Review Article

The impact of a tax on sugar-sweetened beverages according to socio-economic position: a systematic review of the evidence

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Abstract

Objective: A tax on sugar-sweetened beverages (SSB) has been proposed to address population weight gain but the effect across socio-economic position (SEP) is unclear. The current study aimed to clarify the differential impact(s) of SSB taxes on beverage purchases and consumption, weight outcomes and the amount paid in SSB taxes according to SEP.

Design: Databases (OVID and EMBASE) and grey literature were systematically searched in June 2015 to identify studies that examined effects of an SSB price increase on beverage purchases or consumption, weight outcomes or the amount paid in tax across SEP, within high-income countries.

Results: Of the eleven included articles, three study types were identified: (i) those that examined the association between variation in SSB taxes and SSB consumption and/or body weight (*n* 3); (ii) price elasticity estimation of SSB demand (*n* 1); and (iii) modelling of hypothetical SSB taxes by combining price elasticity estimates with population SEP-specific beverage consumption, energy intake or body weight (*n* 7). Few studies statistically tested differences in outcomes between SEP groups. Nevertheless, of the seven studies that reported on changes in weight outcomes for the total population following an increase in SSB price, all reported either similar reductions in weight across SEP groups or greater reductions for lower compared with higher SEP groups. All studies that examined the average household amount paid in tax (*n* 5) reported that an SSB tax would be regressive, but with small differences between higher- and lower-income households (0·10–1·0 % and 0·03 %–0·60 % of annual household income paid in SSB tax for low- and high-income households, respectively).

Conclusions: Based on the available evidence, a tax on SSB will deliver similar population weight benefits across socio-economic strata or greater benefits for lower SEP groups. An SSB tax is shown to be consistently financially regressive, but to a small degree.

The prevalence of obesity follows a socio-economic pattern. In high-income countries, individuals with a lower income, a lower education or who live in more disadvantaged areas are at a higher risk for excess weight gain and obesity[1,2]. Accordingly, it was recommended in the 2010 UK *Fair Societies, Healthy Lives* report that evidence-based, universal interventions that address the causes of obesity across the socio-economic gradient be implemented[3]. However, very few obesity prevention interventions are evaluated according to their impact across socio-economic strata[4–7].

A tax on sugar-sweetened beverages (SSB) features prominently in the suite of recommended regulatory approaches to address population weight gain[8–11]. Evidence demonstrates that regular consumption of SSB is associated with excess weight gain and a number of

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co-morbid conditions[12], including diabetes, CVD and dental caries[13]. Moreover, SSB lack nutritional value and, in the absence of satiety signals, commonly represent excess energy in the daily diet[14,15]. Individuals from lower socio-economic groups commonly consume more SSB than their higher socio-economic counterparts[16,17], potentially contributing to the observed inequalities in excess weight and associated disease. Finally, SSB are consumed in relatively high quantities (in 2012, 26·3 % of US adults consumed SSB one or more times daily[18]) leading to greater price sensitivity compared with products consumed at low frequencies and volumes[19].

Although several high-income countries around the world already have a tax on SSB, these are often small in magnitude (e.g. across all US states, SSB taxes average approximately 4 %[11]) and are implemented for revenue-, rather than health-related reasons. The latter is important as a tax implemented for health-related reasons is likely to additionally act as a health communication campaign. In 2014, Mexico became the first country to impose a national health-related excise tax on beverages with added sugar of 1 peso per litre (approximately a 10 % price increase). Recent evaluation of the tax revealed a reduction in the purchase of sugary drinks of 12 %, 12 months post policy implementation, compared with the counterfactual scenario based on pre-tax trends[20]. In that study, the greatest declines were observed among households of a lower socio-economic position (SEP), with a 12-month decline in sugary drinks of 17 % compared with pre-tax trends[20].

Price elasticity estimates of SSB demand suggest that a 10 % tax on SSB could lead to an 8–10 % reduction in the purchase of these beverages[21]. Modelling studies further predict that a 20 % tax on SSB in the USA could reduce the prevalence of obesity by 3·5 percentage points[22]. However, one of the major concerns about a tax on SSB is that it will be financially regressive, whereby those with a lower income would pay a greater proportion of their income in tax compared with higher income earners[23]. Proponents, on the other hand, argue that this financial regressivity would be justified by the progressive health benefits (greater for those with a lower SEP) given the higher obesity prevalence and greater consumption of SSB among lower socio-economic groups[23].

Although several studies have synthesised the impacts of an SSB tax according to SEP, these studies are usually limited to include specific study designs, single outcomes and do not consider the differential amounts paid in SSB tax as a proportion of income. Understanding the health equity impact of an SSB tax is essential if we wish to prioritise obesity prevention interventions that are most likely to be effective across all socio-economic strata. The aim of the present work was to systematically review the literature for studies (of any study design) conducted in high-income countries that examined the effect of an SSB price increase on beverage purchase or consumption and/or weight outcomes according to an indicator of SEP.

Where possible, we additionally aimed to examine the average amount paid in SSB tax across socio-economic strata (as a percentage of income).

Methods

We conducted a systematic review of the literature to identify studies from high-income countries that reported on one or more of the following outcomes: beverage purchases, beverage consumption (and/or total energy intake) and/or weight outcomes following a change in SSB price according to a marker of SEP. Low- and middle-income countries were excluded due to the relationship between SEP and SSB intake and/or obesity being the reverse (or a varying relationship as a result of undergoing nutritional transition) of that which is consistently observed in high-income countries. From these studies, we were additionally interested in the data pertaining to the amount paid in tax for each SEP group. Because a regressive tax is one where the poor pay a higher percentage of their income in tax compared with the rich, we intended only to include studies where the proportion of income paid in SSB tax across SEP was reported. However, we were also able to include studies that reported only on the absolute amount paid in SSB tax across income groups as these studies reported a greater absolute amount paid in tax among lower-income households, which necessarily equates to a greater proportion of household income.

A protocol was developed for the selection, analysis and reporting of articles in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Equity (PRISMA-Equity) guidelines[24]. Relevant information was extracted from all included studies, including the impact of an SSB price change on beverage purchase and consumption and weight outcomes, as well as the amount paid in tax for all socio-economic groups. Finally, the overall quality of the study was assessed (see below) and the robustness of conclusions evaluated. Due to the heterogeneity in the outcome reported across studies, and therefore a small number of studies for each outcome, we did not examine risk of publication bias.

