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#### Abstract: Background

In March, 2016, the UK government proposed a tiered levy on sugar-sweetened beverages (SSBs; high, moderate, and no tax for drinks with >8g, 5g to 8g, and <5g sugar per 100ml). We estimate the effect of possible industry responses to the levy on obesity, diabetes, and dental caries.

#### Methods

We modelled three possible industry responses: (1) reformulation to reduce sugar concentration, (2) increasing product price, and (3) changing the market share of high-, mid-, and low-sugar drinks. For each response, we defined a better and worse case health scenario. We developed a comparative risk assessment model to estimate the UK health impact of each scenario.

#### Findings

The best modelled scenario for health is SSB reformulation, resulting in 144,000 (95% uncertainty interval: 5,100 to 306,700) fewer adults and children with obesity in the UK, 19,000 (6,900 to 32,700) fewer incident cases of diabetes per year, and 269,000 (82,200 to 470,900) fewer decayed, missing, or filled teeth annually. Increasing the price of SSBs and changes to market share to increase the proportion of low-sugar drinks sold would also result in population health benefits, but to a

lesser extent. The greatest benefit for obesity and oral health would be among individuals under 18 years, with people over 65 years experiencing the largest absolute decreases in diabetes incidence.

#### Interpretation

The health impact of the soft drink levy is dependent on its implementation by industry. There is uncertainty as to how industry will react and in the estimation of health outcomes. Health gains could be maximised by significant product reformulation with additional benefits possible if the levy is passed onto purchasers through raising the price of high- and mid-sugar drinks, and through activities to increase the market share of low-sugar products.

#### Funding

None

## Title

A health impact assessment of the UK soft drinks industry levy: a comparative risk assessment modelling study

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## **Abstract**

### *Background*

In March, 2016, the UK government proposed a tiered levy on sugar-sweetened beverages (SSBs; high, moderate, and no tax for drinks with >8g, 5g to 8g, and <5g sugar per 100ml). We estimate the effect of possible industry responses to the levy on obesity, diabetes, and dental caries.

### *Methods*

We modelled three possible industry responses: (1) reformulation to reduce sugar concentration, (2) increasing product price, and (3) changing the market share of high-, mid-, and low-sugar drinks. For each response, we defined a better and worse case health scenario. We developed a comparative risk assessment model to estimate the UK health impact of each scenario.

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The best modelled scenario for health is SSB reformulation, resulting in 144,000 (95% uncertainty interval: 5,100 to 306,700) fewer adults and children with obesity in the UK, 19,000 (6,900 to 32,700) fewer incident cases of diabetes per year, and 269,000 (82,200 to 470,900) fewer decayed, missing, or filled teeth annually. Increasing the price of SSBs and changes to market share to increase the proportion of low-sugar drinks sold would also result in population health benefits, but to a lesser extent. The greatest benefit for obesity and oral health would be among individuals under 18 years, with people over 65 years experiencing the largest absolute decreases in diabetes incidence.

### *Interpretation*

The health impact of the soft drink levy is dependent on its implementation by industry. There is uncertainty as to how industry will react and in the estimation of health outcomes. Health gains could be maximised by significant product reformulation with additional benefits possible if the levy is passed onto purchasers through raising the price of high- and mid-sugar drinks, and through activities to increase the market share of low-sugar products.

### *Funding*

None

## **Research in context**

### *Evidence before this study*

The UK government announced a soft drinks industry levy in March 2016. Multiple observational and modelling studies have analysed the effect of soft drink taxes in other international settings, however the UK would be first to introduce a tiered industry levy (high, moderate, and no tax for drinks with >8g, 5g to 8g, and <5g sugar per 100ml respectively) rather than a sales tax, as has been applied elsewhere. There have been no peer-reviewed analyses of its potential impact and no international precedent from which to predict the potential response of soft drink manufacturers to the levy.

### *Added value of this study*

This is the first study to estimate the health impact of the UK soft drinks industry levy. It focuses on obesity, diabetes and oral health where evidence of a causal link between soft drink consumption and health is strongest. Previous evidence has suggested that soft drink taxes lead to price rises and subsequent reductions in purchases of targeting drinks. This study goes further and estimates the effects of six scenarios to illustrate the relative health impacts of three possible industry responses to the levy: reformulation, price rises, and changes to product market share.

### *Implications of all the available evidence*

Each of the three responses modelled could lead to important health gains, with industry likely to react to the levy using a combination of all three. This study extends previous analyses of the effect of soft drink taxes to show the benefits of reformulation stimulated by the tiered levy. Our analyses show that there could be substantial health benefits if the levy stimulates reformulation. Further important health benefits from price changes will be mitigated if industry spread the price increase across their entire portfolio. Increases in market share for mid-sugar and low-sugar drinks could have substantial health benefits, but only if the market share comes at the expense of high-sugar drinks rather than people shifting from low-sugar to mid-sugar drinks.

## **Background**

In 2015, the UK Scientific Advisory Committee on Nutrition (SACN) published a report on the evidence between the consumption of carbohydrates and health.<sup>1</sup> The report clarified the role of sugar for the development of dental caries and identified sugar-sweetened beverages (SSBs) as a specific risk factor for weight gain and type 2 diabetes, recommending that SSB consumption should be minimised. Both Public Health England and the UK House of Parliament's health committee subsequently advised a tax on SSBs<sup>2,3</sup> and in March 2016 the budget statement included proposals for a soft drinks industry levy.<sup>4</sup>

Taxes on SSBs have been previously introduced in Mexico, France, Hungary and elsewhere,<sup>5</sup> however the UK would be the first to introduce a three-tiered levy. The levy is presented as an incentive for the industry to reformulate existing products to remove sugar, reduce portion sizes, and promote new or existing low sugar alternatives. The levy is due to be introduced in 2018, subject to parliament passing the legislation in 2017, with revenue hypothecated for increasing physical activity and breakfast clubs in schools.<sup>4</sup>

Whilst the government has expressed a desire that the levy is not passed onto purchasers through price rises, this cannot be mandated and the industry response is unknown. Other outcomes may include reformulation to reduce sugar content, or changes in marketing to encourage purchasers to switch to lower sugar products or smaller portion sizes. Different responses will have differential effects on consumption patterns for soft drinks and hence determine the health effects of the levy.<sup>6</sup>

The aim of this paper is to appraise the health impact of a range of discrete industry responses so that legislation for the soft drinks levy may be designed to maximise health gain.

## **Methods**

We developed a comparative risk assessment model to estimate the effects of SSB reformulation, price changes, and changes to SSB market share on obesity, dental caries, and type 2 diabetes in the UK using 2014 data where possible (figure 1).

### Scenarios

We identified and modelled three possible industry responses. First, reformulation to reduce sugar concentration; second, a rise in price; and third, activities to change the relative market share of high-, mid-, and low-sugar drinks. We refer to these three responses as reformulation, price change, and change in market share, respectively. For each of these, the magnitude of the response is uncertain. Informed by evidence where available and expert opinion, for each response we identified 'better' and 'worse' case scenarios for reduction of sugar consumption, resulting in six scenarios (table 1).

We adopt the government definitions of high-sugar drinks as those with over 8g sugar per 100ml, mid-sugar drinks as those with 5-8g sugar per 100ml, and low-sugar drinks as those with less than 5g sugar/100ml. Soft drinks are defined as all drinks with added sugar or sweetener; SSBs are drinks with added sugar excluding milk-based drinks, tea, and coffee; concentrated SSBs are defined as SSBs that are intended to be diluted with water, and regular SSBs are intended to be drunk as sold.

Small producers will be excluded from the levy.<sup>4</sup> We searched all soft drinks sold through Tesco Online and extracted the names of manufacturers. We used the Companies House website to identify manufacturers fulfilling the UK government definition of a small company<sup>7,8</sup> and identified 13 small companies which together contributed 0.6% of total UK SSB sales. Therefore, we did not adjust our analyses to account for these.

The better case reformulation scenario (scenario 1) assumed that industry would reduce the sugar concentration of high-sugar drinks by 30% and mid-sugar drinks by 15%. This is based on the reformulation of Sprite and Lipton Ice Tea which have both reduced their sugar concentration by 30% since 2013.<sup>9,10</sup> In the worse case scenario (scenario 2) we assumed a 5% reduction in sugar concentration of both high- and mid-sugar drinks. This was based on Coca-Cola's pledge made to the Public Health Responsibility Deal of a 5% reduction in calories across their sparkling drink range between 2012 and 2014; they achieved a 5.3% reduction.<sup>10</sup> Under both these scenarios, the volume consumed is assumed to remain constant.

To derive the price change scenarios we used estimates from the Office for Budget Responsibility that the levy will be 18p per litre on mid-sugar drinks and 24p per litre on high-sugar drinks.<sup>11</sup> Low sugar drinks will not be taxed. Previous sugar drink taxes have been passed on at rates of between 50% and 100%<sup>12-14</sup> and if the tax was entirely passed through to consumers, high-sugar concentrated drinks would, on average, increase in price by 75% and high-sugar regular drinks by 31% (table 2). Such price rises are markedly greater than other examples of SSB taxes (most countries have adopted smaller tax rates and therefore despite high pass on rates, only result in a 5-15% price rise),<sup>15</sup> and are larger than the 20% often cited as being necessary to affect significant behavioural change and improve health.<sup>16</sup>

We therefore assumed that 50% of the price increase would be passed on to purchasers and that companies would not increase prices by more than 20% (table 2). The better case for price change (scenario 3) assumed that the tax is passed on only through SSBs. However, major soft drink manufacturers produce a range of beverages. Therefore, in a worse case for price change (scenario 4) we assume that the levy is passed on evenly across all soft drinks (both diet and SSBs), fruit juice, and bottled water, resulting in a 6% price rise. Passing 100% of the price increase on to consumers was modelled as a sensitivity analysis. As stated by the UK government, tax rates were applied to concentrated drinks given their price per litre as drunk assuming a ratio of concentrate to water of

1:4 as used by the British Soft Drinks Association (BSDA).<sup>9,17</sup> Supplementary material gives details of how the price change was modelled.

A change in SSB market shares may result from changes in product marketing, changing product size, or the introduction of new mid- and low-sugar products. For example, the BSDA reports a 70% increase in expenditure on advertising of low or zero calorie brands and growth in the sales of smaller pack sizes,<sup>9</sup> and new mid-sugar products have emerged such as Coca-Cola Life which has 30% less sugar than full sugar Coca-Cola.<sup>18</sup> There are limited data to inform the extent to which these activities drive changes in purchasing behaviour. However, the soft drink industry has pledged to reduce energy intake from soft drinks by 20% from 2015 levels by 2020.<sup>9</sup> To achieve this, we calculate that the market share of high-sugar drinks would need to fall by 12% alongside a 6% increase for each of mid- and low-sugar drinks. This gives scenario 5, our better case for sugar reduction. The worse case (scenario 6) acknowledges that the increased marketing of new mid-sugar drinks may lead consumers to switch to this category from low-sugar drinks. We assume that mid-sugar drinks double their market share alongside equal reductions in the market share of high- and low-sugar drinks.

#### Health impact modelling

We developed a comparative risk assessment model to estimate the effect of the changes to SSB purchasing on incidence of dental caries and type 2 diabetes, and on the prevalence of obesity. Comparative risk assessment modelling requires the identification of 'risk factor-disease' pairs. In this case, the risk factor is SSB consumption and the diseases are dental caries, type 2 diabetes, and obesity. A two-step process then estimates the impact of the risk factor on the diseases. First, changes in the risk factor between the baseline (current behaviour) and scenarios are estimated. Second, changes in the diseases as a result of changes in the risk factor are calculated using population impact fractions and applied to baseline levels of disease in the population. Such methods are common to the field of comparative risk assessment modelling<sup>19</sup> and are based on model parameters representing baseline risk factor and disease status and the epidemiological relationships between risk factors and diseases, which are assumed to be causal.

Parameters describing the direct relationship between SSB consumption and health outcomes were sought from meta-analyses of randomised controlled trials where available or cohort studies (table 3).<sup>20-25</sup> The relationship between SSB consumption and diabetes and body weight was modelled as a function of SSB consumption. The reformulation scenarios (scenarios 1 and 2) assumed that SSB consumption stays constant, but the level of sugar in the drinks reduces. In order to estimate the impact of these scenarios on obesity and diabetes, we derived estimates of 'equivalised SSB consumption', which rises and falls in direct proportion of a) volume of SSB consumed, and b) average SSB sugar level. We standardised against the average sugar levels in drinks in the baseline scenario. For example, in the baseline scenario the average sugar level of SSBs was 9.2g/100ml and the average consumption was 213ml/d. A reduction in the average sugar concentration to 8.2g/100ml at the same level of consumption



would have an 'equivalised SSB consumption' of 190ml/d. This is because a reduction in consumption of SSBs from 213ml/d to 190ml/d at constant sugar concentrations would result in the same reduction of sugar as a reduction of sugar concentration from 9.2g/100ml to 8.2g/100ml at the same level of consumption. We used equivalised SSB consumption as an input for diabetes and obesity modelling in all scenarios.

