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Body weight impact of the sugar-sweetened beverages tax in Mexican children: A modeling study

Rossana Torres-Álvarez[1] | Rodrigo Barrán-Zubaran[1] | Francisco Canto-Osorio[1] | Luz M. Sánchez-Romero[2] | Dalia Camacho-García-Formentí[1] | Barry M. Popkin[3] | Juan A. Rivera[1] | Rafael Meza[4] | Tonatiuh Barrientos-Gutiérrez[1]

[1]Center for Population Health Research, National Institute of Public Health, Cuernavaca, Mexico
[2]Lombardi Comprehensive Cancer Center, Georgetown University, Washington, District of Columbia
[3]Gillings School of Global Public Health, University of North Carolina, Chapel Hill, North Carolina
[4]Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, Michigan

Correspondence
Tonatiuh Barrientos-Gutiérrez, Center for Population Health Research, National Institute of Public Health, Avenida Universidad 655, Santa María Ahuacatitlán, Cuernavaca, Morelos 62100, México.
Email: tbarrientos@insp.mx

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Summary

Background: In Mexico, a 10% tax to sugar-sweetened beverages was implemented in 2014. Projections of the potential health effect of this tax in children are not available.

Objective: To estimate the 1-year effect of the tax on the body weight of children 5 to 17 years old, and estimated alternative scenarios with higher tax rates (20%, 30%, and 40%).

Methods: We used a dynamical mathematical model, recalibrated to the Mexican population. Input data were obtained from the Mexican National Health and Nutrition Survey 2006 and 2012. We estimated the expected average weight reduction, stratified by category of sugar-sweetened beverages consumption.

Results: With a 10% tax, we estimated an overall weight reduction of 0.26 kg for children and 0.61 kg for adolescents; in high consumers, the reduction could reach 0.50 and 0.87 kg, respectively. Higher tax rates would produce larger weight decreases; in high consumers a 40% tax would result in a reduction of 1.99 kg for children and 3.50 kg for adolescents.

Conclusion: The tax represents an effective component of any child or adolescent weight control program, and must be considered as part of any integrated population-level program for children and adolescent obesity prevention.

KEYWORDS
children, modeling study, obesity, sugar-sweetened beverages, tax

1 | INTRODUCTION

Sugar-sweetened beverages (SSBs) are a primary source of added sugars in children and adolescents.[1] In the United States, SSBs contribute to 6.2% and 9.5% of the total energy intake (TEI) of children and adolescents.[2] In Mexico, soft drinks contribute to 6.8% of the TEI per day in children and 9.1% for adolescents[3]; thus, SSBs intake alone surpass the World Health Organization (WHO) ideal recommendation for daily free sugar consumption (5% TEI), and provide more than half of the current recommendation of 10% TEI.[1] Moreover, added sugars represent 13% of TEI in the Mexican diet and SSBs contribute with 69% of all added sugars.[4] Sugar consumption is increasingly recognized as a key target to improve population health, and reducing SSBs consumption

Abbreviations: BMI, body mass index; BW, body weight; CIs, confidence intervals; CVD, cardiovascular disease; DCGO, dynamics of childhood growth and obesity model; ENSANUT, Mexico National Health and Nutrition Survey; FFM, fat free mass; FFQ, food frequency questionnaire; FM, fat mass; NCDs, non-communicable diseases; SSBs, sugar-sweetened beverages; T2DM, type 2 diabetes mellitus; TEI, total energy intake; WHO, World Health Organization.

is considered to be one of the most effective ways to substantially reduce TEI.[1,5,6]

There is substantial evidence showing that SSBs consumption causes adverse health outcomes in children and adolescents. SSBs consumption has been associated with dental caries, early menarche, and obesity.[6-9] Children affected by obesity at younger ages whom remain affected into adulthood, increase their risk of type 2 diabetes mellitus (T2DM), hypertension, dyslipidemias, and atherosclerosis.[10] Avoiding SSBs consumption during childhood could provide important and long-lasting health benefits for children.[1,11] Recently, international organizations have recommended the implementation of specific interventions to reduce SSBs intake, such as excise taxes, reformulation, or SSBs bans in elementary schools.[11]

In 2014, Mexico implemented a 1 peso-per-liter tax for SSBs (10% approximate price increase), which led to an average purchase decrease of 7.6%.[12] These reductions are expected to produce important health benefits for adults, including the prevention of 189 000 cases of diabetes and 20 000 cases of cardiovascular disease, as well as a 2.6% reduction in the obesity prevalence in a decade.[13] However, Mexican children and adolescents are also high SSBs consumers,[3] and will likely also benefit from SSBs reductions linked to the tax. A study by Ng et al., estimated that, after the tax was implemented in Mexico, high purchasers of taxed beverages experienced greater purchase reductions (−13.2%) compared to low purchasers (−0.4%).[14] To date, no study has attempted to estimate the health benefits of the SSBs tax in children and adolescents in Mexico.

We aimed to estimate the potential impact of Mexico's SSBs tax in children and adolescents. We implemented a dynamical model of childhood growth and obesity, re-calibrated to Mexican population, to estimate the expected 1-year body weight change, assuming that the observed reduction in SSBs purchases reflected changes in SSBs consumption. The model was developed using Mexican nationally representative estimates of SSBs consumption, weight, sex, and age. We estimated the potential effect with the current tax and estimated alternative tax scenarios to explore the impact of strengthening the policy.