Search strategy

Electronic databases (Medline via OVID and EMBASE) and grey literature (System for Information on Grey Literature in Europe, the Virtual Library for Public Health, Google Scholar, plus websites and reports from relevant organizations, including those with a health equity focus) were systematically searched from database inception to June 2015 to identify studies (any study design) that included terms for SSB, taxation and SEP. Each hedge (SSB, taxation and SEP) was combined with the operator 'AND' and within each hedge, search terms were combined using the operator 'OR'. Specific search terms were as follows (used as

keywords unless otherwise stated): SSB (soda, soft drink, carbonated beverage*, sugar-sweetened*, beverage*, beverages/economics (Medical Subject Heading (MeSH)); taxation (price*, subsid*, cost*, tax*, demand elast*, taxes/economics (MeSH)); SEP (income, education*, disadvantage, disparit*, equit*, inequal*, inequit*, occupation, socio*, socioeconomic factors (MeSH), social class (MeSH)). Use of an asterisk denotes an open-ended search term. No limits were placed on the basis of language, country or publication date. The reference lists of all relevant original research and review articles were scanned to capture citations missed by electronic searches. Authors were contacted for missing information.

All retrieved articles were independently scanned in three stages by two reviewers (K.B. and V.L.). First, studies were assessed for relevance of title. If the title appeared relevant, or if authors were unsure, the abstract was next assessed to determine if the study satisfied the inclusion criteria. Included or unclear articles then proceeded to the full manuscript stage to be formally assessed against the inclusion criteria.

Inclusion criteria and data extraction

Studies were included if they reported on the impact of a change in SSB price on beverage purchase or consumption, energy intake and/or body weight outcomes (or another marker of adiposity) according to any marker of SEP (individual- or area-based) within a high-income country.

A matrix table of study characteristics was compiled and the relevant information was extracted from the included articles by two independent authors with disagreements resolved by consensus with other authors. In the few instances where relative consumption or weight outcomes (percentage reduction) were reported we also calculated absolute effects (percentage-point reduction) and present both. Where possible we also converted units of results to the most commonly reported unit for consistency across studies. Study authors were contacted where relevant information was missing.

Quality of studies

We assessed the quality of all studies using a checklist derived from two recent reviews of food and beverage pricing studies[25,26]. The quality criteria assessed were: (i) prospective study of observed behaviour; (ii) evaluation of an actual tax (rather than a hypothetical tax); (iii) price linked directly to purchase within the same population; (iv) consideration of product compensation (cross-price elasticity; CPE); (v) long-run input data across time with sufficient variation in prices used to estimate price elasticities (for experimental studies this included data collected over a period of at least one month, for studies using existing data sets on SSB price this included data collected at intervals no less than two months apart for at least 12 months); (vi) valid and appropriate country-specific data; and (vii) reporting of uncertainty around price elasticity estimates. We report on all quality criteria for all studies and rate each study out of 7, reflecting 1 point for each quality measure. A sensitivity analysis was performed on studies that scored ≥4 points.

Results

Study characteristics

The literature search identified 270 articles in total. After screening for inclusion criteria, eleven articles were selected to be included in the synthesis of evidence (see Fig. 1 for a flowchart of the search strategy). A summary of the study characteristics and the likely effect of an SSB price change on differences by SEP in SSB purchase, consumption or weight outcomes and the tax burden as a result of an SSB tax are presented in Table 1. Briefly, seven studies used data from the USA, with one study from each of the UK, Ireland, Australia and New Zealand. Ten studies used income as an indicator of SEP (nine of these used household income and one used individual income) and one study in adolescents used parental education. Three principal study types were identified: (i) those that examined the association between variation in SSB taxes across US states and individual SSB consumption and/or BMI (n 3[27–29]); (ii) price elasticity estimation of SSB demand from household food and beverage price and expenditure data (n 1[30]); and (iii) modelling to simulate the impact of a hypothetical SSB tax by combining price elasticity estimates with population data on the SEP-specific patterning of beverage consumption, net energy intake or body weight outcomes (n 7[22,31–36]). Four of the seven modelling studies used similar data from the USA (with some overlap of sampling period)[22,31,32,36]; however, model specifications and input parameters differed markedly between studies. Six of the eleven included studies received a score of ≥4 points (out of 7) for quality
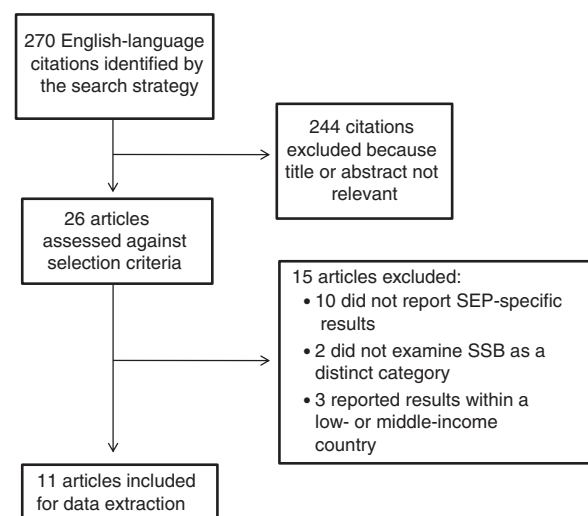

Fig. 1 Flowchart of the search strategy (SEP, socio-economic position; SSB, sugar-sweetened beverage)

Table 1 Summary of the study characteristics and the likely effect of a sugar-sweetened beverage (SSB) price change on differences by socio-economic position (SEP) in SSB purchase, weight benefits and/or tax burden as a result of an SSB tax

