U.S. In the short term, the policy is estimated to be a low-cost strategy to achieve small but meaningful reductions in BMI in both adults and children. Implementing the proposed tax would likely be cost saving to address the obesity epidemic while also generating substantial revenue that could be used for health promotion.

Some researchers have argued that individuals could compensate for a tax by increasing consumption of other food and beverages, thus entirely offsetting the caloric benefit of reducing SSB intake.[18,20] Conversely, another simulation study assumed that tax-induced reductions in SSB intake will not result in any caloric compensation.[65] The empirical association between SSB prices (included tax-driven price changes) and BMI supporting this argument is inconsistent. One repeated cross-sectional study estimated a significant 0.003 BMI unit reduction per 1% increase in soft drink tax rates, which would lead to an estimated reduction of 0.05 BMI units from a 16% tax, near the lower bound of the uncertainty interval in this study.[24] In a repeated cross-sectional analysis, the same authors estimated non-significant BMI differences among adults and youth with a 1%-higher tax rate.[18,20] Powell and colleagues[19] found non-significant associations between state soda tax rates and overall youth BMI.

However, studies that used stronger designs incorporating within-person change-predicting-change analyses

Table 3. Mean Cost-Effectiveness Results With 95% Uncertainty Intervals

Total population reached (millions)	313
First-year intervention cost ($ millions)	51.0 (36.4, 65.5)
Ten-year intervention cost ($ millions)	430 (307, 552)
Annual revenue ($ billions)	12.5 (8.92, 14.1)
Short-term outcomes	
Mean per capita BMI unit reduction for adults >19 years of age)	0.08 (0.03, 0.20)
Mean per capita BMI unit reduction for youth 2–19 years of age	0.16 (0.06, 0.37)
Total BMI units reduced (millions)	31.7 (12.7, 74.3)
Total BMI units reduced (millions) (youth only)	11.7 (4.21, 27.7)
Cost per BMI unit reduced[a] ($) (overall)	3.16 (1.24, 8.14)
Cost per BMI unit reduced ($) (youth only)	8.54 (3.33, 24.2)
Ten-year outcomes	
Total LYs saved (thousands)	32.3 (11.1, 80.1)
Total DALYs[b] averted (thousands)	101 (34.8, 249)
Total QALYs[b] gained (thousands)	871 (342, 2,030)
Healthcare costs[c] ($ billions)	−23.6 (−54.9, −9.33)
Net costs[d] ($ billions)	−23.2 (−54.5, −8.88)
Healthcare cost savings per $ intervention cost ($)	55.0 (21.0, 140)
Net cost per LY saved[e] ($)	Cost-saving[f]
Net cost per DALY averted[e] ($)	Cost-saving[f]
Net cost per QALY gained[e] ($)	Cost-saving[f]

[a]Cost per BMI unit reduced based on 2 years of cost of implementation and total BMI reduction for all ages in the 2015 cohort or for youth only.
[b]DALYs averted and QALYs increased due to the proposed intervention are calculated as the difference in the simulated disability-adjusted years of life lived over 10 years in the intervention cohort compared to the baseline cohort of the U.S. population (>1 year of age) in 2015.
[c]The reduction in health care costs refers to the simulated difference in ten-year healthcare costs due to the intervention for a baseline cohort of the U.S. population in 2015. Healthcare costs and health effects are estimated annually and are reported as present value in July 2014 dollars discounted at 3% annually.
[d]Net costs include total implementation costs and healthcare cost savings over 10 years.
[e]Values are calculated as the ratio of mean incremental costs over LYs saved, DALYs averted, and QALs increased in the intervention scenario compared to the no-intervention scenario, with the mean and 95% uncertainty intervals reported from 10,000 iterations of the @Risk BMI simulation model and one million iterations of the BMI-to-DALY/QALY simulation.
[f]Interventions are considered “Cost-saving,” and summary statistics are not calculated when they result in both a cost savings and a reduction in DALYs or an increase in QALYs.[55]
$, 2014 U.S. dollars; DALYs, disability-adjusted life-years; QALYs, quality-adjusted life-years; LY, life-years.

have found significant associations between higher soft drink prices and lower weight in youth and adults.[22] One study found that a 10% price increase for carbonated beverages led to a 0.42% decrease in average child’s BMI.[23] This corresponds to a 0.13 BMI unit reduction given a modeled 16% price increase, which is very similar to the 0.16 change estimated in this study.