2 | METHODS

We obtained baseline SSB consumption, and anthropometric measurements, among children in Mexico using the 2012 National Health and Nutrition Survey (ENSANUT). The ENSANUT 2012 is a cross-sectional, multistage, probabilistic survey nationally representative that measures the health and nutritional status of the Mexican population. The study protocol, questionnaires, and informed consent procedures for the 2012 National Survey of Health and Nutrition were approved by the ethics, research, and biosecurity committee of the National Institute of Public Health. All children and adolescents provided assent to participate in the study, in addition to parental written consent.[15]

2.1 | Model inputs

2.1.1 | Anthropometric measurements

All anthropometric measurements were obtained following standardized procedures and instruments.[16] Individuals with implausible body mass index (BMI) <10 kg/m^2 or >58 kg/m^2 and pregnant adolescents were excluded from the analysis.[17] Our final analytical sample consisted of a total of 1123 school age children (5-11 years); and 1390 adolescents (12-18 years).

2.2 | Dietary intake

We used ENSANUT's seven-day semiquantitative food frequency questionnaire (FFQ) to calculate SSBs consumption and TEI (kcal/day). The questionnaire was administered to mothers or caretakers of school age children; adolescents self-reported their food consumption. Details about ENSANUT's FFQ methodology are available elsewhere.[18] SSBs intake was obtained by adding the estimated daily consumption (kcal) of four taxed SSBs: soda, industrialized natural fruit juice with added sugar, industrialized beverage or flavored water, and industrialized fruit nectar. Following the work of Ng and colleagues, we classified children as low consumers if their SSBs intake was lower than 150.3 mL/day, and as high consumers if their intake was 150.3 mL or higher. TEI was obtained from the FFQ; we excluded individuals that reported implausible values of daily TEI (<500 kcal or >7000 kcal).[19]

2.3 | Tax impact by SSB consumption level

Based on the evidence from Ng et al.,[14] we estimated the weighted average relative purchase change of the combined sets of all higher and all lower purchasers of taxed beverages after the Mexican tax. We obtained an average purchase change of −8.1% and −2.0% in 2014 and −18.2% and 1.3% in 2015 for high consumers and low consumers, respectively. This yielded an average purchase decline of −13.2% for high consumers and −0.4% for low consumers in both years.

2.4 | Model simulations

For our main analyses, we present the change in weight after 1-year SSBs tax implementation, simulating the impact of four potential tax scenarios: 10%, 20%, 30%, and 40%, assuming null caloric compensation from other beverages.

The Dynamics of Childhood Growth and Obesity Model (DCGO) proposed by Hall and colleagues,[20] has been previously validated with experimental weight data.[21,22] This model predicts changes in weight over time *(t)* using a system of two differential equations to predict fat mass ($FM(t)$) and fat free mass ($FFM(t)$). The sum of $FM(t)$ and $FFM(t)$

provides the predicted body weight (*BW(t)*) at time *t*. For the *BW(t)* calculation, we also considered the relation between energy intake rate and energy expenditure, adjusted by a growth term. All these variables are dependent on individual characteristics, such as age, sex, initial body weight, height, and other parameters that account for the complex physiological processes that occur during childhood and adolescence. The DGCO model does not provide confidence intervals (CIs) to the estimated weight change, therefore our CIs only consider the sources of error captured by the survey data. A more detailed description of the DCGO model, sensitivity analyses, data sources for inputs used, and algorithm implementation, are presented in the Supporting Information (Appendix S1).

2.5 | Sensitivity analyses

In the main analysis, we assumed no energy compensation and a range of possible taxation levels from 10% to 40%. In real life, caloric compensation could vary due to intermeal interval and energy density of foods.[23] Therefore, we decided to conduct a sensitivity analysis to estimate the potential impact of different SSBs tax scenarios (from 0% to 100%) in combination with different compensation rates (from 0% to 100%). Although the tax scenarios considered in this article vary between 10% and 40%, for the purpose of the sensitivity analysis we used the whole range from 0% to 100%, similarly, we used caloric compensation rates between 0% and 100%. No evidence exists of caloric compensation when replacing SSBs with water. However, we considered a study by Katan et al., that estimated caloric compensation rates by replacing SSBs with sugar-free beverages, ranging from 13% to 65%.[24] The most plausible scenarios are shown within the red box in Figure 2 (tax from 10% to 40% and caloric compensation from 0% to 70%).

3 | RESULTS

Table 1 shows the proportion of the population in each level of SSBs consumption and the average baseline proportion of TEI from SSB consumption, reported in ENSANUT 2012. Overall, 38.5% were low consumers and high consumers represent 61.5% of the population. On average, 6.9% of the TEI comes from SSB consumption for the whole children and adolescent population. The proportion of energy intake from SSBs for low consumers was 2.2% and goes up to 9.9% for high consumers. This proportion is slightly different between children and adolescents, for each level of consumption, with adolescents having a higher proportion of energy intake from SSBs than young children.

Table 2 presents expected caloric intake reduction after the implementation of a 10% tax. Considering the average tax effect of each level of consumption, TEI was expected to decrease 17.56 kcal/person/day for the whole children and adolescent population. Among low consumers, the reduction could be less than 1 kcal/person/day, while high consumers could reach up to 29.21 kcal/person/day with an SSBs tax of 10%. We observed an average reduction of 11.69 and 24.44 kcal/person/day for children and for adolescents, respectively.