Study	Country	Study type	SEP measure	SSB definition	Size and type of tax	Outcome reported	Own-price elasticity	Modelled effect	Tax burden
Studies evaluating existing SSB taxes									
Powell et al.[27]	USA	Association between existing state-level SSB taxes (over 10 years) & adolescent cross-sectional BMI	Parents' education	Soft drinks	State-level sales taxes in grocery stores (mean 4·25 %) and vending machines (mean 4·51 %) between 1997 and 2006	BMI	Similar†	n/a	n/a
Sturm et al.[28]	USA	Association between existing state-level SSB taxes & children's cross-sectional SSB consumption and 1-year weight change	Family income	Carbonated beverages	State-level sales taxes in grocery stores in 2004 (mean 4·2 %)	SSB purchased BMI	Progressive†	n/a	n/a
Fletcher et al.[29]	USA	Association between existing state-level SSB taxes & adult cross-sectional BMI	Individual income Educational attainment	Soft drinks	State-level sales taxes between 1990 and 2006 (range 3–5 %)	BMI	Progressive†	n/a	n/a
Studies where the primary result was estimated price elasticities									
Ni Mhurchu et al.[30]	New Zealand	Price elasticites	Household income	Carbonated soft drinks	n/a	SSB purchase	Progressive	n/a	n/a
Summary of modelling studies									
Finklestein et al.[31]	USA	Price elasticities & modelling of SSB tax	Household income	Regular soda, fruit drinks, sports energy drinks	20 % and 40 % sales tax	Energy intake Body weight	Similar	Similar	n/a
Lin et al.[22]	USA	Price elasticities & modelling of SSB tax	Household income	Regular soft drinks, sports and energy drinks, and fruit drinks	20 % excise tax	Energy intake Body weight	Regressive	Similar	Regressive
Zhen et al.[32]	USA	Price elasticities & modelling of SSB tax	Household income	Carbonated soft drink	0·5 cents per ounce* excise tax	SSB purchased	Regressive	Similar	Regressive
Briggs et al.[33]	UK	Price elasticities & modelling of SSB tax	Household income	Soft drinks with added sugar	20 % sales tax	SSB purchase Energy intake Obesity prevalence	Regressive	Similar	Regressive
Briggs et al.[34]	Ireland	Price elasticities & modelling of SSB tax	Household income	Soft drinks with added sugar	10 % excise tax	Energy intake Obesity prevalence	n/a	Similar	n/a
Sharma et al.[35]	Australia	Price elasticities & modelling of SSB tax	Household income	Regular soft drinks, cordial and fruit drinks	20 cents per litre excise tax 20 % sales tax	Body weight	Progressive	Progressive	Regressive
Zhen[36]	USA	Price elasticities & modelling of SSB tax	Household income	Regular carbonated soft drinks, sports/energy drinks & juice drinks	0·5 cents per ounce* excise tax	SSB purchased Total energy intake Body weight	Similar	Progressive	Regressive

n/a, not applicable.

'Progressive' refers to when the effect sizes are greater for lower socio-economic groups compared with higher socio-economic groups. 'Regressive' refers to when the effect sizes are greater for higher socio-economic groups compared with lower socio-economic groups.

*1 fl. oz (US) = 29·574 ml.

†These studies did not estimate own-price elasticities: Powell et al. reported no association between state-level SSB taxes and adolescent BMI across income categories; Sturm et al. reported that lower existing SSB tax rates were associated with less SSB consumption for children from low-income households, which was not observed for children overall; Fletcher et al. reported that increases in state-level SSB tax rates were associated with decreases in state-level BMI over time.

appraisal[22,31–33,35,36] (Table 2). Few studies statistically tested differences in outcomes between SEP groups.

Results (point estimates, variance and when tested, significance) are outlined below and in Table 3 for all eleven of the included studies (analysis of only those studies scoring ≥4 points in quality appraisal revealed similar conclusions). Details of the data sets used and the general methods employed for each study can be found in the online supplementary material.

Beverage purchase, consumption and weight impacts of a sugar-sweetened beverage tax according to socio-economic position

Studies evaluating existing sugar-sweetened beverage taxes
Three studies examined the association between variations in state-level SSB taxes (average of 4 %) across the USA and individual-level SSB consumption and/or BMI according to a marker of SEP.

Powell et al.[27] reported no relationship between variation in SSB taxes and adolescents' BMI for any parental education group. In the study by Sturm et al.[28] associations between variations in existing SSB tax rates and SSB consumption and BMI were examined for the entire population and for children from low-income households. For the whole population, no association was observed between SSB taxes and overall SSB consumption or mean BMI change. However, among children from low-income families, a 1 percentage point increase in the SSB tax rate (in excess of other food items) resulted in a significant reduction in the total number of SSB consumed of 0·142 SSB/week. A 1 percentage point higher differential SSB tax rate was also associated with a significant reduction in BMI of 0·013 kg/m² between the third and fifth grades for the total population, but this did not hold up under all statistical analyses. For low-income populations higher tax rates were not associated with a significant reduction in BMI; however, the authors noted that reduced statistical power limited the results from subgroup analyses. Fletcher et al.[29] reported a stronger relationship between variation in SSB taxes and weight outcomes for adults with lower (compared with higher) income and for those with a higher (compared with a lower) education level. Between 1990 and 2006, a 1 percentage point increase in existing SSB tax rates was associated with a significant 0·015 kg/m² reduction in BMI for low-income adults and a 0·008 kg/m² decrease in BMI for high-income adults. When using education as the SEP indictor, a 1 percentage point increase in the SSB tax rate was associated with a significant 0·0031 kg/m² and 0·0076 kg/m² reduction in BMI for high-school graduates and college graduates, respectively.

Studies where the primary result was estimated price elasticities
One study estimated the income-specific change in SSB demand following a change in SSB price (own-price elasticity; OPE) in New Zealand[30]. In that study, lower-income

Table 2 Quality checklist for included studies

Study	Prospective study of observed behaviour	Evaluation of actual tax (rather than hypothetical)	Price linked directly to purchase in same population	All studies Consideration of product compensation	Long-run input data	Valid and appropriate country specific data	Reporting of uncertainty around outcome estimates	Quality score (out of 7)
Powell et al.[27]	✗	✓	✗	✓*	✗	✓	✗	3
Finklestein et al.[31]	✗	✗	✓	✓	✗	✓	✓	4
Sturm et al.[28]	✗	✓	✗	✓*	✗	✓	✗	3
Fletcher et al.[29]	✗	✓	✗	✓*	✗	✓	✓	3
Lin et al.[22]	✗	✗	✓	✓	✓	✓	✗	5
Zhen et al.[32]	✗	✗	✓	✓	✗	✓	✓	5
Briggs et al.[33]	✗	✗	✓	✓	✓	✓	✓	4
Briggs et al.[34]	✗	✗	✓	✗	✗	✗	✓	2
Ni Mhurchu et al.[30]	✗	✗	✓	✗	✗	✓	✓	3
Sharma et al.[35]	✗	✗	✓	✓	✗	✓	✓	4
Zhen et al.[36]	✗	✗	✓	✓	✓	✓	✓	5

*These studies examined the association between variations in state-level sugar-sweetened beverage taxes and cross-sectional BMI, which therefore implicitly took into account product substitution.