Uncertainty intervals reflect the uncertainty in baseline sugar drink sales and consumption, disease burden, sensitivity to price changes, and associations between sugar or sugar drinks consumption and health outcomes. They were estimated using 5000 iterations of a Monte Carlo analysis with model parameters being drawn from the published or estimated uncertainty of each parameter (see supplementary material).

All results were applied to the 2014 UK population,<sup>26</sup> and separate estimates for each outcome were made by sex and age group using age and sex specific estimates of baseline SSB consumption and disease burden. Further details of the health impact model are in the supplementary material, including estimates of the effect on obesity if an energy balance equation was used instead of estimating the direct effect on weight of SSB consumption, as used by Briggs et al.<sup>27</sup>

### **Role of the funding source**

There was no specific funding for this work. No funders had any role in the writing of the manuscript or the decision to submit it for publication. The corresponding author had full access to all the data in the study and has final responsibility for the decision to submit for publication.

### **Findings**

#### Change in equivalised SSB consumption

The better case for reformulation (scenario 1) resulted in a fall in average sugar content of SSBs equivalent to 59mls (95% uncertainty interval: 55 to 63; 10kcal [9 to 10]) of SSBs per person per day (table 4). This is the largest reduction among scenarios modelled. All simulated scenarios led to a fall in equivalised SSB consumption except for the worse case for market share which resulted in a small increase (4ml [3 to 4]; scenario 6). The largest falls for both males and females were among 11-18 year olds who consume the largest volume of SSBs.

#### Obesity

The reduction in obesity prevalence resulting from each scenario is estimated to be greatest following scenario 1 (better case for reformulation, table 5), leading to 144,400 (5,100 to 306,700) fewer individuals with obesity, 0.9% of the obese population. This is compared to the better cases for price change (scenario 3) and change in market share (scenario 5), which reduce the obese population by 81,600 (3,600 to 182,700) and 91,000 (4,300 to 204,900) respectively, although note that uncertainty intervals are very wide (NB: uncertainty intervals for analyses restricted to adults include zero for all scenarios).

Results varied by age with 10% and 6% falls in the number of children with obesity aged 4-10 years and 11-18 years respectively in scenario 1, compared to just 0.4% in adults aged 19-64 years. Males were predicted to experience a greater relative reduction in obesity prevalence than females because males consume a greater volume of SSBs (supplementary table 2). Effect size estimates were significantly increased when using an energy balance equation (supplementary table 3).

### Diabetes

Across the scenarios modelled, the pattern of results seen with obesity is repeated for diabetes. Scenario 1 (better case for reformulation) resulted in an estimated 19,100 (6,900 to 32,700) fewer new cases of diabetes per year and scenario 6 (worse case for change in market share) led to an increase of 1237 (455 to 2359) cases per year (table 6).

However, in contrast to the obesity results, adults over 65 years saw the largest absolute reduction in diabetes incidence rates reflecting the positive association between age and disease burden.

### Dental caries

All scenarios except scenario 6 led to a fall in the numbers of teeth affected with dental caries (measured by the number of decayed, missing, or filled teeth, DMFT, table 3). The better case for reformulation (scenario 1) had the largest effect size reducing the annual incidence of DMFT by 269,400 (82,200 to 470,900). As with results for obesity and diabetes, the better case for change in market share and price change scenarios (scenarios 5 and 3) had the next largest effects respectively. Those aged 11-18 years were expected to experience the greatest relative benefit due to their higher baseline SSB consumption.

### Sensitivity analysis

If 100% of the levy were passed on to consumers, equivalised SSB consumption would reduce by 71mls (66 to 77) per person per day. This would lead to 174,800 (7,500 to 367,600) fewer obesity individuals, and 23,000 (8,400 to 40,000) fewer cases of diabetes and 324,500 (89,100 to 553,800) fewer DMFT per year.

### **Interpretation**

The proposed UK soft drinks industry levy has the potential to reduce obesity prevalence, diabetes incidence, and dental caries incidence. The effect on health and the ranking of scenarios is sensitive to the manner in which industry responds to the levy and the uncertainty in the modelling. Our estimates suggest the greatest benefits will result from reformulation, with less but still positive health effects following price changes and changes to SSB market share to increase the proportion of low-sugar drinks sold. Children will have the greatest relative health benefit in terms of obesity and caries, with absolute reductions in diabetes incidence rates increasing with age.

### Strengths and weaknesses

The main strength of this study is the timely assessment of a planned government policy by simulating a set of discrete scenarios for how industry might respond to the levy to inform the detail of the legislation. Other strengths include the modelling of multiple health outcomes, the use of age and sex specific data, use of own- and cross-price elasticities for high-, mid-, and low-sugar drinks, and use of equivalised SSB consumption to allow for changes in both sugar content and SSB volume.

Uncertainty intervals estimate the uncertainty arising from model parameters, however, the greatest uncertainty is how the soft drinks industry will respond to the levy. Given this uncertainty, our results should not be read as precise estimates of the impact of the levy, but instead should be used to compare the relative effects of different scenarios. Moreover, industry is likely to respond with a blended approach that combines elements of reformulation, price changes, and marketing. Note that although the results have wide and overlapping uncertainty analyses, much of the uncertainty is correlated between the scenarios. In 100% of the iterations of our Monte Carlo analysis, the best case reformulation scenario was associated with the best health outcomes, which suggests that the ranking of scenarios is robust. We have not estimated uncertainty in how much of the levy is passed-on to consumers (although a 100% pass-on is modelled as a sensitivity analysis), and we did not use child-specific estimates of the effect of SSB consumption on diabetes and dental caries incidence due to lack of data available.

We have assumed that disease risk from SSBs is dependent on the quantity of sugar consumed (more sugar = higher risk). While studies have shown benefits from swapping from SSBs to artificially sweetened beverages, we are not aware of any studies that have described the effect of swapping SSBs with a high sugar content to SSBs with a low sugar content.

We have not modelled a temporal component. The effects on DMFT may occur relatively soon after the change in SSB consumption, and the trials used to parameterise the relationship between SSB consumption and weight suggest that falls in obesity would be expected within 6 months for adults and 12 months for children.<sup>21-24</sup> The effects on type 2 diabetes may take longer to be realised (median follow up of observational studies used for this parameter ranged between 3.4 years and 21.1 years).<sup>20</sup> We have also not modelled results for different subgroups. Individuals from different socio-economic backgrounds, ages, and baseline consumption levels may respond differently to each industry response simulated.

Finally, we have not modelled the long-term health benefits of falls in obesity, the possible educational role the levy may have in highlighting that SSBs cause disease,<sup>28</sup> and the health impact of using the revenue to improve school sport and nutrition.

#### Comparisons with other studies

This is the first peer-reviewed study to appraise the potential effects of the UK soft drinks industry levy.

The results of our study vary from the results of an industry-funded assessment of the impact of the levy.<sup>29</sup> Oxford Economics calculated the impact of a price change associated with a 100% pass-on of the levy to targeted products only, with no reformulation or market share (most similar to our scenario 3). The authors estimated that the levy would result in a 5kcal per person per day fall in energy intake. Our sensitivity analysis of a 100% pass-on rate would result in a reduction of 11kcal per person per day (before adjustment for BSDA sales figures). There are two principle explanations for the difference. Firstly, we estimate the average price before tax of dilutables as £0.22 per litre, whereas Oxford Economics estimate it as £1.76 per litre. This is likely to be due to Oxford Economics applying the tax before dilution. Secondly, Oxford Economics used estimates of how consumers respond to price changes of diet and non-diet SSBs taken from our 2013 study estimating the effect on obesity of a 20% UK SSB tax.<sup>27</sup> In our current study we have calculated estimates separately for high-, mid-, and low-sugar drinks.

Our 2013 study estimated that a 20% price rise would lead to a 1.3% fall in the number of obese adults in the UK, compared to our scenario 3 estimate of 0.5% (following an average price rise of 15%).<sup>27</sup> Our 2013 study did not estimate price elasticities separately for high- and mid-sugar drinks, did not quantify the effect of the tax on children, and did not adjust for BSDA sales figures. It also used an energy balance equation rather than quantifying the direct effect of SSBs on body weight, which estimates larger effects on body weight (see supplementary material). Conversely in this paper, we used an estimate of the direct relationship between body weight and SSBs, which may more accurately represent substitution and other compensatory mechanisms secondary to changes in sugar (and energy) consumed from SSBs. The present analysis confirms our 2013 findings of greater relative reductions in obesity among younger adults compared with older adults. This is explained by teenagers and young adults drinking more SSBs than older adults (supplementary table 2) and trial data suggesting that SSBs have a greater effect on weight gain in children than adults.<sup>21-24</sup>

Considering reformulation, Ma et al. estimated that a 40% reduction in sugar across all SSBs in the UK would lead to 800,000 fewer individuals with obesity.<sup>30</sup> This is substantially more than our estimate in scenario 1 (144,400), which assumed a 30% reduction in sugar content of high-sugar drinks and 15% reduction of mid-sugar drinks. This is in part due to Ma et al. estimating that the average reduction in energy consumed would be approximately twice our estimate, and then using an energy balance equation to estimate the effect of energy intake on weight. Of note, estimates for the reduction in diabetes were similar between our current study and Ma et al.

More generally, we recognise that there are uncertainties around all parameters in the model that will affect the comparison of results with other simulation studies.

### Interpretation and implications

The UK soft drinks industry levy has the potential to lead to important improvements in population health, particularly among children. Policymakers should engage with stakeholders to encourage responses to the levy that will maximise the potential health benefits of the new policy. Our results demonstrate the need for ongoing monitoring of the implementation strategies adopted by industry alongside modelling to estimate the long-term health consequences of their actions.

Our results suggest that of the scenarios modelled, reformulation would lead to the largest health benefits. Price rises and changes to product market share may also lead to important improvements in health. However, effects would be attenuated if manufacturers choose to pass the tax on to purchasers across all drinks, or other products, in their portfolio rather than just those targeted by the levy. Moreover, negative health effects may arise if the increase in market share of mid-sugar drinks comes at the expense of low-sugar drinks. Conversely, further health benefits may be realised if manufacturers pass-on more than 50% of the levy to consumers or choose to reformulate to a greater extent than that modelled (as recently announced by Tesco and Lucozade Ribena Suntory).<sup>31,32</sup>

### Conclusion

The UK soft drink industry levy could have valuable population health benefits but the magnitude of its health impact will depend on how industry responds. The detail of the levy is yet to be decided but we show important health benefits that could be maximised by significant product reformulation with further health gains arising through raising the price of high- and mid-sugar drinks and increasing the market share of low-sugar products.

### **Declaration of interests**

RT and AK have previously done work on SSB taxes that was funded by the Union of European Soft Drinks Associations (UNESDA). MR is chair of Sustain and the Children's Food Campaign which have campaigned for sugar drink taxes in the UK. AB and OTM are members of the Faculty of Public Health which has a position statement supporting sugary drink taxes. OTM is a member of the UK Health Forum which has also supported a UK sugar drinks tax. SAJ was the independent Chair of the Department of Health Public Health Responsibility Deal Food Network from 2010 to 2015.

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**Contributions of authors**

ADMB, OTM, MR, SAJ, and PS contributed to the conception of the work; all authors contributed to the design of the scenarios analysed; ADMB, OTM, AK, RT, TB, and PS designed the methodology; ADMB, OTM, AK, AE, and PS identified data and ran the analyses; all authors contributed to the interpretation of the results; ADMB drafted the first draft of the manuscript; all authors commented on the manuscript and made critical revisions; all authors approve the final version of the manuscript; all authors are accountable for all aspects of the work.