Regarding the potential magnitude of compensatory consumption, a double-blind, placebo-controlled randomized trial by de Ruyter et al.[46] provides strong evidence for some, but far from complete, compensation. Randomization to consume 104 kcal/day of SSBs resulted in a 1-kg greater weight gain after 18 months, approximately 70% of what might be expected over this time period among children aged 8 years if there was no compensation.[51] These results suggesting small compensatory effects are consistent with two other randomized trials in youth that replaced SSBs with free non-caloric beverages.[66,67] Estimates of the impact of a change in SSB intake on weight from change-in-change studies among adults used in the present analysis found evidence of greater compensation. Mozaffarian and colleagues[43] found that each additional serving of SSBs was associated with a 1.32-pound greater weight gain over 4 years, less than 10% of what would be expected if there was no compensation.[43,47] At the other end of the range modeled in this study, Chen et al.[42] found that each additional serving of SSBs was associated with a 3.6-pound greater weight gain, about 40% of what would be expected with no compensation. So, although we agree that individuals will compensate in part for changes in SSB intake resulting from increased relative SSB prices, and explicitly incorporate compensation into our model, the best evidence does not suggest complete compensation.

The proposed tax is estimated to generate $12.5 billion/year in tax revenue in 2015, similar to the $13.3 billion estimated in another analysis using industry sales data from 2008,[68] and the analysis from the Congressional Budget Office, which calculated that a federal excise tax of $0.03/12 ounces of SSBs would generate $4.7 billion in 2010.[69] Arguments against an SSB tax, frequently made by groups supported by the beverage industry, focus on the potential regressive effect of the

Table 4. Mean Sensitivity Analyses Results With 95% Uncertainty Intervals

	Secondary scenario: impact on BMI based on TEI studies	Tertiary scenario: impact on BMI based on beverage substitution	Costs as 3% of annual tax revenue	50% tax pass-through rate[a]	150% tax pass-through rate[a]	Lowest identified own-price elasticity
Total population reached (millions)	313	313	313	313	313	313
First-year intervention cost ($ millions)	51.0 (36.4, 65.5)	51.0 (36.4, 65.5)	375 (268, 422)	51.0 (36.4, 65.5)	51.0 (36.4, 65.5)	51.0 (36.4, 65.5)
Ten-year intervention cost ($ millions)	430 (307, 552)	430 (307, 552)	3,170 (2,250, 3,560)	430 (307, 552)	430 (307, 552)	430 (307, 552)
Short-term outcomes						
Mean per capita BMI unit reduction for adults >19 years of age	0.38 (0.18, 0.84)	0.35 (0.15, 0.83)	0.08 (0.03, 0.20)	0.04 (0.02, 0.10)	0.13 (0.05, 0.30)	0.05 (0.03, 0.07)
Mean per capita BMI unit reduction for youth 2–19 years of age	0.62 (0.30, 1.40)	0.27 (0.06, 0.73)	0.16 (0.06, 0.37)	0.08 (0.03, 0.19)	0.24 (0.09, 0.56)	0.09 (0.04, 0.14)
Total BMI units reduced (millions)	135 (66.1, 302)	102 (41.7, 250)	31.7 (12.7, 74.3)	15.8 (6.37, 37.2)	47.5 (19.1, 111)	18.0 (9.97, 26.0)
Cost per BMI unit reduced[b] ($)	0.74 (0.30, 1.64)	0.98 (0.37, 2.55)	23.3 (7.2, 63.1)	6.31 (2.48, 16.3)	2.10 (0.83, 5.42)	5.56 (3.23, 10.74)
Ten-year outcomes						
Total LYs saved (thousands)	126 (54.4, 290)	114 (32.2, 317)	32.3 (11.1, 80.1)	16.2 (5.55, 40.2)	48.3 (16.6, 120)	18.4 (8.45, 31.6)
Total DALYs averted[c] (thousands)	393 (172, 895)	401 (127, 1,060)	101 (34.8, 249)	50.5 (17.4, 125)	151 (52.2, 372)	57.2 (26.6, 97.9)
Total QALYs gained[c] (thousands)	2,160 (1,050, 4,770)	1,890 (834, 4,530)	871 (342, 2,030)	438 (171, 1,020)	1,300 (513, 3,020)	496 (281, 716)
Healthcare costs[d] ($ billions)	−57.1 (−127, −27.8)	−47.5 (−116, −19.5)	−23.6 (−54.9, −9.33)	−11.9 (−27.7, −4.67)	−35.3 (−81.7, −14.0)	−13.5 (−19.4, −7.61)
Net costs[e] ($ billions)	−56.7 (−126, −27.3)	−47.0 (−116, −19.1)	−20.5 (−52.6, −5.86)	−11.4 (−27.3, −4.23)	−34.9 (−81.3, −13.5)	−13.0 (−19.0, −7.19)
Healthcare cost savings per $ intervention cost ($)	133 (59.6, 319)	110 (42.6, 294)	7.46 (2.69, 23.8)	27.6 (10.5, 70.4)	82.1 (31.4, 208)	31.3 (16.1, 54.5)