Table 3 Price elasticity estimates and likely impact of a sugar-sweetened beverage (SSB) tax on socio-economic inequalities in SSB consumption, energy intake, population levels of mean BMI and/or obesity prevalence, and the associated tax burden

Study	Price elasticities	Size and type of tax	Modelled effects of hypothetical SSB tax or relationship with existing state-level SSB taxes				
			Consumption	Energy intake	Weight or BMI	Obesity prevalence	Tax burden
Studies evaluating existing SSB taxes							
Powell et al.[27]	n/a	State-level SSB sales taxes in grocery stores (mean 4·25 %) and vending machines (mean 4·51 %)	n/a	n/a	No significant association between variation in state-level SSB taxes and adolescent BMI across any parental education categories	n/a	n/a
Sturm et al.[28]	n/a	State-level SSB sales taxes in grocery stores (mean 4·2 %)	No significant association between existing state-level SSB taxes and children's SSB consumption for the total population. For children from low-income families, for every 1 % higher tax rate across states (over and above the tax on other foods within the state) there was a 0·142* and 0·039* reduction in the total drinks/week consumed and drinks/week consumed at school, respectively	n/a	No significant association between variation in state-level SSB taxes and children's BMI for any income groups	n/a	n/a
Fletcher et al.[29]	n/a	State-level SSB sales taxes (range 3–5 %)	n/a	n/a	A 1 %-point increase in existing SSB tax rates was associated with a 0·015 kg/m^2* reduction in BMI for low-income adults and a 0·008 kg/m^2* decrease in BMI for high-income adults. The corresponding reductions were 0·0031 kg/m^2* and 0·0076 kg/m^2* for high-school graduates and college graduates, respectively	A 1 %-point increase in existing SSB tax rates was associated with a 0·08 %-point* reduction in obesity and a 0·1 %-point* reduction in overweight for low-income adults and a 0·05 %-point* and 0·08 %-point* reduction in obesity and overweight, respectively, for high-income adults. The corresponding reductions were 0·02* and 0·02 %-points* for high-school graduates and 0·04* and 0·04 %-points* for college graduates, respectively	n/a
Studies where the primary result was estimated price elasticities							
Ni Mhurchu et al.[30]	OPE for carbonated soft drinks (SE) Q1: −2·20 (1·16) Q2: −3·47 (0·99) Q3: −0·14 (0·43) Q4: −2·95 (0·52) Q5: −1·26 (0·44) No statistically significant difference in OPE between Q1 & Q5	n/a	n/a	n/a	n/a	n/a	n/a

Table 3 *Continued*

			Modelled effects of hypothetical SSB tax or relationship with existing state-level SSB taxes				
Study	Price elasticities	Size and type of tax	Consumption	Energy intake	Weight or BMI	Obesity prevalence	Tax burden
Summary of modelling studies							
Finkelstein et al.[31]	Carbonated SSB Across all households the OPE (SE) was −0·73 (0·09)*, with estimates ranging from −1·02 (0·17)* for households in the 50–75 % income quartile to −0·49 (0·20)* for the 0–25 % income quartile of households All SSB Income-specific OPE not reported CPE Examined but not reported	20 % or 40 % sales tax on carbonated SSB 20 % or 40 % sales tax on all SSB	n/a	20 % tax on carbonated SSB (kcal/d)‡ No statistically significant reduction in beverage calories for households in the lowest- and highest-income quartiles. Across all households beverage purchases reduced by a mean of 4·2*, which was entirely driven by the middle-income households 40 % tax on carbonated SSB (kcal/d)‡ Across all households beverage purchases reduced by a mean of 7·8*, which was entirely driven by middle-income households	BMI change (SE) (kg/m²) 20 % tax on carbonated SSB: Q1, 0·01 (0·20); Q2, −0·37* (0·14); Q3, −0·36* (0·14); Q4, 0·03 (0·13) 40 % tax on carbonated SSB: Q1, −0·004 (0·36); Q2, −0·68* (0·26); Q3, −0·65* (0·25); Q4, 0·04 (0·24) 20 % tax on all SSB: Q1, −0·12 (0·23); Q2, −0·46* (0·17); Q3, −0·68* (0·15); Q4, 0·07 (0·15) 40 % tax on all SSB: Q1, −0·23 (0·43); Q2, −0·83* (0·30); Q3, −1·20* (0·26); Q4, 0·13 (0·28)	n/a	n/a
Lin et al.[22]	OPE (SE) High income: −1·29 (0·096)* Low income: −0·95 (0·082)* CPE High income: significant substitution for skimmed milk, low-fat milk, juice, bottled water and significant complementary reduction in diet drinks Low income: significant substitution for juices and complementary reduction in diet drinks, skimmed milk, low-fat milk and whole milk	20 % excise tax	n/a	Change in energy intake (kcal/d)‡ High income: Adults, −37 from all beverages, −38 from SSB Children, −45 from all beverages, −50 from SSB Low income: Adults, −33 from all beverages, −35 from SSB Children, −33 from all beverages, −36 from SSB	10-year weight change (kg), adults only High income: −1·80 Low income: −1·90	10-year % change in prevalence of obesity (%-points), adults only High income: −10·5 (3·46) Low income: −10·2 (3·58)	Annual tax burden ($US) attributable to SSB tax Low income: 19·97 High income: 18·84 SSB tax as % of all food and beverage spending Low income: 1 % High income: 0·6 %
Zhen et al.[32]	OPE for regular carbonated soft drinks Low-income households: −1·22 (myopic), −1·06 (rational) High-income households: −1·44 (myopic), −1·54 (rational)	0·5 cents per ounce† excise tax	% Long-run household change in monthly demand for regular carbonated soft drinks (reduction in ounces) Low income: −27·4, −33·9 (−82·81, −102·62) High income: −34·4, −35·6 (−88·92, −92·23)	n/a	n/a	n/a	Annual tax burden ($US) (% of annual income) Low income: 17·64–18·60 (0·1) High income: 15·84–16·92 (0·03)