## References

- 1 Scientific Advisory Committee on Nutrition. Carbohydrates and health. London, 2015  
[https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/445503/SACN\\_Carbohydrates\\_and\\_Health.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/445503/SACN_Carbohydrates_and_Health.pdf).
- 2 Public Health England. Sugar reduction: the evidence for action. London, 2015  
[https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/470179/Sugar\\_reduction\\_The\\_evidence\\_for\\_action.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470179/Sugar_reduction_The_evidence_for_action.pdf).
- 3 House of Commons Health Committee. Childhood obesity - brave and bold actions. London, 2015.
- 4 HM Treasury. Budget 2016. London, 2016.
- 5 Cornelsen L, Carreido A. Health related taxes on foods and beverages. London, 2015.
- 6 Briggs A. Sugar tax could sweeten a market failure. *Nature* 2016; **531**: 551.
- 7 www.gov.uk. Micro-entities, small and dormant companies. 2016.  
<https://www.gov.uk/annual-accounts/microentities-small-and-dormant-companies> (accessed Aug 16, 2016).
- 8 Companies House. Search the register. 2016.  
<https://beta.companieshouse.gov.uk/> (accessed Aug 16, 2016).
- 9 British Soft Drinks Association. Leading the Way. Annual report 2016. London, 2016.
- 10 Coca-Cola. Tackling Obesity: Choice and Information. 2015.  
<http://www.coca-cola.co.uk/stories/health/choice-and-information/tackling-obesity-choice-and-information>.
- 11 Office for Budget Responsibility. Economic and fiscal outlook. London, 2016.
- 12 Falbe J, Rojas N, Grummon AH, Madsen KA. Higher Retail Prices of Sugar-Sweetened Beverages 3 Months After Implementation of an Excise Tax in Berkeley, California. *Am J Public Health* 2015; **105**: 2194–201.
- 13 Berardi N, Sevestere P, Tepaut M, Vigneron A. The impact of a 'soda tax' on prices: evidence from French Micro data. 2012 [http://www.banque-france.fr/uploads/tx\\_bdfdocumentstravail/DT-415\\_01.pdf](http://www.banque-france.fr/uploads/tx_bdfdocumentstravail/DT-415_01.pdf).
- 14 Colchero MA, Salgado JC, Unar-Munguía M, Molina M, Ng S, Rivera-Dommarco JA. Changes in Prices After an Excise Tax to Sweetened Sugar Beverages Was Implemented in Mexico: Evidence from Urban Areas. *PLoS One* 2015; **10**: e0144408.
- 15 World Cancer Research Fund International. Use economic tools. 2016.  
[www.wcrf.org/int/policy/nourishing-framework/use-economic-tools](http://www.wcrf.org/int/policy/nourishing-framework/use-economic-tools) (accessed Aug 11, 2016).
- 16 Mytton O, Clarke D, Rayner M. Taxing unhealthy food and drinks to improve health. *Br Med J* 2012; **344**: e2931.
- 17 HM Revenue & Customs, HM Treasury. Soft Drinks Industry Levy Consultation document. London, 2016.
- 18 Coca-Cola. Coca-Cola Life™ Launch Backed With Massive Marketing Push. 2014. <http://www.coca-cola.co.uk/newsroom/press-releases/coca-cola-life-marketing-campaign>.
- 19 Newton JN, Briggs ADM, Murray CJL, *et al.* Changes in health in England,

- with analysis by English regions and areas of deprivation, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015; **386**: 2257–74.
- 20 Imamura F, O'Connor L, Ye Z, *et al*. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: systematic review, meta-analysis, and estimation of population attributable fraction. *BMJ* 2015; **351**: h3576.
- 21 de Ruyter JC, Olthof MR, Seidell JC, Katan MB. A trial of sugar-free or sugar-sweetened beverages and body weight in children. *N Engl J Med* 2012; **367**: 1397–406.
- 22 Maersk M, Belza A, Stødkilde-Jørgensen H, *et al*. Sucrose-sweetened beverages increase fat storage in the liver, muscle, and visceral fat depot: a 6-mo randomized intervention study. *Am J Clin Nutr* 2012; **95**: 283–9.
- 23 Tate DF, Turner-McGrievy G, Lyons E, *et al*. Replacing caloric beverages with water or diet beverages for weight loss in adults: main results of the Choose Healthy Options Consciously Everyday (CHOICE) randomized clinical trial. *Am J Clin Nutr* 2012; **95**: 555–63.
- 24 Ebbeling CB, Feldman HA, Chomitz VR, *et al*. A randomized trial of sugar-sweetened beverages and adolescent body weight. *N Engl J Med* 2012; **367**: 1407–16.
- 25 Bernabé E, Vehkalahti MM, Sheiham A, Aromaa A, Suominen AL. Sugar-sweetened beverages and dental caries in adults: A 4-year prospective study. *J Dent* 2014; **42**: 952–8.
- 26 Office for National Statistics. Population estimates for UK, England and Wales, Scotland and Northern Ireland, revised: mid-2012, mid-2013 and mid-2014. London, 2016.
- 27 Briggs ADM, Mytton OT, Kehlbacher A, Tiffin R, Rayner M, Scarborough P. Overall and income specific effect on prevalence of overweight and obesity of 20% sugar sweetened drink tax in UK: econometric and comparative risk assessment modelling study. *BMJ* 2013; **347**: f6189.
- 28 Mytton OT, Eyles H, Ogilvie D. Evaluating the Health Impacts of Food and Beverage Taxes. *Curr Obes Rep* 2014; **3**: 432–9.
- 29 Oxford Economics. The economic impact of the soft drinks levy. Oxford, 2016  
[http://www.britishsoftdrinks.com/write/MediaUploads/Publications/The\\_Economic\\_Impact\\_of\\_the\\_Soft\\_Drinks\\_Levy.pdf](http://www.britishsoftdrinks.com/write/MediaUploads/Publications/The_Economic_Impact_of_the_Soft_Drinks_Levy.pdf).
- 30 Ma Y, He FJ, Yin Y, Hashem KM, MacGregor GA. Gradual reduction of sugar in soft drinks without substitution as a strategy to reduce overweight, obesity, and type 2 diabetes: a modelling study. *Lancet Diabetes Endocrinol* 2016; **4**: 105–14.
- 31 Tesco PLC. Tesco reduces sugar content in all own brand soft drinks. 2016. <https://www.tescopl.com/news/news-releases/2016/tesco-reduces-sugar-content-in-all-own-brand-soft-drinks/> (accessed Nov 14, 2016).
- 32 Lucozade Ribena Suntory. Our responsibilities. 2016. <https://www.lrsuntory.com/our-responsibilities/> (accessed Nov 14, 2016).
- 33 Bernabé E, Vehkalahti MM, Sheiham A, Lundqvist A, Suominen AL. The Shape of the Dose-Response Relationship between Sugars and Caries in Adults. *J Dent Res* 2016; **95**: 167–72.





**Table 1.** Simulated scenarios

Category of response	Better case for sugar reduction	Worse case for sugar reduction
Reformulation	<i>Scenario (1):</i> High-sugar drinks reduce sugar content by 30%, mid-sugar drinks by 15%	<i>(2):</i> Mid- and high-sugar drinks both reduce sugar content by 5%
Price change	<i>(3):</i> Increase in price of high- and mid-sugar drinks such that fifty per cent of levy is passed on to consumers with a maximum 20% price rise.	<i>(4):</i> Increase in price of all packaged drinks <sup>1</sup> by the same percentage such that 50% of the tax is borne by customers
Change to SSB market share	<i>(5):</i> Breakdown in sales of soft drinks shifts from 58%/6%/36% to 64%/12%/24% for low-, mid-, and high-sugar drinks respectively	<i>(6):</i> Breakdown in sales of soft drinks shifts to 55%/12%/33% for low-, mid-, and high-sugar drinks respectively

Low-sugar drinks: <5g sugar/100ml, medium-sugar drinks: 5-8g sugar/100ml, high-sugar drinks: >8g sugar/100ml. SSB, sugar sweetened beverage.

<sup>1</sup>including low or zero sugar drinks, bottled water, fruit juice, sweetened milk drinks, not including tea, coffee, unsweetened milk, alcohol

**Table 2.** Baseline price and change in price for the taxed drinks categories with different rates of tax pass-through and as modelled in scenario 3 (percentages in parentheses indicated percentage change in baseline price)

Drink category	Baseline price (pence per litre; p/l)	Price with 100% pass through (p/l)	Price with 50% pass through (p/l)	Scenario 3 modelled price (p/l)
Concentrated high-sugar	32.1	56.1 (+75%)	44.1 (+37%)	38.6 (+20%)
Concentrated mid-sugar	40.1	58.1 (+45%)	49.1 (+22%)	48.1 (+20%)
Regular high-sugar	77.6	101.6 (+31%)	89.6 (+15%)	89.6 (+15%)
Regular mid-sugar	99.0	117.0 (+18%)	108.0 (+9%)	108.0 (+9%)

**Table 3.** Model input parameters and data sources (95% confidence interval)

Model outcome	Parameter	Data source
Body weight	Increase in weight of 0.09kg (-0.11 to 0.29) in adults and 0.45kg (0.24 to 0.66) in children per additional 100ml SSB consumed per day.	Meta-analysis of randomised controlled trials of SSB consumption and body weight. Two studies identified and combined for adults <sup>22,23</sup> and two

		for children. <sup>21,24</sup>
Diabetes	Relative risk of incident diabetes of 1.42 (1.19 to 1.69) per additional 250ml serving per day for adults and children	Imamura et al. <sup>20</sup>
Dental caries	Increase in number of decayed, missing, or filled teeth of 0.008 (0.002 to 0.014) per person for every additional 10g of sugar consumed per day.	Bernabé et al. <sup>33</sup>

SSB, sugar sweetened beverage

**Table 4.** Reduction in equivalised\* volume of sugar sweetened beverage consumed with each scenario [95% uncertainty interval]

Age and sex group	Reduction in mean equivalised volume of sugary drink consumed (ml per person per day)					
	Reformulation		Price change		Change in market share	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Boys, 4-10	61.7	11.2	34.5	12.4	38.6	-3.8
Boys, 11-18	137.6	25.0	77.0	27.7	86.0	-8.6
Men, 19-64	71.0	12.9	39.7	14.3	44.4	-4.4
Men, 65+	24.0	4.4	13.4	4.8	15.0	-1.5
Girls, 4-10	51.9	9.5	29.1	10.4	32.5	-3.2
Girls, 11-18	93.2	17.0	52.1	18.7	58.3	-5.8
Women, 19-64	49.7	9.0	27.8	10.0	31.1	-3.1
Women, 65+	23.5	4.3	13.2	4.7	14.7	-1.5
Average	58.5 [54.5 to 62.6]	10.7 [10.0 to 11.4]	32.7 [30.3 to 35.3]	11.8 [10.9 to 12.7]	36.6 [34.9 to 38.3]	-3.6 [-3.8 to -3.4]

\*where equivalisation results in the same sugar intake for each equivalised unit of sugar sweetened beverage.

**Table 5.** Reduction in the number of obese individuals following each scenario (% reduction in number obese) [95% uncertainty interval]

Age and sex group	Reduction in number of obese individuals (% of obese individuals)					
	Reformulation		Price change		Change in market share	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Boys, 4-10	29227 (10.4%)	5524 (2.0%)	16689 (6.0%)	6095 (2.2%)	18592(6.6%)	-1911 (-0.7%)
Boys, 11-18	31793 (6.0%)	5907 (1.1%)	17987 (3.4%)	6521 (1.2%)	20066 (3.8%)	-2033 (-0.4%)
Men, 19-64	25582 (0.5%)	4663 (0.1%)	14324 (0.3%)	5149 (0.1%)	16005(0.3%)	-1596 (0.0%)
Men, 65+	3002 (0.2%)	547 (0.0%)	1680 (0.1%)	603 (0.0%)	1877 (0.1%)	-187 (0.0%)
Girls, 4-10	16455 (8.9%)	3097 (1.7%)	9374 (5.0%)	3418 (1.8%)	10447 (5.6%)	-1070 (-0.6%)
Girls, 11-18	17581 (4.8%)	3257 (0.9%)	9930 (2.7%)	3595 (1.0%)	11081 (3.0%)	-1120 (-0.3%)
Women, 19-64	17328 (0.3%)	3157 (0.1%)	9700(0.2%)	3487 (0.1%)	10839 (0.2%)	-1081 (0.0%)

Women, 65+	3415 (0.2%)	622 (0.0%)	1911 (0.1%)	697 (0.0%)	2135 (0.1%)	-213 (0.0%)
Total	144383 (0.9%) [5102 to 306743]	26774 (0.2%) [1276 to 63806]	81594 (0.5%) [3588 to 182669]	29555 (0.2%) [1379 to 69804]	91042 (0.6%) [4289 to 204903]	-9211 (-0.1%) [-22776 to -485]

**Table 6.** Reduction in the number of cases of diabetes per year following each scenario (reduction in incidence per 100,000 person-years) [95% uncertainty interval]