(continued on next page)

Table 4. Mean Sensitivity Analyses Results With 95% Uncertainty Intervals *(continued)*

	Secondary scenario: impact on BMI based on TEI studies	Tertiary scenario: impact on BMI based on beverage substitution	Costs as 3% of annual tax revenue	50% tax pass-through rate[a]	150% tax pass-through rate[a]	Lowest identified own-price elasticity
Net cost per LY saved ($)	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]
Net cost per DALY averted ($)	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]
Net cost per QALY gained ($)	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]	Cost-saving[f]

[a]Pass-through rates refer to the proportion of the total value of the imposed excise tax incorporated into the price paid by consumers.[56]
[b]Cost per BMI unit reduced based on 2 years of cost of implementation and total BMI reduction for all ages in the 2015 cohort.
[c]DALYs averted and QALYs gained due to the proposed intervention are calculated as the difference in the simulated health-adjusted years of life lived in the intervention cohort over 10 years compared to the baseline cohort of the United States population >1 year of age in 2015.
[d]The reduction in health care costs refers to the simulated difference in 10-year healthcare costs due to the intervention for a baseline cohort of the U.S. population in 2015. Healthcare costs and health effects are estimated annually and are reported as present value in July 2014 dollars discounted at 3% annually.
[e]Net costs include total implementation costs and healthcare cost savings over 10 years.
[f]Interventions are considered "Cost-saving," and summary statistics are not calculated when they result in both a cost savings and a reduction in DALYs or an gain in QALYs.[55]
DALYs, disability-adjusted life-years; Dollars, July 2014 U.S. dollars; LYs, life-years; TEI, total energy intake.

tax.[64,70] Though several studies have estimated a lower price elasticity and potentially higher relative tax burden among low-income households,[71,72] empirical research indicates that SSB taxes pose a greater health benefit to children who are already overweight, African American children, and children living in low-income households,[21] thereby reducing disparities in obesity. Nevertheless, the impact of the proposed intervention was not evaluated by race/ethnicity, income level, or weight status.

Previous industry-sponsored studies have highlighted the potential loss of jobs to industry as a result of excise taxes on SSBs.[27] In a recent analysis, Powell and colleagues[73] found that although implementing SSB taxes in California and Illinois would lead to job losses in the beverage industry, SSB taxes would lead to a slight increase in overall employment as a result of offsetting employment increases in non-beverage industry and government. Given the success of beverage industry marketing efforts to date, it is likely that a shift in marketing expenditures toward products not subject to the proposed excise tax on SSBs would counteract the projected impact on beverage industry revenue and employment.

It could be argued that a reduction in SSB consumption as a result of the proposed SSB tax would reduce consumer surplus as a result of the lost pleasure gained from drinking SSBs and that this cost should be included in the present analysis. Recent cost–benefit analyses conducted by the U.S. Food and Drug Administration reduced the expected societal benefits of public health policies by half as a result of lost consumer surplus.[74,75] We do not believe that current consumer decisions regarding SSB intake meet the assumptions underlying a potential lost consumer surplus analysis of perfectly rational decision makers operating with full information, accurate foresight, and stable time preferences.[76,77] Most importantly, given the emerging evidence linking SSB intake to a range of negative health outcomes, it is unlikely that consumers are making fully informed decisions about the risks of SSB intake. This is particularly true for children and adolescents who are repeatedly exposed to emotionally based SSB advertisements and may become addicted to caffeine and sugar in SSBs before they are capable of fully understanding the long-term risks of SSB consumption.[78]

Our analysis highlights the importance of several key uncertainties. Although this model's estimate of the relationship between SSB intake and BMI is based on a double-blind, placebo-controlled trial in youth and four large observational studies in adults, there is a need for additional RCTs and evaluations of environmental interventions. It is also possible that the relationship between