Table 3 *Continued*

Study	Price elasticities	Size and type of tax	Modelled effects of hypothetical SSB tax or relationship with existing state-level SSB taxes				
			Consumption	Energy intake	Weight or BMI	Obesity prevalence	Tax burden
	CPE High-income households substitute SSB more readily than low-income households (predominantly with sports and energy drinks)						
Briggs *et al.*[33]	OPE (SE) for non-concentrated SSB Lowest-income third: −0·79* (0·044) Middle-income third: −0·80* (0·038) Highest-income third: −0·85* (0·040) CPE For non-concentrated SSB, relatively large substitution effects occurred for non-concentrated diet soft drinks, concentrated SSB, milk, fruit juice, tea and coffee. Substitution patterns were similar across all income thirds with a trend towards larger substitution effects in the lowest-income third	20 % sales tax on all SSB (concentrated and non-concentrated)	% Change in non-concentrated SSB consumption (change in kJ/d) Low income: −15·2 (−18·1) Middle income: −15·9 (−12·4) High income: −16·8 (−17·1)	Change in energy intake per person (95 % CI) (kcal/d)‡ Lowest-income third: −4·6* (−7·0, −1·8) Middle-income third: −3·2* (−5·1, −1·1) Highest-income third: −5·5* (−7·5, −3·6) The smaller reductions in energy intake for the two lowest-income thirds compared with the highest third are primarily due to a greater substitution with high-fat milk (from both concentrated and non-concentrated SSB) No significant difference between income groups	Change in mean BMI (95 % CI) (kg/m²) Lowest-income third: −0·08* (−0·13, −0·03) Middle-income third: −0·06* (−0·09, −0·02) Highest-income third: −0·10* (−0·13, −0·06) No significant difference between income groups	% Change in prevalence of obesity (95 % CI) Lowest-income third: −1·3* (−2·0, −0·3) Middle-income third: −0·9* (−1·6, −0·1) Highest-income third: −2·1* (−2·9, −1·3) No significant difference between income groups	Increase in expenditure (95 % CI) on all beverages (£ sterling) per person per year; % increase (95 % CI) Lowest-income third: 4·9* (3·2, 6·9); 2·1 %* (1·4, 3·0) Middle-income third: 4·7* (3·4, 6·2); 1·7 %* (1·2, 2·2) Highest-income third: 3·1* (1·7, 4·6); 0·8 %* (0·4, 1·2)
Briggs *et al.*[34]	OPE −0·9 (derived from literature and assumed to be the same across income groups)	10 % excise tax	n/a	Change in energy intake per person (kcal/d)‡ Lowest-income group: −2·2 (women), −1·6 (men), −1·9 (overall) Middle-income group: −1·9 (women), −1·9 (men), −1·9 (overall) Highest-income group: −1·9 (women), −2·6 (men), −2·3 (overall)	n/a	% Change in prevalence of obesity (95 % CI) Lowest-income group: −1·4* (−1·0, −1·9) for women, −0·7* (−0·5, −1·0) for men, −1·1* (−0·7, −1·4) overall Middle-income group: −1·2* (−0·8, −1·6) for women, −1·0* (−0·7, −1·3) for men, −1·1* (−0·7, −1·4) overall Highest-income group: −1·2* (−0·8, −1·6) for women, −1·5* (−1·0, −1·9) for men, −1·4* (−0·9, −1·8) overall	n/a

Table 3 *Continued*

			Modelled effects of hypothetical SSB tax or relationship with existing state-level SSB taxes				
Study	Price elasticities	Size and type of tax	Consumption	Energy intake	Weight or BMI	Obesity prevalence	Tax burden
Sharma *et al.*[35]	Income-specific OPE and CPE estimated but not explicitly reported; however, it is noted that high-income households had the least elastic demand for regular soft drinks	20 % sales tax 20 cents per litre excise tax	% Change in SSB consumption per capita (reduction in ounces/quarter)† 20 % sales tax: Low income, −15·05 (−52·1)* Middle income, −14·92 (−50·7)* High income, −13·10 (−35·17)* 20 cents per litre excise tax: Not reported by income	n/a	Weight change (kg) 20 % sales tax: Low income, −0·40 Middle income, −0·37 High income, −0·23 20 cents per litre excise tax: Low income, −0·56 Middle income, −0·69 High income, −0·35 Differences between high- and low-income groups significant*	n/a	Annual per capita tax burden ($AU) attributable to SSB tax (% of annual income) 20 % sales tax: Low income, 20·89 (0·22 %) Middle income, 17·74 (0·07 %) High income, 16·60 (0·03 %) 20 cents per litre excise tax: Low income, 19·00 (0·15 %) Middle income, 14·77 (0·05 %) High income, 13·81 (0·04 %) Differences between high- and low-income groups significant*
Zhen *et al.*[36]	OPE Low-income households: −1·03* High-income households: −1·04* CPE Broadly similar across income groups	0·5 cents per ounce† excise tax	Change in regular carbonated soft drink consumed per capita, reduction in (ounces/quarter)† Low income: −65·8 High income: −49·3	Change in energy intake per person (kcal/d)‡ Low income: −13·2 High income: −5·6	Change in weight (kg) Low income: −0·37 in 1 year and −0·70 in 10 years High income: −0·16 in 1 year and −0·31 in 10 years	n/a	Average tax burden of approximately $US 20 per year per household with a difference of approximately $US 5 per household per year between high- and low-income households

n/a, not applicable; OPE, own-price elasticity; CPE, cross-price elasticity; Q, quintile.
*Significant effect size. Note: the significance of point estimates and differences between socio-economic groups are stated, otherwise significance not reported. Values in parentheses represent 95 % confidence (or credible) intervals. For a given outcome, all values are converted to the most common unit reported across studies for comparison.
†1 fl. oz (US) = 29·574 ml.
‡1 kcal = 4·184 kJ.

households were generally more responsive to an increase in the price of SSB compared with high-income households, with OPE (SE) reported as −2·20 (1·16), −3·47 (0·99), −0·14 (0·43), −2·95 (0·52) and −1·27 (0·44) for Q1 (lowest-income quintile) to Q5 (highest-income quintile), respectively; however, the difference between quintiles 1 and 5 was not statistically significant (difference in OPE was 0·07 (95 % CI −4·71, 4·84)). Income-specific CPE were not reported.