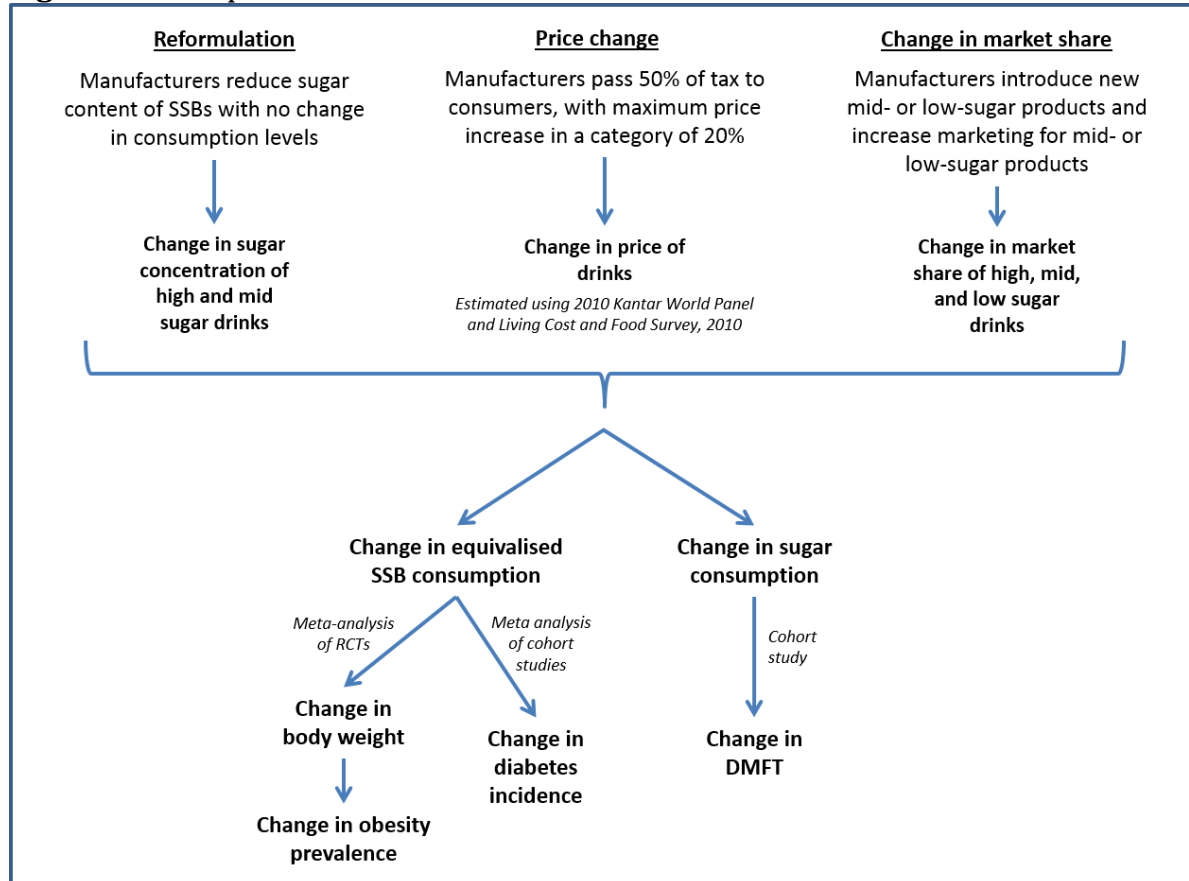
Age and sex group	Reduction in number of incident cases of diabetes per year (reduction in incidence per 100,000 person-years)					
	Reformulation		Price		Change in market share	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Boys, 4-10	71 (2.6)	13 (0.5)	40 (1.5)	15 (0.5)	45 (1.6)	-5 (-0.2)
Boys, 11-18	224 (7.5)	44 (1.5)	131 (4.3)	49 (1.6)	145 (4.8)	-15 (-0.5)
Men, 19-64	8364 (43.5)	1585 (8.2)	4783 (24.9)	1749 (9.1)	5327 (27.6)	-549 (-2.8)
Men, 65+	2539 (49.4)	469 (9.1)	1431 (27.8)	517 (10.1)	1598 (31.1)	-160 (-3.1)
Girls, 4-10	52 (2.0)	10 (0.4)	29 (1.1)	11 (0.4)	33 (1.2)	-3 (-0.1)
Girls, 11-18	223 (7.8)	43 (1.5)	128 (4.5)	47 (1.7)	143 (4.9)	-15 (-0.5)
Women, 19-64	5192 (26.7)	972 (5.0)	2950 (15.1)	1073 (5.5)	3289 (16.9)	-336 (-1.7)
Women, 65+	2429 (38.8)	448 (7.2)	1369 (21.8)	495 (7.9)	1528 (24.4)	-1549 (-2.5)
Total	19094 (31.1) [6920 to 32678]	3584 (5.8) [1289 to 6466]	10861 (17.7) [3899 to 18964]	3955 (6.4) [1420 to 7085]	1528 (19.7) [4414 to 21785]	-1238 (-2.0) [-2359 to -455]

**Table 7.** Reduction in number of decayed, missing, or filled teeth (DMFT) per year following each scenario (reduction in number of DMFT per 1,000 person-years) [95% uncertainty interval]

Age and sex group	Reduction in number of DMFT per year (reduction in number of DMFT per 1,000 person-years)					
	Reformulation		Price		Change in market share	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Boys, 4-10	12735 (4.6)	2318 (0.8)	7022 (2.6)	3376 (1.2)	8096 (2.9)	-741 (-0.3)

Boys, 11-18	31040 (10.3)	5650 (1.9)	17268 (5.7)	7015 (2.3)	19967 (6.6)	-1922 (-0.6)
Men, 19-64	102477 (5.3)	18654 (1.0)	56909 (3.0)	23776 (1.2)	65792 (3.4)	-6282 (-0.3)
Men, 65+	9239 (1.8)	1682 (0.3)	5081 (1.0)	2554 (0.5)	5924 (1.2)	-563 (-0.1)
Girls, 4-10	10225 (3.9)	1861 (0.7)	5645 (2.2)	2640 (1.0)	6496 (2.5)	-593 (-0.2)
Girls, 11-18	19977 (7.0)	3637 (1.2)	11099 (3.9)	4610 (1.6)	12808 (4.5)	-1216 (-0.4)
Women, 19-64	72625 (3.7)	13220 (0.7)	40270 (2.1)	17240 (0.9)	46516 (2.4)	-4397 (-0.2)
Women, 65+	11056 (1.8)	2013 (0.3)	6086 (1.0)	3029 (0.5)	7119 (1.1)	-688 (-0.1)
Total	269375 (4.4) [82211 to 470928]	49036 (0.8) [14929 to 85630]	149378 (2.4) [45231 to 262013]	64240 (1.1) [19643 to 112371]	172718 (2.8) [47919 to 294499]	-16401 (-0.3) [- 28037 to -4604]

**Figure 1. Conceptual model**



DMFT, decayed missing or filled teeth; SSB, sugar sweetened beverage; RCT, randomised controlled trial

## A health impact assessment of the UK soft drinks industry levy: a comparative risk assessment modelling study

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### Supplementary material: Description of the modelling process

#### Modelling price change

The effect of a price change on purchases of SSBs and on complementing and substituting drinks was modelled using own- and cross-price elasticities. Own-price elasticities describe how purchases of a good change due to a price increase, and cross-price elasticities describe the effect of the price change on other goods. For example, if bread has an own price elasticity of -1.0 and a cross price elasticity with butter of -0.2 and of 0.1 with cereal, a 10% increase in the price of bread will result in 10% less bread, 2% less butter (butter is a complement) and 1% more cereal (cereal is a substitute) being purchased.

Conditional own- and cross-price elasticities were estimated for 25 food and drink categories; supplementary figure 1 shows these categories and illustrates the demand system hierarchy. Demand systems 1 to 5 were estimated using 2010 Living Costs and Food Survey (LCF) data and using an Almost Ideal Demand System (AIDS)<sup>1,2</sup> with infrequency of purchase<sup>3</sup> which assumes that censoring arises because households consume from stock. Adding up, symmetry, homogeneity and concavity are imposed in the estimation. Because the covariance matrix is singular we drop one of the share equations, obtaining estimates that are invariant to which equation is dropped.<sup>4</sup> Food categories are aggregated using the EKS quantity index<sup>5,6</sup> which is a multi-lateral version of the superlative Fisher Ideal index, and is used to compute the implicit price index. A superlative index offers some mitigation towards the concerns over the potential endogeneity of prices.<sup>7</sup> The LCF data are a cross-section of 5,236 households which are chosen using multi-stage stratified random sampling. Data on 270 categories of food expenditures and quantities purchased for consumption at home are collected from each household over a two week period using food diaries and these periods are distributed across the year for different households. For the estimation of the elasticities of concentrated and regular mid- and high- sugar drinks (demand systems 6 and 7), we used selected product codes from the 2010 Kantar World Panel UK data, a panel of 30,000 households demographically representative of Great Britain. These data are collected over 52 weeks and we therefore used an AIDS with double hurdle model that assumes censoring arises because households prefer to not purchase a given drink. Estimation was carried out using Markov chain Monte Carlo methods where the Gibbs sampler draws 10,000 samples sequentially from the conditional posterior distributions after a burn-in of 2,000. The conditional elasticities of the seven demand systems were combined to obtain unconditional elasticities which allow for expenditure to vary within all food and drinks categories.<sup>8</sup> The own and cross-price elasticity estimates was used to estimate the change in consumption of each drink category by multiplying the elasticity matrix with the price changes modelled. The percentage change in price is estimated by applying the proposed levy rates to expenditure of each taxed drink category in LCF, 2014. See supplementary table 1 for price elasticity matrix.

We assumed that the price elasticities apply uniformly across the population whereas in reality individuals may respond differently to the price rise based on their age, baseline consumption, and socio-economic group.<sup>9,10</sup> Furthermore, price elasticities are estimated using data containing price variations which are smaller than the price increases modelled. Therefore greater price increases have greater uncertainty surrounding the estimated responses of households.

#### Modelling health outcomes

We estimate the effect of changing SSB and sugar consumption on obesity prevalence in the UK, and on annual diabetes incidence and incidence of decayed, missing, and filled teeth (DMFT).

Baseline drink consumption was taken from LCF, 2014.<sup>11</sup> Drinks were categorised into milk, water, fruit juice, soft drinks regular low calorie, soft drinks regular not low calorie, soft drinks concentrated low calorie, soft drinks concentrated not low calorie, tea and coffee, other beverages, beer, wine, and other alcohol. Regular soft drinks include carbonates, energy drinks, and fruit juice with added sugar.

The LCF divides SSBs into *soft drinks concentrated, not low calorie*, and *soft drinks regular, not low calorie*. In order to estimate the effect of the levy on mid-sugar drinks, these categories were split into high-sugar and mid-



sugar drink categories using the following method. The volume purchased and sugar concentration of each of the *not low-calorie soft drink* categories is reported by the LCF. The volume purchased for each of the mid-sugar categories was estimated by assuming that the concentration of sugar in drinks in the high-sugar category is 10g sugar/100ml and in the mid-sugar category is 6.5g sugar/100ml, which is supported by an analysis of Kantar World Panel Data.<sup>12</sup> Using these data, the ratio of high- to mid-sugar drink volume purchased for each of regular and concentrated drinks was calculated and applied to the volume of *not low-calorie soft drinks* purchased thereby estimating the baseline volume of each of mid-sugar drinks and high-sugar drinks.

The volume purchased within some drinks categories in the LCF is considerably lower than industry reported sales data from the British Soft Drinks Association (BSDA).<sup>13</sup> Therefore, as with previous studies,<sup>14</sup> purchases of fruit juice, water, regular soft drinks and concentrated soft drinks were initially adjusted upwards based on 2015 industry reported total volume sales.<sup>13</sup> Volume consumed was assumed to be the same as that purchased minus wastage estimated for carbonated soft drinks, bottled water, fruit juice, and concentrated soft drinks by the Waste and Resources Action Programme (WRAP), a survey of approximately 1,800 households in the UK with detailed measurement of weight and types of and drink waste.<sup>15</sup>

As the LCF reports at the household level, age and sex specific estimates of drinks consumed were derived by dividing the total volume of SSBs purchased per person in the LCF by the relative consumption of each drink category by age and sex reported by The National Diet and Nutrition Survey rolling programme, 2008/09-2011/12 (NDNS).<sup>16</sup> The NDNS is a four day diary of food consumption for both children and adults and the 2008/09 – 2011/12 data are based on data collected for over 6,000 participants.

We have assumed there is no excess health risk associated with artificially sweetened beverages (ASBs). While we note that some studies have reported that ASBs are associated with obesity and type 2 diabetes in prospective studies many authors suggest these associations may be due to reverse causation and there is no strong plausible biological explanation for an aetiological association.<sup>17,18</sup> However we note that ASBs are linked to enamel erosion, and the harm associated with this has not been modelled.<sup>19</sup>

Data from BSDA 2015 suggest that the market share of low- middle-, and high-sugar drinks is 58%, 6%, and 36% respectively, compared to our estimates from LCF 2014 of 50%, 17% and 33%. Therefore for scenarios 5 and 6, baseline volumes of concentrated and non-concentrated soft drinks consumed were adjusted to fit BSDA reported 2015 market shares. The new market shares described in table 1 of the manuscript were then compared to this new baseline. The concentration of sugar in each category and their prices were assumed to remain the same.

Finally, the model is static meaning that we do not estimate the effect of scenarios on disease over time and have not incorporated current disease or risk factor trends. Results therefore relate to 2014 disease incidence and prevalence rates.

#### *Modelling obesity*

The relationship between SSB consumption and body weight was derived following a random effects meta-regression of randomised controlled trials describing the change in body weight following change in volume of SSBs consumed. No published meta-regressions exist and therefore a search of the literature was completed in Medline and four trials were identified and combined, two in children<sup>20,21</sup> and two in adults.<sup>22,23</sup> Based on these data, we assumed a linear relationship between body weight and SSB consumption; for every additional 100ml of SSB consumed per day, we assumed 0.09kg (-0.11 to 0.29) of additional weight in adults and 0.45kg (0.24 to 0.66) in children. Weight increases were then converted into change in body mass index (BMI) using age and sex specific measures of height and weight from the Health Survey for England (HSfE, assumed to apply to the UK population).<sup>24</sup> Overweight and obesity in children was defined as being above the 91<sup>st</sup> and 98<sup>th</sup> centile respectively for weight based on sex specific Royal College of Paediatrics and Child Health growth charts.<sup>25</sup> For both of the childhood studies included in the meta-analysis, body weight was recorded one year after the introduction of the intervention. Overweight and obesity in adults was defined as a body mass index (BMI) of 25-30kg/m<sup>2</sup> and >30kg/m<sup>2</sup> respectively. For the adult studies included in the meta-analyses, body weight was recorded six months after introduction of the intervention.