Table 3 presents the 1-year expected reduction in body weight under the four tax scenarios, for children and adolescents, considering their baseline SSBs consumption (low, high). Counterfactual body weight is the 1-year predicted body weight of ENSANUT 2012, using the DCGO model without intervention. We can observe that the gap between low and high consumer's counterfactual body weight is 5.47 kg. Under the current 10% tax scenario, the average body weight reduction is expected to be 0.42 kg; high consumers are expected to lose 0.70 kg, while low consumers body weight reduction is virtually zero. As the tax increases, the expected body weight reductions become larger. At a 40% tax, the average body weight reduction is expected to reach 1.68 kg in the first year. This decrease is larger in high SSBs consumers, whom under the 40% tax are expected to experience a 2.80 kg reduction. Dividing high consumers into children and adolescents, we can observe an average body weight reduction of 0.50 and 0.87 kg, respectively, with a 10% tax. This could go up to 1.99 kg reduction for children and 3.50 kg for adolescents with a 40% tax.

Figure 1 shows predicted change in body weight for children and adolescents one year after the implementation of the SSBs tax. The figure illustrates four different tax scenarios, ranging from 10% to 40%. For children, we projected a 0.26 kg body weight reduction with a 10% tax, which could reach 1.03 kg assuming a 40% tax. For adolescents, the body weight reduction with a 10% tax would be 0.61 kg, increasing to 2.46 kg at 40%.

Figure 2 shows the results of our one-year sensitivity analysis, testing different tax levels in combination with various compensation rates. Overall, we observed that the potential effect of taxation on body weight reduction could range between 0.42 kg with a 10% tax

TABLE 1 Baseline proportion of total energy intake (TEI) from sugar-sweetened beverages in Mexican children from ENSANUT 2012

		Baseline proportion of TEI from SSB consumption (%) (95% CI)		
Type of consumer	**N (%)**	**All**	**6 to 11 years old**	**12 to 18 years old**
All	2374 (100%)	6.9% (6.6%, 7.3%)	5.6% (5.2%, 6.1%)	8.0% (7.5%, 8.6%)
Low	915 (38.5%)	2.2% (2.1%, 2.3%)	2.2% (2.0%, 2.3%)	2.2% (2.0%, 2.4%)
High	1459 (61.5%)	9.9% (9.4%, 10.4%)	8.8% (8.1%, 9.5%)	10.6% (9.9%, 11.2%)

Note: Low SSBs consumption (< median of SSB consumption); High SSBs consumption (≥ median of SSB consumption).
Abbreviation: SSB, sugar-sweetened beverage.

TABLE 2 Estimated caloric intake reductions after the implementation of a 10% SSB tax increase

Type of consumer	Caloric intake reduction with a 10% tax (kcal/person/day) (95% CI) All	6 to 11 years old	12 to 18 years old
All	−17.56 (−18.81, −16.31)	−11.69 (−12.89, −10.48)	−24.44 (−26.60, −22.28)
Low	−0.19 (−0.20, −0.18)	−0.17 (−0.18, −0.16)	−0.22 (−0.24, −0.20)
High	−29.21 (−30.77, −27.64)	−22.62 (−24.21, −21.03)	−34.87 (−37.29, −32.45)

Note: Low SSBs consumption (< median of SSB consumption); High SSBs consumption (≥ median of SSB consumption).
Abbreviation: SSB, sugar-sweetened beverage.

TABLE 3 Expected body weight reduction in children and adolescents 1 year after the implementation of the SSB tax in Mexico

Age group	Type of consumer	Counterfactual body weight†	Reduction in body weight due to the tax (kg) (95% CI) 10%	20%	30%	40%
All	All	46.22 (45.40, 47.04)	−0.42 (−0.45, −0.39)	−0.84 (−0.90, −0.78)	−1.26 (−1.35, −1.17)	−1.68 (−1.81, −1.56)
	Low	42.95 (41.73, 44.17)	0.00 (0.00, 0.00)	−0.01 (−0.01, −0.01)	−0.01 (−0.01, −0.01)	−0.02 (−0.02, −0.02)
	High	48.42 (47.38, 49.46)	−0.70 (−0.73, −0.66)	−1.39 (−1.47, −1.32)	−2.10 (−2.21, −1.98)	−2.80 (−2.96, −2.65)
6 to 11 years old	All	35.71 (35.06, 36.35)	−0.26 (−0.28, −0.23)	−0.51 (−0.57, −0.46)	−0.77 (−0.85, −0.69)	−1.03 (−1.13, −0.92)
	Low	35.20 (34.29, 36.11)	0.00 (0.00, 0.00)	−0.01 (−0.01, −0.01)	−0.01 (−0.01, −0.01)	−0.01 (−0.02, −0.01)
	High	36.18 (35.28, 37.08)	−0.50 (−0.53, −0.46)	−0.99 (−1.06, −0.92)	−1.49 (−1.60, −1.39)	−1.99 (−2.13, −1.85)
12 to 18 years old	All	58.55 (58.10, 58.99)	−0.61 (−0.66, −0.55)	−1.22 (−1.33, −1.11)	−1.84 (−2.00, −1.67)	−2.46 (−2.67, −2.24)
	Low	57.65 (56.94, 58.35)	−0.01 (−0.01, 0.00)	−0.01 (−0.01, −0.01)	−0.02 (−0.02, −0.01)	−0.02 (−0.02, −0.02)
	High	58.93 (58.38, 59.49)	−0.87 (−0.93, 0.81)	−1.74 (−1.86, −1.62)	−2.62 (2.80, 2.44)	−3.50 (−3.75, −3.26)

