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Original article

Estimating the effects of a calorie-based sugar-sweetened beverage tax on weight and obesity in New York City adults using dynamic loss models

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ABSTRACT

Purpose: Sugar-sweetened beverages (SSBs) contribute to weight gain and increase the risk of obesity. In this article, we determine the effects of an innovative SSB tax on weight and obesity in New York City adults.
Methods: Dynamic weight loss models were used to estimate the effects of an expected 5800-calorie reduction resulting from an SSB tax on weight and obesity. Baseline data were derived from the New York City Community Health Survey. One, five, and 10-year simulations of weight loss were performed.
Results: Calorie reductions resulted in a per-person weight loss of 0.46 kg in year 1 and 0.92 kg in year 10. A total of 5,531,059 kg was expected to be lost over 10 years when weighted to the full New York City adult population. Approximately 50% of overall bodyweight loss occurred within the first year, and 95% within 5 years. Results showed consistent but nonsignificant decreases in obesity prevalence.
Conclusions: SSB taxes may be viable strategies to reduce obesity when combined with other interventions to maximize effects in the population.

Introduction

Obesity poses a continued threat to the health of the American population, increasing risks for diabetes, stroke, and cardiovascular disease, [1] and with high levels of body mass index (BMI) increasing both all-cause and cause-specific mortality [2]. Sugar-sweetened beverage (SSB) consumption has been linked with weight gain [3–10] and poor diet [11–13], and increases in SSB consumption are associated with greater risks of obesity and overweight obesity [14–23]. SSBs are a substantial contributor to daily calorie intake, constituting more than 7% of the national per-capita energy consumption [24–26]. In New York City, more than 58% of the adult population is overweight or obese, and obesity has risen from 18% to 24% between 2002 and 2012 [27]. Adult SSB consumers in New York City derive 193 daily calories, or 10.6% of total energy intake, from SSBs [23].

As a food environment regulation, sugary drink taxes are frequently proposed strategies to improve nutrition and reduce obesity at the population level [24,28–30]. Previous simulations using econometrically estimated price elasticity of SSB demand showed that expected calorie reductions from a 20% targeted tax on SSBs, assumed to fully pass on to retail prices, may significantly reduce weight, obesity prevalence, and diabetes incidence [28,31,32]. However, quasi-experimental studies show that current soda taxes do not influence overall calorie intake and are ineffective in reducing population weight, but they may have larger effects in specific high-risk populations [33–36]. It should be noted that US soda taxes are generally small in magnitude, with a mean of roughly 5% and are not reflected in the shelf price in the case of sales tax [37]. Thus, it may not be surprising that existing taxes are ineffective in changing behavior because of their low visibility to consumers [38,39].

In a recent study, New York supermarket beverage sales data were used to predict the effectiveness of a hypothetical calorie-based SSB tax [24]. Using an innovative econometric demand model that formally accounted for substitutions among hundreds of beverage brands and assumed full tax pass-through to retail price, the authors demonstrated that a new .04-cent per kcal excise tax on SSBs would reduce energy consumption from SSBs from supermarket sources by 9.3%. Compared with a per-ounce tax that achieves the same level of beverage calorie reduction, the 0.04-cent per

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kcal SSB tax had a smaller adverse impact on consumer grocery budget, as the latter was more effective in nudging consumers to substitute low-calorie drinks for high-calorie ones. When applied to all market sources, where demand was assumed to respond to price changes similarly, total beverage energy was predicted to reduce by a national average of 5800 calories per person per year. Although this is one of the most sophisticated estimates of the effects of a calorie-based SSB tax on beverage demand to date, the impact of this reduction on population weight and obesity is still unknown.

Given the utility of economic modeling in predicting effects of potential public health interventions, it is critical to present estimated impacts in a form useful to both public health practitioners and the general public. Proper estimation of the health impact of proposed policies can lead to more informed interventions designed to reduce the burden of obesity and associated noncommunicable diseases. In New York City, a number of population-wide interventions have been proposed in efforts to reduce adult obesity prevalence but rarely produce appreciable effects that can be widely understood. In this study, we convert predicted per-capita calorie reductions described previously into expected immediate and long-term weight loss in the New York City adult population. In doing so, we assess the viability of an SSB tax as a standalone obesity intervention. The study is innovative in that it predicts the real-world impact of caloric reductions generated using a novel econometric demand model simulating a calorie-based SSB tax. First, self-reported data from the annual New York City Community Health Survey (CHS) were used to estimate individual body fat composition and resting metabolic rates. These were then combined with a 5800-calorie reduction and applied to a dynamic weight loss predictive model to estimate the effects of dietary change on population weight and obesity. Model simulations were performed over periods of 1, 5, and 10 years. Changes in obesity prevalence were tested for statistical significance. Results were compared using both BMI and percent-body fat estimates of obesity. We hypothesized that changes in dietary intake due to an SSB tax would significantly reduce obesity as measured by BMI and percent body fat over 10 years.