We assumed that the effect of changing SSB consumption on diabetes and dental caries would be the same in adults and children whereas we assumed different effect sizes among adults when modelling obesity. The differences in effect size reported by trials estimating the effect of SSB consumption on weight gain may in part be due to the adult trials reporting after six months whereas the trials in children reported at 1 year post intervention.<sup>20-23</sup> The adult trials used may under-report the potential total weight loss, meaning our obesity

results are conservative. Results estimate the number of obese individuals in 2014 had the population been consuming SSBs as modelled in each scenario rather than current consumption. We repeated the obesity estimates using Christiansen and Garby's energy balance equation, which estimates significantly greater falls in obesity prevalence (as used by Briggs et al., see supplementary table 3).<sup>26,27</sup> Hall and Jordan's dynamic model estimates a two-fold greater loss of weight than we estimate after six months (but with further weight loss to be expected if the calorie change is maintained), again suggesting that we may be conservative in our estimates.<sup>28</sup>

#### *Modelling diabetes*

We assumed a relative risk of 1.42 (95% confidence interval: 1.19 to 1.69) per 250ml SSB serving for diabetes incidence, based on the results of a random effects meta-analysis of 17 prospective cohort studies with median follow up ranging from 3.4 years to 21.1 years.<sup>18</sup> This estimate was unadjusted for obesity as obesity is on the causal pathway between SSB consumption and type 2 diabetes. We assumed no relationship between artificially sweetened beverages and type 2 diabetes. It was assumed that the same relative risk applies equally to both adults and children. Baseline incidence of diabetes by age and sex was taken from Holden et al.<sup>29</sup>

#### *Modelling dental caries*

We were unable to identify data to estimate the dose-response of SSB consumption on dental caries. We therefore assumed that for every additional 10g sugar consumed per day there would be 0.008 (0.002 to 0.014) extra DMFT per person in a given year. This estimate was from an 11 year-long longitudinal study of sugar consumption and oral health in Finnish adults controlling for a variety of confounders including socio-economic status and tooth brushing habits, the time for DMFT to manifest from a change SSB consumption was not observed.<sup>30</sup> Change in sugar consumption was estimated across all drinks consumed and not only change in SSB consumption. We assumed that there was no substitution from drinks to food when estimating the change in sugar consumption.

#### *Uncertainty analysis*

We conducted a Monte Carlo analysis with 5000 iterations to quantify the uncertainty in the modelled results due to uncertainty around the model parameters. In each iteration, the model parameters were drawn randomly from a specified distribution and the six scenarios were modelled using this random set of model parameters. Results for the iteration were saved, and uncertainty intervals for the results were based on the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles of the results across the 5000 iterations. Uncertainty around the following parameters were included in the analysis: baseline consumption of drinks categories estimated by the LCF; volume of sales of drinks categories estimated by the BSDA; percentage of waste of food categories estimated by WRAP; sugar drink consumption by age and sex estimated by the NDNS; diabetes incidence by age and sex estimated by Holden et al.;<sup>29</sup> height and weight by age and sex estimated by the HSfE; own price elasticities for the soft drinks categories; and the parameters associating changes in sugar or sugar drink consumption and DMFT, diabetes incidence (drawn from the literature), and obesity prevalence (bespoke meta-analyses of two randomised controlled trials for both children<sup>20,21</sup> and adults).<sup>22,23</sup> Due to heterogeneity of study design we conducted random effects meta-analyses, therefore the parameters are averages of results reported in the literature, weighted by the inverse of the standard error. For most of these parameters, the prior distributions were estimated using data from the source material. This was not possible for some of the parameters, where there are no published estimates of their uncertainty. In these cases, we categorised our confidence in the data source as either 'confident' or 'moderately confident'. For data sources categorised as 'confident' (data from LCF, BSDA, Holden et al.) we used normal distributions with the published estimate as the mean and set the standard deviation as 5% of the mean. For those categorised as 'moderately confident' (data from WRAP), we set the standard deviation as 10% of the mean.

Due to unknown covariance between own-price and cross-price elasticities, we were unable to conduct a full probabilistic uncertainty analysis of the uncertainty due to the price elasticity matrix. The analysis conducted here is likely to capture most of this uncertainty (since the own-price elasticities drive most of the price effects from the price elasticity matrix) but some uncertainty associated with price change will be underestimated.

#### **References**

- 1 Deaton AS, Muellbauer J, Deaton A, Muellbauer J. An Almost Ideal Demand System. *Am Econ Rev* 1980; **70**: 312–26.
- 2 Department for the Environment Food and Rural Affairs. Family Food 2010. London, 2011.
- 3 Tiffin R, Arnoult M. The demand for a healthy diet: estimating the almost ideal demand system with infrequency of purchase. *Eur Rev Agric Econ* 2010; **37**: 501–21.
- 4 Barten AP. Maximum likelihood estimation of a complete system of demand equations. *Eur Econ Rev* 1969; **1**: 7–73.

- 5 Elteto O, Koves P. On a problem of index number computation relating to international comparison. *Statisztikai Szle* 1964; **42**: 507–18.
- 6 Szulc B. Indices for multiregional comparisons. *Prz Stat* 1964; **3**: 239–54.
- 7 Diewert WE. Exact and superlative index numbers. *J Econom* 1976; **4**: 115–45.
- 8 Edgerton DL. Weak Separability and the Estimation of Elasticities in Multistage Demand Systems. *Am J Agric Econ* 1997; **79**: 62–79.
- 9 Tiffin R, Kehlbacher A, Salois M. The Effects of A Soft Drink Tax in the UK. *Health Econ* 2015; **24**: 583–600.
- 10 Finkelstein EA, Zhen C, Nonnemaker J, Todd JE. Impact of targeted beverage taxes on higher- and lower-income households. *Arch Intern Med* 2010; **170**: 2028–34.
- 11 Office for National Statistics. Family Spending: 2015. A report on the Living Costs and Food Survey 2014. London, 2015.
- 12 Oxford Economics. The economic impact of the soft drinks levy. Oxford, 2016  
[http://www.britishsoftdrinks.com/write/MediaUploads/Publications/The\\_Economic\\_Impact\\_of\\_the\\_Soft\\_Drinks\\_Levy.pdf](http://www.britishsoftdrinks.com/write/MediaUploads/Publications/The_Economic_Impact_of_the_Soft_Drinks_Levy.pdf).
- 13 British Soft Drinks Association. Leading the Way. Annual report 2016. London, 2016.
- 14 Ma Y, He FJ, Yin Y, Hashem KM, MacGregor GA. Gradual reduction of sugar in soft drinks without substitution as a strategy to reduce overweight, obesity, and type 2 diabetes: a modelling study. *Lancet Diabetes Endocrinol* 2016; **4**: 105–14.
- 15 Quedest T, Ingle R, Parry A. Household Food and Drink Waste in the United Kingdom 2012. Banbury, 2013.
- 16 Public Health England. National Diet and Nutrition Survey: Results from Years 1 - 4 (combined) of the Rolling Programme (2008/2009 – 2011/12). London, 2014.
- 17 Pereira MA. Sugar-sweetened and artificially-sweetened beverages in relation to obesity risk. *Adv Nutr* 2014; **5**: 797–808.
- 18 Imamura F, O'Connor L, Ye Z, *et al*. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: systematic review, meta-analysis, and estimation of population attributable fraction. *BMJ* 2015; **351**: h3576.
- 19 Nadimi H, Wesamaa H, Janket S-J, Bollu P, Meurman JH. Are sugar-free confections really beneficial for dental health? *Br Dent J* 2011; **211**: E15.
- 20 de Ruyter JC, Olthof MR, Seidell JC, Katan MB. A trial of sugar-free or sugar-sweetened beverages and body weight in children. *N Engl J Med* 2012; **367**: 1397–406.
- 21 Ebbeling CB, Feldman HA, Chomitz VR, *et al*. A randomized trial of sugar-sweetened beverages and adolescent body weight. *N Engl J Med* 2012; **367**: 1407–16.
- 22 Maersk M, Belza A, Stødkilde-Jørgensen H, *et al*. Sucrose-sweetened beverages increase fat storage in the liver, muscle, and visceral fat depot: a 6-mo randomized intervention study. *Am J Clin Nutr* 2012; **95**: 283–9.
- 23 Tate DF, Turner-McGrievy G, Lyons E, *et al*. Replacing caloric beverages with water or diet beverages for weight loss in adults: main results of the Choose Healthy Options Consciously Everyday (CHOICE) randomized clinical trial. *Am J Clin Nutr* 2012; **95**: 555–63.
- 24 Health and Social Care Information Centre. Health Survey for England 2014. London, 2015.
- 25 Royal College of Paediatrics and Child Health. School age charts and resources. 2015.  
<http://www.rcpch.ac.uk/improving-child-health/public-health/uk-who-growth-charts/school-age-2-18-years/school-age-charts-an>.
- 26 Christiansen E, Garby L. Prediction of body weight changes caused by changes in energy balance. *Eur J Clin Invest* 2002; **32**: 826–30.
- 27 Briggs ADM, Mytton OT, Kehlbacher A, Tiffin R, Rayner M, Scarborough P. Overall and income specific effect on prevalence of overweight and obesity of 20% sugar sweetened drink tax in UK: econometric and comparative risk assessment modelling study. *BMJ* 2013; **347**: f6189.
- 28 Hall KD, Jordan PN. Modeling weight-loss maintenance to help prevent body weight regain. *Am J Clin Nutr* 2008; **88**: 1495–503.
- 29 Holden SH, Barnett AH, Peters JR, *et al*. The incidence of type 2 diabetes in the United Kingdom from 1991 to 2010. *Diabetes Obes Metab* 2013; **15**: 844–52.
- 30 Bernabé E, Vehkalanti MM, Sheiham A, Lundqvist A, Suominen AL. The Shape of the Dose-Response Relationship between Sugars and Caries in Adults. *J Dent Res* 2016; **95**: 167–72.

**Supplementary table 1. Price elasticity matrix**

	Dairy & Eggs	Meat & Fish	Fats & Starches	Fruits & Nuts	Veg	Milk	Water	Fruit Juice	SD conc, diet	<i>SD conc, regular</i>	<i>SD conc, mid-range</i>	SD diet	<i>SD regular</i>	<i>SD mid-range</i>	Tea & Coffee	Other beverages	Beer	Wine	Other alcohol
Dairy & Eggs	-0.534	0.000	-0.004	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.003	0.000	-0.003	0.000	0.000	0.002	0.000
Meat & Fish	0.000	-0.633	-0.005	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.003	0.000	-0.003	0.000	-0.002	-0.015	-0.001
Fats & Starches	0.000	-0.003	-0.564	0.000	0.000	-0.005	0.000	0.000	0.000	-0.002	-0.002	-0.002	-0.016	-0.002	-0.016	0.000	0.001	0.010	0.001
Fruits & Nuts	0.000	0.000	0.001	-0.809	0.000	0.002	0.000	0.000	0.000	0.001	0.001	0.001	0.006	0.001	0.006	0.000	-0.003	-0.021	-0.002
Veg	0.000	-0.002	-0.004	0.000	-0.503	-0.003	0.000	0.000	0.000	-0.001	-0.001	-0.001	-0.008	-0.001	-0.008	0.000	-0.001	-0.004	0.000
Milk	0.000	0.000	-0.005	0.000	0.000	-0.971	0.000	0.000	0.000	0.003	0.002	0.002	0.018	0.002	0.017	0.000	0.002	0.017	0.002
Water	0.000	0.000	-0.001	0.000	0.000	0.017	-0.835	0.000	0.000	0.001	0.001	0.001	0.010	0.001	-0.041	0.000	0.001	0.005	0.000
Fruit Juice	0.000	0.000	-0.004	0.000	0.000	0.014	0.000	-0.977	0.000	0.004	0.002	0.004	0.026	0.004	0.024	0.000	0.002	0.013	0.001
SD conc, diet	0.000	0.000	-0.003	0.000	0.000	0.000	0.000	0.000	-0.940	0.103	0.068	0.010	-0.008	-0.001	0.007	0.000	0.001	0.009	0.001
<i>SD conc, regular</i>	0.000	0.000	-0.004	0.000	0.000	0.001	0.000	0.000	0.004	-0.881	-0.023	0.017	0.045	0.006	0.010	0.000	0.002	0.014	0.001
<i>SD conc, mid-range</i>	0.000	0.000	-0.004	0.000	0.000	0.001	0.000	0.000	0.005	-0.049	-0.879	0.018	0.046	0.007	0.011	0.000	0.002	0.015	0.001
SD diet	0.000	0.000	-0.006	0.000	0.000	0.001	0.000	0.000	0.000	-0.003	-0.002	-1.013	0.016	0.002	0.016	0.000	0.003	0.022	0.002
<i>SD regular</i>	0.000	0.000	-0.006	0.000	0.000	0.001	0.000	0.000	-0.001	-0.013	-0.009	0.003	-0.952	0.004	0.015	0.000	0.003	0.020	0.002
<i>SD mid-range</i>	0.000	0.000	-0.006	0.000	0.000	0.001	0.000	0.000	-0.001	-0.013	-0.009	0.003	0.035	-0.976	0.015	0.000	0.003	0.020	0.002
Tea & Coffee	0.000	0.000	-0.005	0.000	0.000	0.010	0.000	0.000	0.000	0.006	0.004	0.006	0.044	0.006	-0.938	-0.002	0.002	0.017	0.002
Other beverages	0.000	0.000	-0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.002	0.001	0.001	0.011	0.001	0.099	-0.680	0.001	0.004	0.000
Beer	0.000	-0.002	0.003	0.000	0.000	0.005	0.000	0.000	0.000	0.002	0.001	0.002	0.015	0.002	0.015	0.000	-1.009	0.015	0.002
Wine	0.000	-0.003	0.005	0.000	0.000	0.007	0.000	0.000	0.000	0.003	0.002	0.003	0.022	0.003	0.021	0.000	0.000	-1.008	-0.001
Other alcohol	0.000	-0.002	0.003	0.000	0.000	0.005	0.000	0.000	0.000	0.002	0.001	0.002	0.015	0.002	0.015	0.000	0.003	0.000	-0.934