Note: Low SSBs consumption (< median of SSB consumption); High SSBs consumption (≥ median of SSB consumption).
Abbreviation: SSB, sugar-sweetened beverage.
[a]One-year counterfactual body weight without intervention.

to 4.28 kg with a 100% tax, assuming no caloric compensation. Nonetheless, even with a high caloric compensation (60%), we could still observe average potential body weight reductions that could vary between 0.17 and 1.68 kg with 10% and 100% taxes, respectively. The most plausible scenarios are shown inside the red box.

4 | DISCUSSION

We estimated the potential body weight reduction for children one year after the implementation of the SSBs tax in Mexico. Under the current 10% SSB tax, children and adolescents should have experienced an average reduction in body weight over the first year of 0.26 and 0.61 kg, respectively. For higher SSB consumers, we expect an average body weight reduction of 0.50 kg for children and 0.87 kg for adolescents, which could be 1.99 kg for children and 3.50 kg for adolescents with a 40% tax. These body weight changes, if maintained during childhood and into adulthood could provide important short and long-term benefits, such as improvements in cardiovascular risk factors (lower triglycerides and low-density lipoprotein-cholesterol), and insulin sensitivity.[25-27]

High consumption of SSBs plays an important role in the development of non-communicable diseases (NCDs). Several biological mechanisms link the consumption of SSBs with increased body weight gain and risk of many NCDs. The high sugar content of SSBs and liquid calories do not suppress appetite and energy intake in subsequent meals, as do calories consumed as solid foods. This leads to additional energy intake, which can result in body weight gain.[6,28] This continuous energy imbalance causes a chronic inflammatory state, which generates a sustained release of leukocytes into the adipose tissue, contributing to the development of insulin resistance and NCDs like type 2 diabetes.[29] Furthermore, the presence of obesity can cause

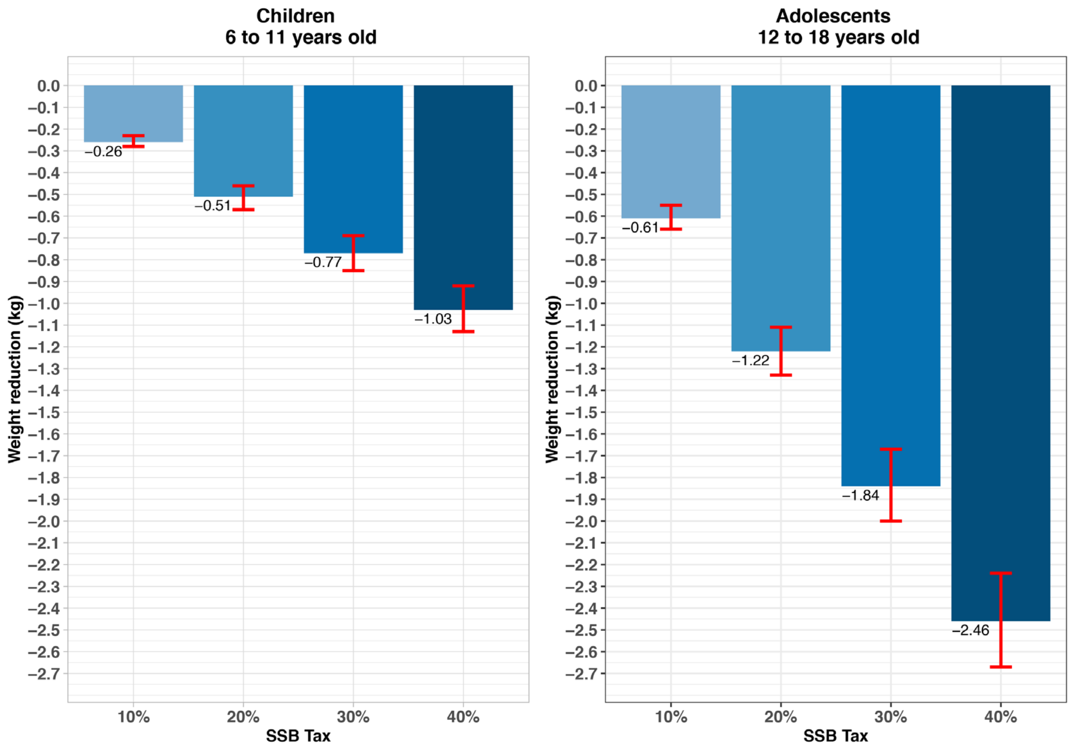
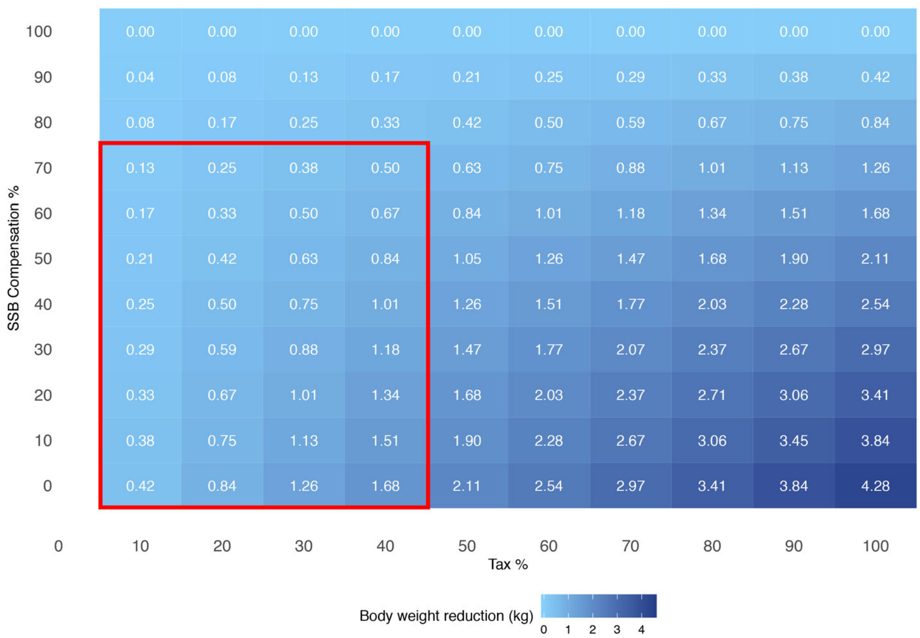