Methods

Data

Data providing baseline weight status for the New York City adult population were derived from the New York City CHS. Self-reported height, weight, age, and gender were used to estimate per-person resting metabolic rates and body fat mass. The CHS is a disproportionate, stratified, dual-sample (cellular and landline) clustered random survey conducted annually by the New York City Department of Health and Mental Hygiene and provides a representative sample of noninstitutionalized adult New Yorkers. The 2012 sample consisted of 8797 adults aged 18 years and older [27]. All data from the CHS are self-reported. Deidentified public use data sets of the CHS are available online through the New York City Department of Health and Mental Hygiene Web site. The most recently listed response rate was 40.0% in 2011, with a cooperation rate of 89.1%.

Simulated weight loss

Dynamic weight loss modeling was used to simulate the effects of anticipated calorie reductions from an SSB tax on population weight change. Dynamic models use initial body conditions and metabolic parameters to estimate the effects of dietary change on body composition, while adjusting for the physiological adaptations that occur in response to changes in diet or physical activity [28,40–43]. This process produces more reliable estimates of weight loss than traditional static models, which assume a fixed 3500-calorie requirement per pound of weight loss [40,44]. Although the advantages of dynamic weight loss models have been explained in detail elsewhere, a summary of benefits is as follows: weight loss is nonlinear and thus more appropriately modeled as a dynamic process; second, weight loss varies depending on the proportion of body fat relative to total body composition, so modeling initial body parameters is critical; and finally, bodyweight contributes to individual energy needs, so models should adjust for the diminishing returns to weight loss because energy requirements decrease when total overall bodyweight decreases [28,40,45,46]. Simulations using dynamic loss models can be conducted over multiple years, supporting their use in modeling the long-term effects of public health policies, and simulation results closely match those from experimental research [43]. For weight loss estimates, we assume that calorie reductions from an SSB tax are averaged across the New York City adult population. For comparison, we provide estimates of weight change for both dynamic and static loss models.

The Laboratory of Biological Modeling at the National Institute of Diabetes and Digestive and Kidney Diseases provided code for the dynamic weight loss model, which has been described in detail elsewhere [40]. Briefly, body fat and lean tissue change are modeled using a set of differential equations that use an overall energy expenditure function, consisting of parameters for resting metabolic rates for fat mass and lean tissue, thermogenesis, altered energy expenditure in response to changes in calorie intake, sodium intake, biochemical energies for protein and fat synthesis, and physical activity. These parameters are then combined with a user-supplied calorie reduction and used to model long-term weight loss.

Model parameters

Individual resting metabolic rates for CHS respondents were computed using the Mifflin-St. Jeor equations [47], per-person body fat mass was computed using the sex-specific equations derived from Jackson et al (2002), and initial lean mass was calculated by subtracting total bodyweight from estimated fat mass [28,48]. The proportion of bodyweight attributable to fat mass was used to determine percent body fat. Average sodium intake was specified as 3239 mg/day based on a previous study in New York City using 24-hour urinalysis [49]. Previous studies show that body fat predictive models account for a high proportion of variance in body fat and have a standard error of estimate of approximately 4% [50]. Urinalysis is considered the gold standard for measuring sodium intake [49]. Thermogenesis rates, biochemical energies for fat and protein synthesis, and average physical activity expenditure were provided by the National Institute of Diabetes and Digestive and Kidney Diseases.

Calorie reductions

Calorie reductions used in analysis were based off previously published results from a new econometric model simulating a 0.04-cent per calorie SSB tax [24]. Based on New York sales data for 178 beverage brands accounting for 95% of all supermarket volume sales, an average of 3414 beverage ounces were consumed from supermarkets per capita for 2007 to 2011, resulting in a total energy purchase of 22,663 calories per person per year. Using a fully modified distance metric demand model, the authors estimated demand elasticities for SSBs in response to a hypothesized tax while adjusting for product-level substitution of alternative beverages and incorporating product heterogeneity into estimated cross-price effects. This method avoided overestimation of the net effect of beverage taxes on beverage calorie intake that has been