Modelling studies
Seven studies used price elasticity estimates to model the impact of an SSB tax on total energy or weight outcomes (with one of these studies modelling the effect of an SSB tax on total beverage consumption[32]). It is important to note that such modelling allowed for possible differences in baseline SSB consumption and in the prevalence of unhealthy weight across SEP groups (both of which were generally higher for lower-income groups). Consequently, differences in price elasticity estimates across socio-economic strata did not necessarily translate to similar differences in SSB consumption, net energy intake and/or adiposity outcomes following the examination of a hypothetical SSB tax. For example, lower price elasticity for SSB demand among groups with lower SEP (compared with higher SEP groups) may nevertheless result in a similar or greater decline in SSB consumption, net energy intake and/or adiposity outcomes for lower SEP strata, simply because baseline SSB consumption and the prevalence of excess weight are greater in this population. Six of the seven modelling studies estimated OPE in addition to an estimate of the change in demand of a related food/beverage following a change in SSB price (CPE)[22,31–33,35,36]. One study used existing OPE estimates from the literature to inform the modelling analysis and did not take CPE into account[34]. The responsiveness to a change in SSB price was variable among the six studies that estimated OPE, with three studies reporting high-income households to be more price elastic[22,32,33], two studies reporting similar price elasticity across household income categories[31,36] and one study reporting low-income households to be more price elastic[35]. Income-specific substitution effects to related products (CPE) were similarly variable across studies. All six modelling studies that reported on energy intake or body weight outcomes and the one modelling study that reported on SSB purchases consistently reported similar (*n* 5)[22,31–34] or greater (*n* 2)[22,35,36] impact of an SSB tax for lower-income groups.

Finklestein *et al.*[31] modelled the impact of a 20 % and 40 % sales tax on either carbonated beverages or all SSB in the USA. Across all households the estimated OPE were significant and similar across income groups. OPE (SE) for carbonated beverages were −0·73 (0·09), with estimates ranging from −1·02 (0·17) for households in the 50–75 % income quartile to −0·49 (0·20) for households in the

0–25 % income quartile. The modelled tax on carbonated SSB significantly reduced the mean per capita beverage kilocalories purchased across the entire population by 4·2 and 7·8 kcal/d (17·6 and 32·6 kJ/d) following a 20 % and 40 % SSB tax, respectively (taking into account both OPE and CPE), which was driven entirely by middle-income households, with no statistical change reported for low- or high-income households. When extrapolating a reduction in kilocalories purchased to annual weight loss (using a static calorie-to-weight relationship), taxes on carbonated SSB of 20 % and 40 % generated significant annual weight losses (SE) of 0·20 (0·07) and 0·37 (0·13) kg per person, respectively. Expanding the tax to include all SSB, it was estimated that a 20 % and 40 % tax would result in significantly annual weight losses of 0·32 (0·09) and 0·59 (0·16) kg per person, respectively. Again, this was driven by the middle two quartiles, with changes for households in the lowest- and highest-income quartiles not statistically significant.

Lin *et al.*[22] modelled the impact of a 20 % excise tax on SSB on changes in beverage consumption, net energy intake, weight loss and body weight status in the USA. OPE estimates were significant for both income groups; however, high-income demand for SSB was more price elastic than low-income demand (OPE (SE): −1·29 (0·096) and −0·95 (0·082) for high- and low-income groups, respectively). When the price of SSB increased, individuals from high-income households were likely to substitute SSB for skimmed milk, bottled water or juice, whereas low-income households were likely to substitute to juice only. A 20 % tax on SSB translated to a larger reduction of SSB energy intake among adults from low-income households compared with adults from high-income households (a reduction of 38 and 35 kcal/d (159 and 146 kJ/d) for low- and high-income households, respectively). For children, a 20 % tax on SSB translated to a reduction of 33 and 45 kcal/d (138 and 188 kJ/d) for children from low- and high-income households, respectively. Simulating a 20 % SSB tax resulted in a 1-year weight loss of 0·95 kg (1·8 kg at 10 years) and 1·04 kg (1·96 kg at 10 years) for high- and low-income groups, respectively (predictions not made for children).

Zhen *et al.*[32] simulated the impact of a 0·5 cents per ounce (1 fl. oz (US) = 29·574 ml) excise tax on SSB consumption in the USA, taking into account habit formation (estimating a myopic and rational model to account for beverage addiction). Demand for SSB was less elastic for low-income households compared with high-income households (OPE: −1·06 (rational) and −1·22 (myopic) for low-income households and −1·54 (rational) and −1·44 (myopic) for high-income households); however, high-income households were found to substitute SSB more readily than low-income households (predominantly with sports and energy drinks). This, combined with a greater baseline consumption of SSB for lower SEP groups, resulted in a similar reduction of regular

carbonated SSB consumption for both income strata (low income: 82·81/2449 (rational) and 102·68/3037 (myopic) ounces/ml per household per month; high income: 88·92/2630 (myopic) and 92·23/2728 (rational) ounces/ml per household per month).

Briggs *et al.*[33] modelled the impact of a 20 % sales tax on any soft drinks with added sugar in the UK. The OPE (SE) for non-concentrated SSB were −0·79 (0·044), −0·80 (0·038) and −0·85 (0·040) for low-, middle- and high-income groups, respectively. For non-concentrated SSB, relatively large substitution effects occurred for non-concentrated diet soft drinks, concentrated SSB, milk, fruit juice, tea and coffee. Substitution patterns were similar across all income thirds with a trend towards larger substitution effects in the lowest-income third. The tax reduced consumption of non-concentrated SSB by 15·2 % (17·1 kJ/d), 15·9 % (12·4 kJ/d) and 16·8 % (18·1 kJ/d) for the lowest-, middle- and highest-income groups, respectively. Daily net energy intake (95 % CI) was reduced by 19·2 (−29·3, −7·6), 13·4 (−21·2, −4·8) and 23·2 (−31·3, −15·0) kJ per person for low-, middle- and high-income groups, respectively. The smaller reductions in energy intake for the low- and middle-income groups compared with the highest-income group were partly due to a greater substitution with high-fat milk; however, the confidence intervals for these estimates were wide and overlap. Corresponding reductions in mean population BMI (95 % CI) were 0·08 (−0·13, −0·03), 0·06 (−0·09, −0·02) and 0·10 (−0·13, −0·06) kg/m², with no significant difference across income groups.

Briggs *et al.*[34] estimated the effect of a 10 % SSB excise tax on SSB purchases and consumption in Ireland. OPE were derived from the literature and were assumed to be −0·9 across all income groups. The estimated daily reduction in SSB energy intake (kcal/kJ per person) following a 10 % SSB excise tax was 2·2/9·2 (women) and 1·6/6·7 (men) for the lowest-income group, 1·9/7·9 (women and men) for the middle-income group and 1·9/7·9 (women) and 2·6/10·9 (men) for the highest-income group. This resulted in a similar percentage reduction (95 % CI) in the prevalence of obesity across income groups, which was 1·4 (1·0, 1·9) for women and 0·7 (0·5, 1·0) for men in the lowest-income group, 1·2 (0·8, 1·6) for women and 1·0 (0·7, 1·3) for men in the middle-income group and 1·2 (0·8, 1·6) for women and 1·5 (1·0, 1·9) for men in the highest-income group.