FIGURE 1 Expected body weight reductions 1 year after the implementation of the 10% sugar-sweetened beverages tax in Mexico, and alternative scenarios (20%-40% tax) in children and adolescents. The red error bar represents 95% confidence intervals

FIGURE 2 Sensitivity analysis for estimated body weight (kg) change after one year, based on different sugar reductions and compensation rates. The red box contains the most plausible scenarios (tax from 10% to 40% and caloric compensation from 0% to 70%)



resistance to leptin, a hormone which intervenes in different physiological processes such as: regulation of appetite and energy balance and fat metabolism.[30] All of the above generate a chronic cycle of high-energy consumption with low expenditure, aggravating body weight gain, and increasing the risk of obesity.

Overweight and obesity during childhood are strong predictors for obesity later in life.[31] Nearly 50% of children with high BMI will become adults with obesity.[31] Moreover, recent evidence shows that childhood obesity increases the risk of NCDs at younger ages.[32] For example, in the United States, nearly 70% of children with obesity have at least one cardiovascular risk factor and 40% at least two risk factors, compared with normal body weight children.[33] In addition, high BMI in childhood or adolescence has been associated with higher blood pressure and cholesterol levels at younger ages and with higher cardiovascular disease (CVD) risk later in adulthood.[34,35] Given the above, it is very important to prevent body weight gain at an early age. Our results suggest that taxing SSBs could provide a new tool for the prevention of body weight gain at early ages, although many other additional population and individual strategies will be required to reduce the current burden of obesity in children in Mexico.[17] Regulatory efforts, such as the restriction of junk food sales in schools,[36] shifting the current front of pack food labels used in Mexico,[37] which are not effective, to warning labels such as the ones used in Chile,[38] banning SSB´s advertisement to children or reformulating SSBs[39] are all promissory avenues for obesity prevention in children, which should be consider all in tandem as part of a global strategy.

To the best of our knowledge, this is the first study to individually estimate the expected impact of a nutritional-based intervention on body weight, that takes into account a growth factor among children and adolescents. A recent study in Mexican children by Basto-Abreu et al., estimated the future impact of SSB tax among children and adolescents. Assuming the average annual decrease of SSB (7.6%), they estimated an approximate caloric intake reduction of −7.3 kcal/person/day that yields a reduction of 94 000 cases of obesity for 10 years; no comparable body weight change was available.[40] In contrast, our results showed an overall caloric reduction of −17.56 kcal/person/day. However, these estimates are not directly comparable; Basto-Abreu et al., modeled the overall tax impact in consumption, while we used the more recent estimates that take into consideration the differential impact of the tax by levels of consumption.

Smith et al., simulated a 20% tax for 1 year in U.S. children and adolescents, and estimated a reduction of 2.00 kg.[41] Assuming a 20% SSBs tax, we estimated that children and adolescents could reduce their body weight by 0.84 kg. Children and adolescent growth is a complex process; it involves different age dependent energy needs that, if modified by internal and/or external factors, could encourage excess body weight gain. The existing simulation literature for these age groups, fails to consider the physiological effect of natural growth and its impact on energy requirements.[20] The use of a dynamic model that explicitly considers a growth factor and individual changes, could explain the differences in our estimates with those previously reported.