SD, soft drink; conc, concentrated

**Supplementary table 2. Baseline SSB consumption from NDNS years 1-4**

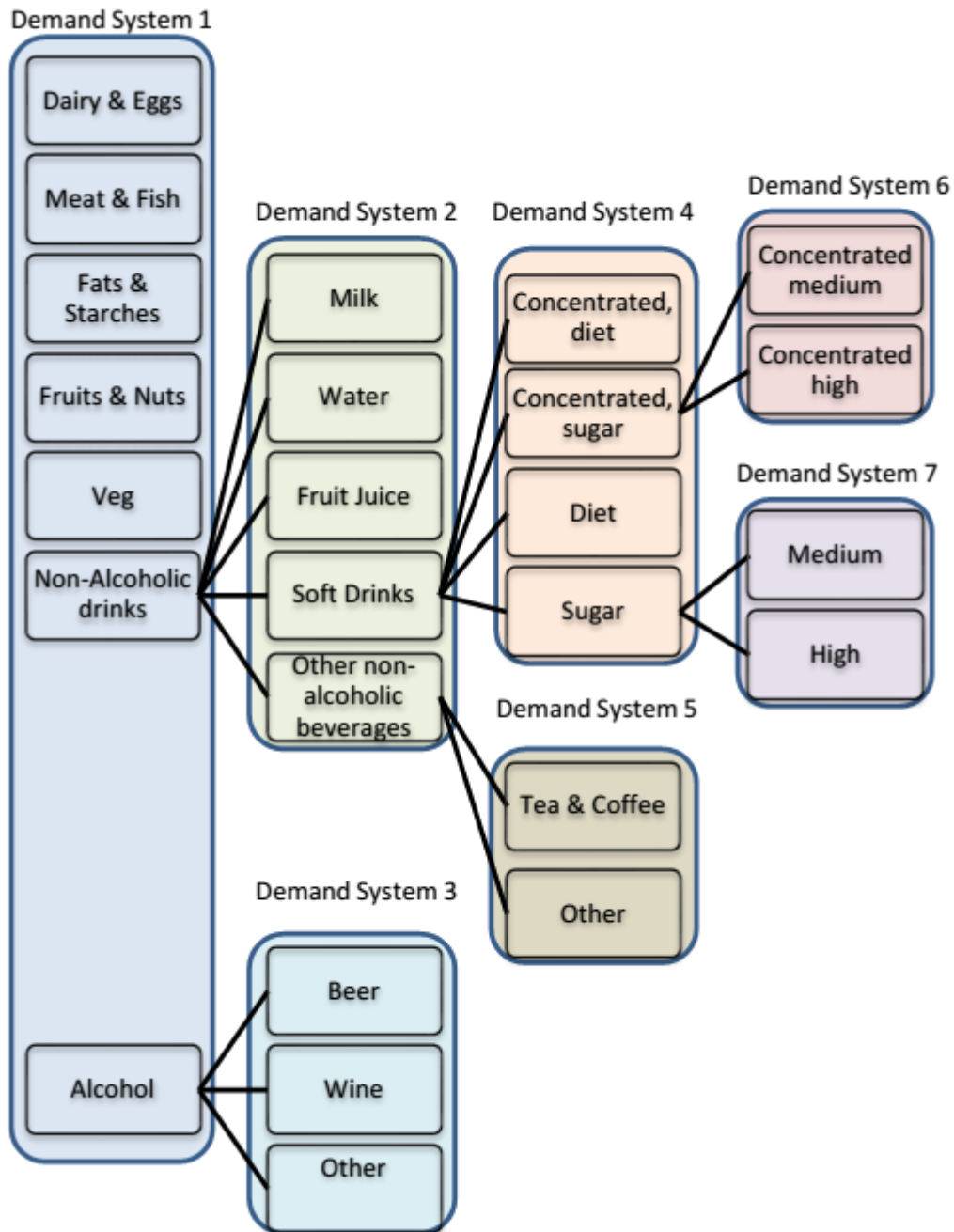
<b>Age and sex group</b>	<b>Sugar drink consumption (ml/d)</b>
Boys, 4-10	139
Boys, 11-18	310
Men, 19-64	160
Men, 65+	54
Girls, 4-10	117
Girls, 11-18	210
Women, 19-64	112
Women, 65+	53

SSB, sugar sweetened beverage; NDNS, National Diet and Nutrition Survey

**Supplementary table 3. Change in obesity prevalence using an energy balance equation**

<b>Scenario</b>	<b>Change in number of obese individuals</b>
1: Reformulation best case	908773 (502697 to 1203852)
2: Reformulation worst case	168549 (96762 to 229847)
3: Price change best case	484621 (272800 to 651200)
4: Price change worst case	206642 (112800 to 282900)
5: Market share best case	592034 (324255 to 791264)
6: Market share worst case	-59925 (-33520 to -83278)

Supplementary figure 1. Demand system hierarchy for economic modelling



## **Title**

A health impact assessment of the UK soft drinks industry levy: a comparative risk assessment modelling study

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## **Abstract**

### *Background*

In March, 2016, the UK government proposed a tiered levy on sugar-sweetened beverages (SSBs; high, moderate, and no tax for drinks with >8g, 5g to 8g, and <5g sugar per 100ml). We estimate the effect of possible industry responses to the levy on obesity, diabetes, and dental caries.

### *Methods*

We modelled three possible industry responses: (1) reformulation to reduce sugar concentration, (2) increasing product price, and (3) changing the market share of high-, mid-, and low-sugar drinks. For each response, we defined a better and worse case health scenario. We developed a comparative risk assessment model to estimate the UK health impact of each scenario.

### *Findings*

The best modelled scenario for health is SSB reformulation, resulting in 144,000 (95% uncertainty interval: 5,100 to 306,700) fewer adults and children with obesity [in the UK](#), 19,000 (6,900 to 32,700) fewer incident cases of diabetes per year, and 269,000 (82,200 to 470,900) fewer decayed, missing, or filled teeth annually. Increasing the price of SSBs and changes to market share [to increase the proportion of low-sugar drinks sold](#) would also result in population health benefits, but to a lesser extent. The greatest benefit for obesity and oral health would be among individuals under 18 years, with people over 65 years experiencing the largest absolute decreases in diabetes incidence.

### *Interpretation*

The health impact of the soft drink levy is dependent on its implementation by industry. There is uncertainty as to how industry will react and in the estimation of health outcomes. Health gains could be maximised by significant product reformulation with additional benefits possible if the levy is passed onto purchasers through raising the price of high- and mid-sugar drinks, and through activities to increase the market share of low-sugar products.

### *Funding*

None



## Research in context

### *Evidence before this study*

The UK government announced a soft drinks industry levy in March 2016. Multiple observational and modelling studies have analysed the effect of soft drink taxes in other international settings, however the UK ~~is unique in proposing to~~ would be first to introduce a tiered industry levy (high, moderate, and no tax for drinks with  $\geq 8$ g, 5g to 8g, and  $< 5$ g sugar per 100ml respectively) rather than a sales tax, ~~as has which have~~ been applied elsewhere. There have been no peer-reviewed analyses of its potential impact and no international precedent from which to predict the potential response of soft drink manufacturers to the levy.

### *Added value of this study*

This is the first study to estimate the health impact of the UK soft drinks industry levy. It focuses on obesity, diabetes and oral health where evidence of a causal link between soft drink consumption and health is strongest. Previous evidence has suggested that soft drink taxes lead to price rises and subsequent reductions in purchases of targeting drinks. This study goes further and estimates the effects of six scenarios to illustrate the relative health impacts of three possible industry responses to the levy: reformulation, price rises, and changes to product market share.

### *Implications of all the available evidence*

Each of the three responses modelled could lead to important health gains, with industry likely to react to the levy using a combination of all three. This study extends previous analyses of the effect of soft drink taxes to show the benefits of reformulation stimulated by the tiered levy. Our analyses show that there could be substantial health benefits if the levy stimulates reformulation. Further important health benefits from price changes will be mitigated if industry spread the price increase across their entire portfolio. Increases in market share for ~~mid~~ moderate-sugar and low-sugar drinks could have substantial health benefits, but only if the market share comes at the expense of high-sugar drinks rather than people shifting from low-sugar to mid-sugar drinks.

## Background

In 2015, the UK Scientific Advisory Committee on Nutrition (SACN) published a report on the evidence between the consumption of carbohydrates and health.<sup>1</sup> The report clarified the role of sugar for the development of dental caries and identified sugar-sweetened beverages (SSBs) as a specific risk factor for weight gain and type 2 diabetes, recommending that SSB consumption should be minimised. Both Public Health England and the UK House of Parliament's health committee subsequently advised a tax on SSBs<sup>2,3</sup> and in March 2016 the budget statement included proposals for a soft drinks industry levy.<sup>4</sup>

Taxes on SSBs have been previously introduced in Mexico, France, Hungary and elsewhere,<sup>5</sup> however the UK would be the first to introduce a framing of the proposed three-tiered UK levy is unique. The levy is presented as an incentive for the industry to reformulate existing products to remove sugar, reduce portion sizes, and promote new or existing low sugar alternatives. The levy is due to will be introduced in 2018, subject to parliament passing the legislation in 2017, with revenue hypothecated for increasing physical activity and breakfast clubs in schools.<sup>4</sup>

Whilst the government has expressed a desire that the levy is not passed onto purchasers through price rises, this cannot be mandated and the industry response is unknown. Other outcomes may include reformulation to reduce sugar content, or changes in marketing to encourage purchasers to switch to lower sugar products or smaller portion sizes. Different responses will have differential effects on consumption patterns for soft drinks and hence determine the health effects of the levy.<sup>6</sup>

The aim of this paper is to appraise the health impact of a range of discrete industry responses so that legislation for the soft drinks levy may be designed to maximise health gain.

## Methods

We developed a comparative risk assessment model to estimate the effects of SSB reformulation, price changes, and changes to SSB market share on obesity, dental caries, and type 2 diabetes in the UK using 2014 data where possible (figure 1).

## Scenarios

We identified and modelled three possible industry responses. First, reformulation to reduce sugar concentration; second, a rise in price; and third, activities to change the relative market share of high-, mid-, and low-sugar drinks. We refer to these three responses as reformulation, price change, and change in market share, respectively. For each of these, the magnitude of the response is uncertain. Informed by evidence where available and expert opinion, for each response we identified 'better' and 'worse' case scenarios for reduction of sugar consumption, resulting in six scenarios (table 1).

We adopt the government definitions of high-sugar drinks as those with over 8g sugar per 100ml, mid-sugar drinks as those with 5-8g sugar per 100ml, and low-sugar drinks are those with less than 5g sugar/100ml. Soft drinks are defined as all drinks with added sugar or sweetener; SSBs are drinks with added sugar excluding milk-based drinks, tea, and coffee; concentrated SSBs are defined as SSBs that are intended to be diluted with water, and regular SSBs are intended to be drunk as sold.

Small producers will be excluded from the levy.<sup>4</sup> We searched all soft drinks sold through Tesco Online and extracted the names of manufacturers. We used the Companies House website to identify manufacturers fulfilling the UK government definition of a small company<sup>7,8</sup> and identified 13 small companies which together contributed 0.6% of total UK SSB sales. Therefore, we did not adjust our analyses to account for these.

The better case reformulation scenario (scenario 1) assumed that industry would reduce the sugar concentration of high-sugar drinks by 30% and mid-sugar drinks by 15%. This is based on the reformulation of Sprite and Lipton Ice Tea which have both reduced their sugar concentration by 30% since 2013.<sup>9,10</sup> In the worse case scenario (scenario 2) we assumed a 5% reduction in sugar concentration of both high- and mid-sugar drinks. This was based on Coca-Cola's pledge made to the Public Health Responsibility Deal of a 5% reduction in calories across their sparkling drink range between 2012 and 2014; they achieved a 5.3% reduction.<sup>10</sup> Under both these scenarios, the volume consumed is assumed to remain constant.