Sharma *et al.*[35] modelled the effect of a 20 % sales tax and a 20 cents per litre excise tax on SSB consumption, net energy reduction and body weight by household income level in Australia. Following a 20 % SSB sales tax, the demand for regular soft drinks was estimated to be slightly less responsive for high-income households (a significant per capita reduction of 13·10 % (35·17 ounces (1040 ml)/quarter), 14·92 % (50·7 ounces (1499 ml)/quarter) and 15·05 % (52·1 ounces (1541 ml)/quarter) for high-, middle- and low-income households, respectively; significant differences between income groups not tested). Differences across income groups were more pronounced for fruit drinks (a significant reduction of 11·82 %, 36·61 % and 3·08 % for high-, middle- and low-income households, respectively) and cordial (45·55 %, 35·63 % and 29·98 % for high-, middle- and low-income households, respectively). A 20 % sales tax resulted in a reduction in body weight for all income groups, which was significantly greatest for those with the lowest compared with highest incomes (0·40 kg compared with 0·37 kg for middle-income and 0·23 kg for high-income groups). This was a result of greater price elasticity and greater baseline consumption of SSB for lower-income groups. A 20 cents per litre tax resulted in a reduction in weight of 0·56, 0·69 and 0·35 kg for low-, middle- and high-income households, respectively.

Zhen *et al.*[36] estimated the impact of a 0·5 cents per ounce SSB excise tax (approximating an average increase in retail SSB price of 26 %) on US household purchases of energy and on the nutrients fat and sodium. OPE for regular carbonated soft drinks for high- and low-income households were similar (−1·03 and −1·04 for low- and high-income households, respectively). CPE were also broadly similar across income groups. Across all households, Zhen *et al.* estimated that this tax would reduce per capita daily energy intake by 13·2 kcal (55·2 kJ) for low-income households and by 5·6 kcal (23·4 kJ) for high-income households. Using a dynamic energy–weight loss model, these reductions in energy intake were estimated to translate to reductions in weight of 0·37 and 0·16 kg/person in 1 year and 0·70 and 0·31 kg/person in 10 years for low- and high-income households, respectively (the significance of these estimates was not tested).

Amount paid in sugar-sweetened beverage tax according to socio-economic position following an increase in sugar-sweetened beverage price

Five of the studies included in the current review examined the amount paid in tax following an increase in the price of SSB by SEP[22,32,33,35,36]. All of these studies reported the tax to be financially regressive whereby lower-income households would pay a greater proportion of their income in additional tax. Results for each study are described below. For comparison across studies, the difference in SSB tax paid between the highest- and lowest-income households are also presented annually and in $US using 2015 conversion rates.

Lin *et al.*[22] reported, across all household income groups, that the tax burden following a 20 % SSB excise tax would represent a small share of the total food and beverage budget, at less than 1 % of annual food and beverage spending. Low-income households, who consume more SSB, would pay slightly more in annual tax ($US 19·97; 1 % of annual food budget) compared with high-income households ($US 18·84; 0·6 % of annual food budget). Zhen *et al.*[32] estimated that low-income households would pay an annual tax of $US 17·64–18·60 (approximately 0·1 % of annual household income) and

high-income households an annual tax of $US 15·84–16·92 (approximately 0·03 % of annual household income) following a 0·5 cents per ounce excise tax on SSB. Following a 20 % sales tax on SSB, Briggs *et al.*[33] reported the greatest increase in beverage expenditure for the lowest-income group (increase (95 % CI) of 9·4 (6·2, 13·4) p per person per week; 2·1 (1·4, 3·0) %) compared with the middle-income group (increase of 9·1 (6·6, 11·9) p per person per week; 1·7 (1·2, 2·2) %) and the high-income group (increase of 6·0 (3·2, 8·8) p per person per week; 0·8 (0·4, 1·2) %). This represented a difference in the annual amount paid in SSB tax of less than $US 2·5 between high- and low-income households. Sharma *et al.*[35] estimated that following a 20 % sales tax, low-income households would pay approximately $AU 20·89 per capita per year in SSB tax (0·22 % of annual household income) compared with $AU 17·74 (0·07 % of annual household income) and $AU 16·60 (0·02 % of annual household income) for middle- and high-income households, respectively, with significant differences between the highest- and lowest-income groups. The tax burden would be lower for a 20 cents per litre excise tax, at $AU 19·00, $AU 14·77 and $AU 13·81 per annum, representing 0·15 %, 0·05 % and 0·04 % of annual household income for low-, middle- and high-income households, respectively. When converted to $US, for both of the modelled taxes, the difference in the annual amount paid in SSB tax between high- and low-income households was less than $US 4. Zhen *et al.*[36] estimated that a 0·5 cents per ounce increase in SSB would result in low-income households paying approximately $US 5 per household per year more in SSB tax compared with high-income households, with an average of $US 20 paid in SSB tax per household per year.

Discussion

The current review synthesises all existing literature on beverage purchase, consumption and weight outcomes, and the amount paid in SSB tax, following an increase in SSB price or an SSB tax across socio-economic strata within high-income countries. We found consistent evidence that a tax on SSB is likely to lead to improvements in population weight of a similar magnitude across SEP groups or of a greater magnitude for lower compared with higher SEP groups. Our review reinforces the regressive financial nature of an SSB tax, whereby lower-income households would pay a greater proportion of their income in additional tax; however, the monetary burden across all households is small, with relatively minor differences between higher- and lower-income households (0·10–1·0 % and 0·03–0·60 % of annual household income paid in SSB tax for low- and high-income households, respectively, equating to less than $US 5 per year). This challenges the significance of the financial regressivity argument commonly put forth to oppose such a tax[23]. The findings from the present review are important as countries begin to consider, and indeed implement, this policy around the world.