Our analysis adds to the emerging evidence about the potential health benefits of SSBs taxes.[13,40] This study complements earlier studies in adults and jointly considers dietary data, fat mass, and fat free mass estimates from Mexican children using a validated model for children body weight change calibrated to the Mexican population. However, our study has several limitations. Dietary intake data from the seven-day FFQ may underestimate TEI; ENSANUT's FFQ was answered by the primary caregiver in children 11 years old and younger. The caregiver could not have been fully aware of the food consumed at school,[42] which could lead to the underestimation of energy intake. Reporting error of dietary intake is also influenced by body weight status, particularly in adolescents with obesity.[43] Despite this limitation, the FFQ is a valid tool to estimate ranges of energy intake and energy from food groups, and, given that it tends to underestimate consumption, it can be interpreted as being conservative.[44]

There is uncertainty as to how much of the energy from SSBs reduction will be translated into an overall caloric reduction, considering that some of the calories reduced through the tax could be substituted by other foods or beverages. Our analysis assumes that the reduction in SSB consumption will be substituted by water; however, there is always the possibility of children substituting SSBs by nonnutritive sweeteners. It is unclear if nonnutritive sweeteners increase body weight in children.[45] If that were the case, our estimates would overestimate the impact of the tax, even in the absence of caloric substitution. Potential substitution estimates go from no substitution (assuming SSBs do not affect satiety, being less likely to be substituted by food) to a 43% substitution that has been observed in adults.[46] Considering this large range of potential values, we conducted a sensitivity analysis for the effects of various tax levels and substitution scenarios; under 0% substitution and the current 10% tax, the average body weight reduction amounts to 0.42 kg, which could be reduced to 0.21 kg if substitution were to be 50%. Further studies are needed to better inform substitution in children under this type of intervention. Furthermore, the DCGO model is designed to predict children's body weight from 5 to 18 years of age. For our analysis, we used data simulating a closed cohort. For this reason, we estimated a one-year impact, because increasing the period would reduce our analytic sample, as adolescents reach adulthood. As a sensitivity analysis, we estimated the body weight impact over 3 years, using the 5 to 15 year old's subsample; we could expect an average body weight reduction 0.48 kg over the 3 years following the implementation of the tax (Figure S4 in Appendix), with 87.4% of the total reduction occurring in the first year.

Our study suggests that the current SSBs tax could represent an effective national policy to reduce body weight in children and adolescents. For high SSBs consumers, which represent 61.5% of the total population, the current 10% tax would produce sizable body weight reductions. Following the WHO recommendation of a 20% tax,[11] our results showed an average body weight reduction of 1.39 kg in high consumers; this could go up to 2.80 kg with a hypothetical 40% tax in high SSBs consumers. These findings suggest that increasing the tax is a key step to further reduce body weight and prevent children and adolescent obesity.

SSBs taxes need to be consistently included as part of the public health strategies to reduce obesity globally. Currently, 19 countries including Mexico have implemented SSBs taxes as part of an integral strategy to reduce obesity, largely focusing in the health benefits for adults.[47] Our results suggest that SSBs taxes could also be beneficial for children and adolescents, helping to reduce the future burden of chronic diseases. Other efforts, such as food labeling or sugar reformulation, will be needed to change the childhood obesity landscape.

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CONFLICT OF INTEREST

No conflict of interest was declared.

AUTHOR CONTRIBUTIONS

Rossana Torres-Álvarez and Rodrigo Barrán-Zubaran conceptualized and performed data curation, formal analysis, investigation, methodology, software, supervision, validation, visualization, and drafted the original manuscript. Dr Luz María Sánchez-Romero and M. S. Francisco Canto-Osorio helped with conceptualization, data curation, formal analysis, investigation, methodology, supervision, interpretation, and reviewed and edited the original draft. Dalia Camacho-García-Formentí and Dr. Rafael Meza assisted with formal analysis, methodology, software, supervision, validation, and critically revised the manuscript for important intellectual content. Drs Juan A. Rivera and Barry M. Popkin obtained the funding acquisition and resources, supervised, and critically revised the manuscript for important intellectual content. Dr Tonatiuh Barrientos-Gutiérrez conceptualized and performed data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, wrote, reviewed, and edited the original draft. All authors were involved in writing the article and had final approval of the submitted and published versions