To derive the price change scenarios we used estimates from the Office for Budget Responsibility that the levy will be 18p per litre on mid-sugar drinks and 24p per litre on high-sugar drinks.<sup>11</sup> Low sugar drinks will not be taxed. Previous sugar drink taxes have been passed on at rates of between 50% and 100%<sup>12-14</sup> and if the tax was entirely passed through to consumers, high-sugar concentrated drinks would, on average, increase in price by 75% and high-sugar regular drinks by 31% (table 2). Such price rises are markedly greater than other examples of SSB taxes (most [countries have adopted smaller tax rates and therefore despite high pass on rates, only result in a 5-15% price rise](#)),<sup>15</sup> and [are larger than the 20% often cited as being necessary to affect significant behavioural change and improve health](#).<sup>16</sup>

We therefore assumed that 50% of the price increase would be passed on to purchasers and that companies would not increase prices by more than 20% (table 2). The better case for price change (scenario 3) assumed that the tax is passed on only through SSBs. However, major soft drink manufacturers produce a range of beverages. Therefore, in a worse case for price change (scenario 4) we assume that the levy is passed on evenly across all soft drinks (both diet and SSBs), fruit juice, and bottled water, resulting in a 6% price rise. [Passing 100% of the price increase on to consumers was modelled as a sensitivity analysis. As stated by the UK government, Tax rates were applied to concentrated drinks given their price per litre as drunk assuming a ratio of concentrate to water of](#)

1:4 as used by the British Soft Drinks Association (BSDA).<sup>9,17</sup> Supplementary material gives details of how the price change was modelled.

A change in SSB market shares may result from changes in product marketing, [changing product size](#), or the introduction of new mid- and low-sugar products. For example, the BSDA reports a 70% increase in expenditure on advertising of low or zero calorie brands [and growth in the sales of smaller pack sizes](#),<sup>9</sup> and new mid-sugar products have emerged such as Coca-Cola Life which has 30% less sugar than full sugar Coca-Cola.<sup>18</sup> There are limited data to inform the extent to which these activities drive changes in purchasing behaviour. However, the soft drink industry has pledged to reduce energy intake from soft drinks by 20% from 2015 levels by 2020.<sup>9</sup> To achieve this, we calculate that the market share of high-sugar drinks would need to fall by 12% alongside a 6% increase for each of mid- and low-sugar drinks. This gives scenario 5, our better case for sugar reduction. The worse case (scenario 6) acknowledges that the increased marketing of new mid-sugar drinks may lead consumers to switch to this category from low-sugar drinks. We assume that mid-sugar drinks double their market share alongside equal reductions in the market share of high- and low-sugar drinks.

#### Health impact modelling

We developed a comparative risk assessment model to estimate the effect of the changes to SSB purchasing on [incidence of dental caries, and type 2 diabetes, and on the prevalence of body weight, and obesity](#). [Comparative risk assessment modelling requires the identification of 'risk factor-disease' pairs. In this case, the risk factor is SSB consumption and the diseases are dental caries, type 2 diabetes, and obesity. A two-step process then estimates the impact of the risk factor on the diseases. First, changes in the risk factor between the baseline \(current behaviour\) and scenarios are estimated. Second, changes in the diseases as a result of changes in the risk factor are calculated using population impact fractions and applied to baseline levels of disease in the population. Such methods are common to the field of comparative risk assessment modelling<sup>19</sup> and are based on model parameters representing baseline risk factor and disease status and the epidemiological relationships between risk factors and diseases, which are assumed to be causal.](#)

Parameters describing the [direct](#) relationship between SSB consumption and health outcomes were sought from meta-analyses of randomised controlled trials where available or cohort studies (table 3).<sup>20-25</sup> [The relationship between SSB consumption and diabetes and body weight was modelled as a function of SSB consumption. The reformulation scenarios \(scenarios 1 and 2\) assumed that SSB consumption stays constant, but the level of sugar in the drinks reduces. In order to estimate the impact of these scenarios on obesity and diabetes, we derived estimates of 'equivalised SSB consumption', which rises and falls in direct proportion of a\) volume of SSB consumed, and b\) average SSB sugar level. We standardised against the average sugar levels in drinks in the baseline scenario. For example, in the baseline scenario the average sugar level of SSBs was 9.2g/100ml and the average consumption was 213ml/d. A reduction in the average sugar concentration to 8.2g/100ml at the same level of consumption](#)

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would have an 'equivalised SSB consumption' of 190ml/d. This is because a reduction in consumption of SSBs from 213ml/d to 190ml/d at constant sugar concentrations would result in the same reduction of sugar as a reduction of sugar concentration from 9.2g/100ml to 8.2g/100ml at the same level of consumption. We used equivalised SSB consumption as an input for diabetes and obesity modelling in all scenarios.

Uncertainty intervals reflect the uncertainty in baseline sugar drink sales and consumption, disease burden, sensitivity to price changes, and associations between sugar or sugar drinks consumption and health outcomes. They were estimated based on using 5000 iterations of a Monte Carlo analysis with 5000 iterations incorporating uncertainty around all model parameters being drawn from the published or estimated uncertainty of each parameter (see supplementary material).

All results were applied to the 2014 UK population,<sup>26</sup> and separate estimates for each outcome were made by sex and age group using age and sex specific estimates of baseline SSB consumption and disease burden. Further details of the health impact model are in the supplementary material, including estimates of the effect on obesity if an energy balance equation was used instead of estimating the direct effect on weight of SSB consumption, as used by Briggs et al.<sup>27</sup>

The relationship between SSB consumption and diabetes and body weight was modelled as a function of SSB consumption. The reformulation scenarios (scenarios 1 and 2) assumed that SSB consumption stays constant, but the level of sugar in the drinks reduces. In order to estimate the impact of these scenarios on obesity and diabetes, we derived estimates of 'equivalised SSB consumption', which rises and falls in direct proportion of a) volume of SSB consumed, and b) average SSB sugar level. As such, it is a single estimate combining both high- and mid-sugar drinks. We used equivalised SSB consumption as an input for diabetes and obesity modelling in all scenarios. Details of the health impact model are in the supplementary material.

#### **Role of the funding source**

There was no specific funding for this work. No funders had any role in the writing of the manuscript or the decision to submit it for publication. The corresponding author had full access to all the data in the study and has final responsibility for the decision to submit for publication.

#### **Findings**

##### Change in equivalised SSB consumption

The better case for reformulation (scenario 1) resulted in a fall in average sugar content of SSBs equivalent to 59mls (95% uncertainty interval: 55 to 63; 10kcal [9 to 10]) of SSBs per person per day (table 4). This is the largest reduction among scenarios modelled. All simulated scenarios led to a fall in equivalised SSB consumption except for the worse case for market share which resulted in a small increase (4ml [3 to 4]; scenario 6). The largest falls for both males and females were among 11-18 year olds who consume the largest volume of SSBs.

### Obesity

The reduction in obesity prevalence resulting from each scenario is estimated to be greatest following scenario 1 (better case for reformulation, table 5), leading to 144,400 (5,100 to 306,700) fewer individuals with obesity, 0.9% of the obese population. This is compared to the better cases for price change (scenario 3) and change in market share (scenario 5), which reduce the obese population by 81,600 (3,600 to 182,700) and ~~12291,0400~~ (4,84,300 to ~~276,2204,900~~) respectively, although note that uncertainty intervals are very wide (**NB: uncertainty intervals for analyses restricted to adults include zero for all scenarios**).

Results varied by age with 10% and 6% falls in the number of children with obesity aged 4-10 years and 11-18 years respectively in scenario 1, compared to just 0.4% in adults aged 19-64 years. Males were predicted to experience a greater relative reduction in obesity prevalence than females because males consume a greater volume of SSBs (supplementary table 2). **Effect size estimates were significantly increased when using an energy balance equation (supplementary table 3).**

### Diabetes

Across the scenarios modelled, the pattern of results seen with obesity is repeated for diabetes. Scenario 1 (better case for reformulation) resulted in an estimated 19,100 (6,900 to 32,700) fewer new cases of diabetes per year and scenario 6 (worse case for change in market share) led to ~~the smallest reduction~~ an increase of ~~1237800~~ (455-4,700 to ~~5,9002359~~) cases per year (table 6).

However, in contrast to the obesity results, adults over 65 years saw the largest absolute reduction in diabetes incidence rates reflecting the positive association between age and disease burden.

### Dental caries

All scenarios except scenario 6 led to a fall in the numbers of teeth affected with dental caries (measured by the number of decayed, missing, or filled teeth, DMFT, table 3). The better case for reformulation (scenario 1) had the largest effect size reducing the annual incidence of DMFT by 269,400 (82,200 to 470,900). As with results for obesity and diabetes, the better case for change in market share and price change scenarios (scenarios 5 and 3) had the next largest effects respectively. Those aged 11-18 years were expected to experience the greatest relative benefit due to their higher baseline SSB consumption.

### Sensitivity analysis

**If 100% of the levy were passed on to consumers, equivalised SSB consumption would reduce by 71mls (66 to 77) per person per day. This would lead to 174,800 (7,500 to 367,600) fewer obesity individuals, and 23,000 (8,400 to 40,000) fewer cases of diabetes and 324,500 (89,100 to 553,800) fewer DMFT per year.**

### **Interpretation**

The proposed UK soft drinks industry levy has the potential to reduce obesity prevalence, diabetes incidence, and dental caries incidence. The effect on health and the ranking of scenarios is sensitive to the manner in which industry responds to the levy and the uncertainty in the modelling. Our estimates suggest the greatest benefits will result from reformulation, with less but still positive health effects following price changes and changes to SSB market share to increase the proportion of low-sugar drinks sold. Children will have the greatest relative health benefit in terms of obesity and caries, with absolute reductions in diabetes incidence rates increasing with age.

#### Strengths and weaknesses

The main strength of this study is the timely assessment of a planned government policy by simulating a set of discrete scenarios for how industry might respond to the levy to inform the detail of the legislation. Other strengths include the modelling of multiple health outcomes, the use of age and sex specific data, use of own- and cross-price elasticities for high-, mid-, and low-sugar drinks, and use of equivalised SSB consumption to allow for changes in both sugar content and SSB volume.

Uncertainty intervals estimate the uncertainty arising from model parameters, reflect the uncertainty in baseline sugar drink sales and consumption, disease burden, sensitivity to price changes, and associations between sugar or sugar drinks consumption and health outcomes. However, the greatest uncertainty is how the soft drinks industry will respond to the levy. Given this uncertainty, our results should not be read as precise estimates of the impact of the levy, but instead should be used to compare the relative effects of different scenarios. Moreover, industry is likely to respond with a blended approach that combines elements of reformulation, price changes, and marketing. Note that although the results have wide and overlapping uncertainty analyses, much of the uncertainty is correlated between the scenarios. In 10096% of the iterations of our Monte Carlo analysis, the best case reformulation scenario was associated with the best health outcomes, which suggests that the ranking of scenarios is robust. We have not estimated uncertainty in how much of the levy is passed-on to consumers (although a 100% pass-on is modelled as a sensitivity analysis), and we did not use child-specific estimates of the effect of SSB consumption on diabetes and dental caries incidence due to lack of data available.

We have assumed that disease risk from SSBs is dependent on the quantity of sugar consumed (more sugar = higher risk). While studies have shown benefits from swapping from SSBs to artificially sweetened beverages, we are not aware of any studies that have described the effect of swapping SSBs with a high sugar content to SSBs with a low sugar content.

We have not modelled a temporal component. The effects on DMFT may occur relatively soon after the change in SSB consumption, and the trials used to parameterise the relationship between SSB consumption and weight suggest that falls in obesity would be expected within 6 months for adults and 12 months for children.<sup>21-24</sup> The effects on type 2 diabetes may take longer to be realised (median follow up of observational studies used for this parameter ranged



~~between 3.4 years and 21.1 years).~~<sup>20</sup> ~~We have also not modelled results for different subgroups. Individuals from different socio-economic backgrounds, ages, and baseline consumption levels may respond differently to each industry response simulated.~~

Finally, we have not modelled the ~~long-term health benefits of falls in obesity, the possible educational role the levy may have in highlighting that SSBs cause disease,~~<sup>28</sup> ~~and/or have we modelled~~ the health impact of using the revenue to improve school sport and nutrition.

#### Comparisons with other studies

This is the first peer-reviewed study to appraise the potential effects of the UK soft drinks industry levy.