Table 5. Implementation and Equity Considerations

Level of evidence	Equity	Acceptability to stakeholders	Feasibility	Sustainability	Side effects	Social and policy norms
Strong evidence for change in BMI/weight from change in sugar-sweetened beverage (SSB) consumption	Some concerns regarding regressive nature of tax	Opposition from beverage industry spending > $4 billion/year on marketing[57]	Beverage excise taxes currently applied at state level with limited difficulty	Likely to be sustainable if implemented based on history of tobacco excise taxes	Positive: Reduction in diabetes, dental caries, and improved bone health in addition to impact on BMI	Substantial potential for shift in social norms based on evidence from tobacco control tax and regulatory efforts[58,60]
Strong evidence of price elasticity of demand from a systematic review	Substantial health benefits accrue to low-income consumers	Public support for tax mixed, but increases with earmarking for prevention[59]			Revenue can be earmarked toward obesity prevention	
Parallel evidence from tobacco excise tax history	Progressive use of earmarking counteracts regressive tax	Mixed policymaker response because of opposition to taxes and need for revenue				
Decision Point: Sufficient evidence of effectiveness	Concerns outweighed by revenue earmarking and health impact	Marginally acceptable to public and some policy makers but opposed by industry	Feasible	Sustainable if implemented	Substantial benefits, limited concerns	Strong potential benefit

Note: Political considerations: Although the intervention is cost saving and would likely have a large societal impact, increasing taxes in the current political environment against strong industry opposition remains a challenge in many localities.

changes in SSB intake and BMI from the trials in youth and observational data in adults may not generalize to tax-induced changes in SSB intake in a free-living population. To address uncertainty in this relationship, we conducted sensitivity analyses using both short-term energy intake studies and econometric analyses of beverage demand systems, the latter of which more closely approximates price-induced changes in total energy intake from beverages. The results of these analyses are consistent with our primary scenario.

As with all similar simulation models, the model results represent the best estimate of a potential effect in the absence of stronger direct evidence. For some model variables there is limited evidence to estimate the effect of the tax, such as predicting the effective price increase resulting from the tax and whether consumers would respond to the tax by shifting to larger container sizes or lower-priced generic SSB brands. However, given that the proposed specific excise tax is per volume rather than cost, it should not encourage a shift to cheaper store brands and to larger serving sizes, as a sales tax would likely initiate. In fact, the relative tax-induced price increase will likely be greater for store brands and for larger containers than the average increase included in this model.

Despite these limitations, this analysis provides a conservative estimate of the potential benefits of the intervention. The model relies on BMI-mediated health effects and healthcare costs and does not incorporate additional expected reductions from reduced SSB intake in metabolic diseases, cardiovascular risk factors, dental caries, or bone fractures.[6,61–63] In a previous analysis, Wang et al.[29] estimated that, independent of its effect on BMI, a $0.01/ounce SSB tax would reduce diabetes incidence by 2.6% among adults aged 25–64 years. The reduction in diabetes incidence independent of weight loss accounted for more than half of the total healthcare cost savings in that analysis. The model in this study also excludes potential health gains from earmarking tax revenues to health promotion. Previous tobacco control efforts demonstrate the potential impact of earmarking SSB tax revenue to obesity prevention: CDC reported in 2007 that almost 90% of funding for state and local tobacco prevention programs came from excise taxes and tobacco settlement funds.[79] Perhaps most importantly, the model does not incorporate indirect costs of obesity due to reduced productivity, increased absenteeism, disability, and early retirement or mortality, which means that the societal savings from the intervention are likely to be substantially underestimated.[80,81] Although the societal savings of the proposed policy are potentially large, the policy may reduce profits in the beverage industry if they are not able to increase sales among unsweetened alternatives.

Conclusions

In the short term, the proposed SSB tax policy would likely reduce excess weight among both youth and adults while increasing potential revenue for health promotion. Over 10 years, the policy would likely reduce healthcare expenditures and increase healthy life expectancy. Implementing the tax could also serve as a powerful social signal to reduce sugar consumption through additional individual behavioral and policy changes. This paper provides important new information to policymakers and the public regarding the substantial savings in both human health and government expenditures that could be achieved by the proposed tax on SSBs.

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Appendix

Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.1016/j.amepre.2015.03.004.