ORCID

Tonatiuh Barrientos-Gutiérrez https://orcid.org/0000-0002-0826-9106

REFERENCES

1. World Health Organization. *Guideline: Sugars Intake for Adults and Children*. Geneva: World Health Organization; 2015.
2. Rosinger A, Herrick K, Gahche J, Park S. *Sugar-Sweetened Beverage Consumption Among U.S. Youth, 2011–2014. NCHS Data Brief, 271*. Hyattsvile, MD: National Center for Health Statistics; 2017.
3. Stern D, Piernas C, Barquera S, Rivera JA, Popkin BM. Caloric beverages were major sources of energy among children and adults in Mexico, 1999-2012. *J Nutr*. 2014;144(6):949-956. https://doi.org/10.3945/jn.114.190652.
4. Sánchez-Pimienta TG, Batis C, Lutter CK, Rivera JA. Sugar-sweetened beverages are the main sources of added sugar intake in the Mexican population. *J Nutr*. 2016;146(9):1888S-1896S. https://doi.org/10.3945/jn.115.220301.
5. Mourao DM, Bressan J, Campbell WW, Mattes RD. Effects of food form on appetite and energy intake in lean and obese young adults. *Int J Obes*. 2007;31:1688. https://doi.org/10.1038/sj.ijo.0803667.
6. Te Morenga L, Mallard S, Mann J. Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ Br Med J*. 2013;346:e7492.
7. Chi DL, Scott JM. Added sugar and dental caries in children: a scientific update and future steps. *Dent Clin N Am*. 2019;63(1):17-33. https://doi.org/10.1016/j.cden.2018.08.003.
8. Carwile JL, CWillett W, Spiegelman D, et al. Sugar-sweetened beverage consumption and age at menarche in a prospective study of US girls. *Hum Reprod*. 2015;30(3):675-683. https://doi.org/10.1093/humrep/deu349.
9. Malik VS, Pan A, Willett WC, Hu FB. Sugar-sweetened beverages and weight gain in children and adults: a systematic review and meta-analysis. *Am J Clin Nutr*. 2013;98(4):1084-1102. https://doi.org/10.3945/ajcn.113.058362.1.
10. Juonala M, Magnussen CG, Berenson GS, et al. Childhood adiposity, adult adiposity, and cardiovascular risk factors. *N Engl J Med*. 2011;365(20):1876-1885. https://doi.org/10.1056/NEJMoa1010112.
11. World Health Organization. Taxes on sugary drinks: Why do it ? 2017. http://www.who.int/iris/handle/10665/260253
12. Colchero MA, Rivera-Dommarco J, Popkin BM, Ng SW. In Mexico, evidence of sustained consumer response two years after implementing a sugar-sweetened beverage tax. *Health Aff*. 2017;36(3):564-571. https://doi.org/10.1377/hlthaff.2016.1231.
13. Sánchez-Romero LM, Penko J, Coxson PG, et al. Projected impact of Mexico's sugar-sweetened beverage tax policy on diabetes and cardiovascular disease: a modeling study. *PLoS Med*. 2016;13(11):e1002158-e1002158. https://doi.org/10.1371/journal.pmed.1002158.
14. Ng SW, Rivera JA, Popkin BM, Colchero MA. Did high sugar-sweetened beverage purchasers respond differently to the excise tax on sugar-sweetened beverages in Mexico? *Public Health Nutr*. 2019;22(4):750-756. https://doi.org/10.1017/S136898001800321X.
15. Gutiérrez JP, Rivera-Dommarco J, Shamah-Levy T, Villalpando-Hernández S, Franco AC-NL, Romero-Martínez MH-ÁM. *Encuesta Nacional de Salud y Nutrición 2012*. Cuernavaca, México: Resultados Nacionales; 2012.
16. Lohman TG, Roche AF, Martorell R. Anthropometric Standarization Reference Manual. *Hum Kinects Publication*. 1988.
17. Hernández-Cordero S, Cuevas-Nasu L, Morán-Ruán MC, Méndez-Gómez Humarán I, Ávila-Arcos MA, Rivera-Dommarco JA. Overweight and obesity in Mexican children and adolescents during the last 25 years. *Nutr Diabetes*. 2017;7(3):e247-e247. https://doi.org/10.1038/nutd.2016.52.
18. Ramírez-Silva I, Jiménez-Aguilar A, Valenzuela-Bravo D, et al. Methodology for estimating dietary data from the semi-quantitative food frequency questionnaire of the Mexican National Health and Nutrition Survey 2012. *Salud Pública México*. 2016;58(6):629-638. https://doi.org/10.21149/spm.v58i6.7974.
19. White AH, James SA, Paulson SW, Beebe LA. Sugar sweetened beverage consumption among adults with children in the home. *Front Nutr*. 2018;5:34.
20. Hall KD, Butte NF, Swinburn BA, Chow CC. Dynamics of childhood growth and obesity: development and validation of a quantitative mathematical model. *Lancet Diabetes Endocrinol*. 2013;1(2):97-105. https://doi.org/10.1016/S2213-8587(13)70051-2.
21. Fomon SJ, Haschke F, Ziegler EE, Nelson SE. Body composition of reference children from birth to age 10 years. *Am J Clin Nutr*. 1982;35(5):1169-1175. https://doi.org/10.1093/ajcn/35.5.1169.
22. Ellis KJ, Shypailo RJ, Abramas SA, Wong WW. The reference child and adolescent models of body composition: a contemporary comparison. *Ann N Y Acad Sci*. 2000;904(1):374-382. https://doi.org/10.1111/j.1749-6632.2000.tb06486.x.
23. Almiron-Roig E, Palla L, Guest K, et al. Factors that determine energy compensation: a systematic review of preload studies. *Nutr Rev*. 2013;71(7):458-473. https://doi.org/10.1111/nure.12048.
24. Katan MB, de Ruyter JC, Kuijper LDJ, Chow CC, Hall KD, Olthof MR. Impact of masked replacement of sugar-sweetened with sugar-free beverages on body weight increases with initial BMI: secondary analysis of data from an 18 month double-blind trial in children. *PLoS One*. 2016;11(7):e0159771. https://doi.org/10.1371/journal.pone.0159771.
25. Ford AL, Hunt LP, Cooper A, Shield JPH. What reduction in BMI SDS is required in obese adolescents to improve body composition and cardiometabolic health? *Arch Dis Child*. 2010;95(4):256-261. https://doi.org/10.1136/adc.2009.165340.