Our results corroborate those of a 2012 systematic review of simulation studies examining the association between food and beverage pricing strategies and changes in purchase or consumption of food and beverage items and health-related outcomes[25]. Similarly, our results align with those of Thow *et al.*[26] (2014) who systematically reviewed the literature for studies that reported the effect of food and beverage taxes and subsidies on food and beverage consumption. When extracting the data pertaining to SSB, both these reviews concluded that the relative health benefits inferred following a price increase on SSB, or a tax on SSB, were greater for consumers of lower (compared with higher) income. Our review updates and extends these reviews by including studies of all designs and reporting on all differential impacts of an SSB tax or price change for a range of outcomes across the intended policy pathway of effect according to SEP (rather than including it as a small subsection within a broader review). We additionally summarise the amount paid in SSB tax for each SEP group, which has not been reported in prior reviews. While the variation in outcomes reported within our review and the differences in the type and size of tax (or price increase) examined precluded synthesis to a single summary effect, it allowed the inclusion of a much broader range of studies, all of which were able to contribute to our conclusion that an SSB tax is likely to have a similar effect on population weight across socio-economic strata or a greater impact for lower SEP groups.

The recent evaluation of the national SSB tax policy in Mexico on the purchase of SSB across different socio-economic groups supports the conclusions from our review herein. One year post implementation of the policy in January 2014, which required an increase in the price of SSB at a rate of one peso per litre (roughly equivalent to a 10 % increase in price), there was a reduction in mean SSB purchases across all socio-economic groups, with the greatest reduction among households with the lowest resources (SSB purchases reduced by 17 % one year after policy implementation in this group compared with 12 % overall)[20]. In the current review we excluded low- to middle-income countries due to the varied and often reverse relationship between SEP and SSB consumption and/or obesity prevalence[37], and thus the likelihood that the equity impact of a tax on SSB may also differ. While Mexico is considered a middle-income country, and data from the 2006 Mexican Household Income and Expenditure Survey indeed reveal a positive relationship between SEP and energy intake from soda[38], these recent results of the impact of the national SSB tax policy are nevertheless congruent with results in our review on high-income countries, where the relationship between SEP and SSB purchase and consumption is reversed.

OPE, and the difference across income groups, were variable across the eight studies that reported income-specific estimates. This variation in OPE estimates across different studies is likely to result from methodological variations (including data sources used, beverage grouping and/or model specifications used to estimate price elasticities) or real country and contextual differences in response to an SSB price change. Understanding the exact sources of variation will be important to inform the evidence base on the likely impact of an SSB tax on population weight. Nevertheless, when studies used price elasticity estimates to simulate the effect of a hypothetical SSB tax on total energy intake and/or health outcomes, results were remarkably consistent across studies, with all studies demonstrating either a similar benefit across households with differing income levels or a greater impact for households with a lower compared with higher income. The impact of an SSB tax on population weight results from a delicate balance between OPE, CPE (product substitution), and the distribution of SSB consumption and weight within a population. While modelling studies have their limitations, they are able to account for these determinants (to a greater or lesser degree, depending on the study). Eight of the eleven studies included in our review reported greater SSB consumption and higher weight and/or obesity prevalence for lower-income households, with mixed reports of differential product compensation across income groups. These results highlight that caution should be taken when concluding on the health equity impact of an SSB tax based on price elasticity data alone.

Strengths and limitations of the study

The strengths of the current study include the comprehensive systematic search of both academic and grey literature and extraction of all relevant data by at least two authors.

The major limitation relates to the limited variability in study types identified. Only three studies evaluated the association between existing real-world SSB taxes and SSB consumption or weight outcomes, and these studies were all limited by the relatively small tax rates (average of approximately 4%) and the limited variability in taxes across US states. The remaining eight studies estimated price elasticities of SSB demand and seven of these simulated the effects of an SSB tax on total SSB consumption, total energy intake or weight outcomes using econometric modelling methods. These latter studies are reliant on household survey or scanner data and a number of assumptions, which may not have been empirically tested. These studies do not consider 'real-world' dynamics, such as the interaction of pricing strategies with other population- or individual-level interventions, the impact on social norms as a result of implementing a 'health-related' tax, possible unintended consequences and the response from the beverage industry, all of which could

have a differential impact according to SEP. Furthermore, only six of studies considered the differential impact of substituting SSB with other beverages and only one considered substitution to food products. As the overall health impact of an SSB tax depends on the net change in energy intake from all foods and beverages it is important to consider all possible substitutions, which may differ according to socio-economic group. For example, Zhen *et al.*[36] estimated that almost half of the reduction in SSB kilocalories caused by an increase in its price could be offset by an increase in kilocalories from other foods, with a probable increase in sodium and fat intake. This highlights the complexity of evaluating the impact of a tax on SSB and the need to consider possible unintended effects across all socio-economic groups. While our conclusions herein remain robust, it is essential that they are confirmed with other study designs. For this reason, as SSB taxation policies are implemented around the world, as they have been recently in Mexico and St Helena, it is important that they are rigorously evaluated with the data disaggregated by SEP. Nevertheless, while real-world evaluations have great external validity, internal validity is difficult to manage. It may therefore also be important that experimental studies be conducted and the conclusion on the health equity impact of a tax on SSB be based on the totality of evidence, as recommended by the US body, the Institute of Medicine[39].

A further limitation is that many of the included studies did not evaluate if the differences in outcomes were significantly different between groups of differing SEP. While this is unlikely to alter our conclusions that an SSB tax is unlikely to increase socio-economic inequalities in weight, we recommend future studies statistically test differences across socio-economic groups.

SSB have been linked to a number of non-communicable diseases, including CVD[13] and diabetes[40] as well as dental caries[41], all of which are more prevalent among lower SEP groups in high-income countries[42–44]. Thus, it is likely that the health equity benefits of a tax on SSB extend beyond the weight outcomes described in the present review. Furthermore, if the revenue generated from the tax was directed towards targeted interventions that improved health among more disadvantaged groups, then the health equity impact of an SSB tax may be greater. A tax on SSB should be considered as just one strategy among many to address the unequal burden of excess weight and health across socio-economic groups.

Conclusion

Current evidence suggests that a tax on SSB is likely to be an effective policy to reduce SSB consumption[25,26]. Here we additionally demonstrate that, within the current evidence base, a tax on SSB is also likely to have a similar impact on consumption and weight outcomes

for high- and low-income households or a greater impact among those with a lower SEP. Our evidence synthesis further challenges the relevance of the argument pertaining to financial regressivity. Careful health equity evaluations of real-world SSB taxation policies and well-controlled experimental studies are required to broaden and strengthen the evidence base in this area.

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Supplementary material

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