26. Reinehr T, Andler W. Changes in the atherogenic risk factor profile according to degree of weight loss. *Arch Dis Child*. 2004;89(5):419-422. https://doi.org/10.1136/adc.2003.028803.
27. Abrams P, Levitt Katz LE, Moore RH, et al. Threshold for improvement in insulin sensitivity with adolescent weight loss. *J Pediatr*. 2013;163(3):785-790. https://doi.org/10.1016/j.jpeds.2013.04.003.
28. Malik VS, Schulze MB, Hu FB. Intake of sugar-sweetened beverages and weight gain: a systematic review. *Am J Clin Nutr*. 2006;84(2):274-288. https://doi.org/10.1093/ajcn/84.1.274.
29. Singer K, Lumeng CN. The initiation of metabolic inflammation in childhood obesity. *J Clin Invest*. 2017;127(1):65-73. https://doi.org/10.1172/JCI88882.
30. Johnson RJ, Sánchez-Lozada LG, Andrews P, Lanaspa MA. Perspective: a historical and scientific perspective of sugar and its relation with obesity and diabetes. *Adv Nutr*. 2017;8(3):412-422. https://doi.org/10.3945/an.116.014654.
31. Whitaker RC, Wright JA, Pepe MS, Seidel KD, Dietz WH. Predicting obesity in young adulthood from childhood and parental obesity. *N Engl J Med*. 1997;337(13):869-873. https://doi.org/10.1056/NEJM199709253371301.
32. Cantoral A, Téllez-Rojo MM, Ettinger AS, Hu H, Hernández-Ávila M, Peterson K. Early introduction and cumulative consumption of sugar-sweetened beverages during the pre-school period and risk of obesity at 8-14 years of age. *Pediatr Obes*. 2016;11(1):68-74. https://doi.org/10.1111/ijpo.12023.
33. Friedemann C, Heneghan C, Mahtani K, Thompson M, Perera R, Ward AM. Cardiovascular disease risk in healthy children and its association with body mass index: systematic review and meta-analysis. *BMJ*. 2012;345:e4759. https://doi.org/10.1136/bmj.e4759.
34. Umer A, Kelley GA, Cottrell LE, Giacobbi P Jr, Innes KE, Lilly CL. Childhood obesity and adult cardiovascular disease risk factors: a systematic review with meta-analysis. *BMC Public Health*. 2017;17(1):683. https://doi.org/10.1186/s12889-017-4691-z.
35. Bekkers MBM, Brunekreef B, Koppelman GH, et al. BMI and waist circumference; cross-sectional and prospective associations with blood pressure and cholesterol in 12-year-olds. *PLoS One*. 2012;7(12):e51801. https://doi.org/10.1371/journal.pone.0051801.
36. Pérez-Ferrer C, Barrientos-Gutierrez T, Rivera-Dommarco JA, et al. Compliance with nutrition standards in Mexican schools and their effectiveness: a repeated cross-sectional study. *BMC Public Health*. 2018;18(1):1411. https://doi.org/10.1186/s12889-018-6330-8.
37. Kaufer-Horwitz M, Tolentino L, Jáuregui A, et al. Sistema de Etiquetado Frontal de Alimentos y Bebidas Para México: Una Estrategia Para La Toma de Decisiones Saludables. 2018; 60. doi: https://doi.org/10.21149/9615
38. Corvalán C, Reyes M, Garmendia ML, Uauy R. Structural responses to the obesity and non-communicable diseases epidemic: update on the Chilean law of food labelling and advertising. *Obes Rev*. 2019;20(3):367-374. https://doi.org/10.1111/obr.12802.
39. Basto-Abreu A, Braverman-Bronstein A, Camacho-García-Formentí D, et al. Expected changes in obesity after reformulation to reduce added sugars in beverages: a modeling study. *PLoS Med*. 2018;15(10):e1002664. https://doi.org/10.1371/journal.pmed.1002664.
40. Basto-Abreu A, Barrientos-Gutiérrez T, Vidaña-Pérez D, et al. Cost-effectiveness of the sugar-sweetened beverage excise tax in Mexico. *Health Aff*. 2019;38(11):1824-1831. https://doi.org/10.1377/hlthaff.2018.05469.
41. Smith T, Lin B-H, Lee J-Y. Taxing caloric sweetened beverages: Potential effects on beverage consumption, calorie intake, and obesity. *USDA-ERS Econ Res Rep No100*. 2010.
42. García-Chávez CG, Rodríguez-Ramírez S, Rivera JA, Monterrubio-Flores E, Tucker KL. Sociodemographic factors are associated with dietary patterns in Mexican schoolchildren. *Public Health Nutr*. 2018;21(4):702-710. https://doi.org/10.1017/S1368980017003299.
43. Livingstone MBE, Robson PJ, Wallace JMW. Issues in dietary intake assessment of children and adolescents. *Br J Nutr*. 2004;92(S2):S213-S222. https://doi.org/10.1079/BJN20041169.
44. Denova-Gutiérrez E, Ramírez-Silva I, Rodríguez-Ramírez S, Jiménez-Aguilar A, Shamah-Levy T, Rivera-Dommarco J. Relative validity of a semi-quantitative food frequency questionnaire for Mexican adolescent and adult population. 2016;58(6):617-628. https://doi.org/10.21149/spm.v58i6.7862.
45. Baker-Smith CM, de Ferranti SD, Cochran WJ. The use of non-nutritive sweeteners in children. *Pediatrics*. 2019;144(5):e20192765. https://doi.org/10.1542/peds.2019-2765.
46. Rogers PJ, Hogenkamp PS, de Graaf C, et al. Does low-energy sweetener consumption affect energy intake and body weight? A systematic review, including meta-analyses, of the evidence from human and animal studies. *Int J Obes*. 2016;40(3):381-394. https://doi.org/10.1038/ijo.2015.177.
47. Du M, Tugendhaft A, Erzse A, Hofman KJ. Sugar-sweetened beverage taxes: industry response and tactics. *Yale J Biol Med*. 2018;91(2):185-190.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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