The results of our study vary from the results of an industry-funded assessment of the impact of the levy.<sup>29</sup> Oxford Economics calculated the impact of a price change associated with a 100% pass-on of the levy to targeted products only, with no reformulation or market share (most similar to our scenario 3). The authors estimated that the levy would result in a 5kcal per person per day fall in energy intake. Our ~~scenario 3 sensitivity analysis of a 100% pass-on rate would also result in a reduction of 511kcal per person per day but with only a 50% pass-on~~ (before adjustment for BSDA sales figures). There are two principle explanations for the difference. Firstly, we estimate the average price before tax of dilutables as £0.22 per litre, whereas Oxford Economics estimate it as £1.76 per litre. This is likely to be due to Oxford Economics applying the tax before dilution. Secondly, Oxford Economics used estimates of how consumers respond to price changes of diet and non-diet SSBs taken from our 2013 study estimating the effect on obesity of a 20% UK SSB tax.<sup>27</sup> In our current study we have calculated estimates separately for high-, mid-, and low-sugar drinks. ~~Using our current model, a 100% pass-on would lead to an average reduction of 11kcal per person per day resulting from a 71ml reduction in equivalised SSB consumption (compared to 59ml in scenario 1, the modelled scenario with the best health outcomes).~~

Our 2013 study estimated that a 20% price rise would lead to a 1.3% fall in the number of obese adults in the UK, compared to our scenario 3 estimate of 0.5% (following an average price rise of 15%).<sup>27</sup> Our 2013 study did not estimate price elasticities separately for high- and mid-sugar drinks, did not quantify the effect of the tax on children, and did not adjust for BSDA sales figures. It also used an energy balance equation rather than quantifying the direct effect of SSBs on body weight, which ~~is likely to estimate~~ larger effects on body weight (see supplementary material). Conversely in this paper, we used an estimate of the direct relationship between body weight and SSBs, which may more accurately represent substitution and other compensatory mechanisms secondary to changes in sugar (and energy) consumed from SSBs. The present analysis confirms our 2013 findings of greater relative reductions in obesity among younger adults compared with older adults. This is explained by teenagers and young adults drinking more SSBs than older adults (supplementary table 2) and



trial data suggesting that SSBs have a greater effect on weight gain in children than adults.<sup>21-24</sup>

Considering reformulation, Ma et al. estimated that a 40% reduction in sugar across all SSBs in the UK would lead to 800,000 fewer individuals with obesity.<sup>30</sup> This is substantially more than our estimate in scenario 1 (144,400), which assumed a 30% reduction in sugar content of high-sugar drinks and 15% reduction of mid-sugar drinks. This is in part due to Ma et al. estimating that the average reduction in energy consumed would be approximately twice our estimate, and then using an energy balance equation to estimate the effect of energy intake on weight. Of note, estimates for the reduction in diabetes were similar between our current study and Ma et al.

More generally, we recognise that there are uncertainties around all parameters in the model that will affect the comparison of results with other simulation studies.

#### Interpretation and implications

The UK soft drinks industry levy has the potential to lead to important improvements in population health, particularly among children. Policymakers should engage with stakeholders to encourage responses to the levy that will maximise the potential health benefits of the new policy. Our results demonstrate the need for ongoing monitoring of the implementation strategies adopted by industry alongside modelling to estimate the long-term health consequences of their actions.

Our results suggest that of the scenarios modelled, reformulation would lead to the largest health benefits. Price rises and changes to product market share may also lead to important improvements in health. However, effects would be attenuated if manufacturers choose to pass the tax on to purchasers across all drinks, or other products, in their portfolio rather than just those targeted by the levy. **Moreover, negative health effects may arise, and if the increase in market share of mid-sugar drinks comes at the expense of low-sugar drinks. Conversely, further health benefits may be realised if manufacturers pass-on more than 50% of the levy to consumers or choose to reformulate to a greater extent than that modelled (as recently announced by Tesco and Lucozade Ribena Suntory).**<sup>31,32</sup>

#### Conclusion

The UK soft drink industry levy could have valuable population health benefits but the magnitude of its health impact will depend on how industry responds. The detail of the levy is yet to be decided but we show important health benefits that could be maximised by significant product reformulation with further health gains arising through raising the price of high- and mid-sugar drinks and increasing the market share of low-sugar products.

#### **Declaration of interests**

RT and AK have previously done work on SSB taxes that was funded by the Union of European Soft Drinks Associations (UNESDA). MR is chair of Sustain

and the Children's Food Campaign which have campaigned for sugar drink taxes in the UK. AB and OTM are members of the Faculty of Public Health which has a position statement supporting sugary drink taxes. OTM is a member of the UK Health Forum which has also supported a UK sugar drinks tax. SAJ was the independent Chair of the Department of Health Public Health Responsibility Deal Food Network from 2010 to 2015.

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### **Contributions of authors**

ADMB, OTM, MR, SAJ, and PS contributed to the conception of the work; all authors contributed to the design of the scenarios analysed; ADMB, OTM, AK, RT, TB, and PS designed the methodology; ADMB, OTM, AK, AE, and PS identified data and ran the analyses; all authors contributed to the interpretation of the results; ADMB drafted the first draft of the manuscript; all authors commented on the manuscript and made critical revisions; all authors approve the final version of the manuscript; all authors are accountable for all aspects of the work.

## References

- 1 Scientific Advisory Committee on Nutrition. Carbohydrates and health. London, 2015  
[https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/445503/SACN\\_Carbohydrates\\_and\\_Health.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/445503/SACN_Carbohydrates_and_Health.pdf).
- 2 Public Health England. Sugar reduction: the evidence for action. London, 2015  
[https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/470179/Sugar\\_reduction\\_The\\_evidence\\_for\\_action.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470179/Sugar_reduction_The_evidence_for_action.pdf).
- 3 House of Commons Health Committee. Childhood obesity - brave and bold actions. London, 2015.
- 4 HM Treasury. Budget 2016. London, 2016.
- 5 Cornelsen L, Carreido A. Health related taxes on foods and beverages. London, 2015.
- 6 Briggs A. Sugar tax could sweeten a market failure. *Nature* 2016; **531**: 551.
- 7 www.gov.uk. Micro-entities, small and dormant companies. 2016.  
<https://www.gov.uk/annual-accounts/microentities-small-and-dormant-companies> (accessed Aug 16, 2016).
- 8 Companies House. Search the register. 2016.  
<https://beta.companieshouse.gov.uk/> (accessed Aug 16, 2016).
- 9 British Soft Drinks Association. Leading the Way. Annual report 2016. London, 2016.
- 10 Coca-Cola. Tackling Obesity: Choice and Information. 2015.  
<http://www.coca-cola.co.uk/stories/health/choice-and-information/tackling-obesity-choice-and-information>.
- 11 Office for Budget Responsibility. Economic and fiscal outlook. London, 2016.
- 12 Falbe J, Rojas N, Grummon AH, Madsen KA. Higher Retail Prices of Sugar-Sweetened Beverages 3 Months After Implementation of an Excise Tax in Berkeley, California. *Am J Public Health* 2015; **105**: 2194–201.
- 13 Berardi N, Sevestere P, Tepaut M, Vigneron A. The impact of a 'soda tax' on prices: evidence from French Micro data. 2012 [http://www.banque-france.fr/uploads/tx\\_bdfdocumentstravail/DT-415\\_01.pdf](http://www.banque-france.fr/uploads/tx_bdfdocumentstravail/DT-415_01.pdf).
- 14 Colchero MA, Salgado JC, Unar-Munguía M, Molina M, Ng S, Rivera-Dommarco JA. Changes in Prices After an Excise Tax to Sweetened Sugar Beverages Was Implemented in Mexico: Evidence from Urban Areas. *PLoS One* 2015; **10**: e0144408.
- 15 World Cancer Research Fund International. Use economic tools. 2016.  
[www.wcrf.org/int/policy/nourishing-framework/use-economic-tools](http://www.wcrf.org/int/policy/nourishing-framework/use-economic-tools) (accessed Aug 11, 2016).
- 16 Mytton O, Clarke D, Rayner M. Taxing unhealthy food and drinks to improve health. *Br Med J* 2012; **344**: e2931.
- 17 HM Revenue & Customs, HM Treasury. Soft Drinks Industry Levy Consultation document. London, 2016.
- 18 Coca-Cola. Coca-Cola Life™ Launch Backed With Massive Marketing Push. 2014. <http://www.coca-cola.co.uk/newsroom/press-releases/coca-cola-life-marketing-campaign>.
- 19 Newton JN, Briggs ADM, Murray CJL, *et al*. Changes in health in England,

- with analysis by English regions and areas of deprivation, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015; **386**: 2257–74.
- 20 Imamura F, O'Connor L, Ye Z, *et al*. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: systematic review, meta-analysis, and estimation of population attributable fraction. *BMJ* 2015; **351**: h3576.
- 21 de Ruyter JC, Olthof MR, Seidell JC, Katan MB. A trial of sugar-free or sugar-sweetened beverages and body weight in children. *N Engl J Med* 2012; **367**: 1397–406.
- 22 Maersk M, Belza A, Stødkilde-Jørgensen H, *et al*. Sucrose-sweetened beverages increase fat storage in the liver, muscle, and visceral fat depot: a 6-mo randomized intervention study. *Am J Clin Nutr* 2012; **95**: 283–9.
- 23 Tate DF, Turner-McGrievy G, Lyons E, *et al*. Replacing caloric beverages with water or diet beverages for weight loss in adults: main results of the Choose Healthy Options Consciously Everyday (CHOICE) randomized clinical trial. *Am J Clin Nutr* 2012; **95**: 555–63.
- 24 Ebbeling CB, Feldman HA, Chomitz VR, *et al*. A randomized trial of sugar-sweetened beverages and adolescent body weight. *N Engl J Med* 2012; **367**: 1407–16.
- 25 Bernabé E, Vehkalahti MM, Sheiham A, Aromaa A, Suominen AL. Sugar-sweetened beverages and dental caries in adults: A 4-year prospective study. *J Dent* 2014; **42**: 952–8.
- 26 Office for National Statistics. Population estimates for UK, England and Wales, Scotland and Northern Ireland, revised: mid-2012, mid-2013 and mid-2014. London, 2016.
- 27 Briggs ADM, Mytton OT, Kehlbacher A, Tiffin R, Rayner M, Scarborough P. Overall and income specific effect on prevalence of overweight and obesity of 20% sugar sweetened drink tax in UK: econometric and comparative risk assessment modelling study. *BMJ* 2013; **347**: f6189.
- 28 Mytton OT, Eyles H, Ogilvie D. Evaluating the Health Impacts of Food and Beverage Taxes. *Curr Obes Rep* 2014; **3**: 432–9.
- 29 Oxford Economics. The economic impact of the soft drinks levy. Oxford, 2016  
[http://www.britishsoftdrinks.com/write/MediaUploads/Publications/The\\_Economic\\_Impact\\_of\\_the\\_Soft\\_Drinks\\_Levy.pdf](http://www.britishsoftdrinks.com/write/MediaUploads/Publications/The_Economic_Impact_of_the_Soft_Drinks_Levy.pdf).
- 30 Ma Y, He FJ, Yin Y, Hashem KM, MacGregor GA. Gradual reduction of sugar in soft drinks without substitution as a strategy to reduce overweight, obesity, and type 2 diabetes: a modelling study. *Lancet Diabetes Endocrinol* 2016; **4**: 105–14.
- 31 Tesco PLC. Tesco reduces sugar content in all own brand soft drinks. 2016. <https://www.tescopl.com/news/news-releases/2016/tesco-reduces-sugar-content-in-all-own-brand-soft-drinks/> (accessed Nov 14, 2016).
- 32 Lucozade Ribena Suntory. Our responsibilities. 2016. <https://www.lrsuntory.com/our-responsibilities/> (accessed Nov 14, 2016).
- 33 Bernabé E, Vehkalahti MM, Sheiham A, Lundqvist A, Suominen AL. The Shape of the Dose-Response Relationship between Sugars and Caries in Adults. *J Dent Res* 2016; **95**: 167–72.



**Table 1.** Simulated scenarios

Category of response	Better case for sugar reduction	Worse case for sugar reduction
Reformulation	<i>Scenario (1):</i> High-sugar drinks reduce sugar content by 30%, mid-sugar drinks by 15%	<i>(2):</i> Mid- and high-sugar drinks both reduce sugar content by 5%
Price change	<i>(3):</i> <b>Increase in price of high- and mid-sugar drinks such that Fifty per cent of levy tax is passed on to consumers with a maximum 20% price rise.</b>	<i>(4):</i> Increase in price of all packaged drinks <sup>1</sup> by the same percentage such that 50% of the tax is borne by customers
Change to SSB market share	<i>(5):</i> Breakdown in sales of soft drinks shifts from 58%/6%/36% to 64%/12%/24% for low-, mid-, and high-sugar drinks respectively	<i>(6):</i> Breakdown in sales of soft drinks shifts to 55%/12%/33% for low-, mid-, and high-sugar drinks respectively

Low-sugar drinks: <5g sugar/100ml, medium-sugar drinks: 5-8g sugar/100ml, high-sugar drinks: >8g sugar/100ml. SSB, sugar sweetened beverage.

<sup>1</sup>including low or zero sugar drinks, bottled water, fruit juice, sweetened milk drinks, not including tea, coffee, unsweetened milk, alcohol

**Table 2.** Baseline price and change in price for the taxed drinks categories with different rates of tax pass-through and as modelled in scenario 3 (percentages in parentheses indicated percentage change in baseline price)

Drink category	Baseline price (pence per litre; p/l)	Price with 100% pass through (p/l)	Price with 50% pass through (p/l)	Scenario 3 modelled price (p/l)
Concentrated high-sugar	32.1	56.1 (+75%)	44.1 (+37%)	38.6 (+20%)
Concentrated mid-sugar	40.1	58.1 (+45%)	49.1 (+22%)	48.1 (+20%)
Regular high-sugar	77.6	101.6 (+31%)	89.6 (+15%)	89.6 (+15%)
Regular mid-sugar	99.0	117.0 (+18%)	108.0 (+9%)	108.0 (+9%)

**Table 3.** Model input parameters and data sources (95% confidence interval)

Model outcome	Parameter	Data source
Body weight	Increase in weight of 0.09kg (-0.11 to 0.29) in adults and 0.45kg (0.24 to 0.66) in children per additional 100ml SSB consumed per day.	Meta-analysis of randomised controlled trials of SSB consumption and body weight. Two studies identified and combined for adults <sup>22,23</sup> and two

		for children. <sup>21,24</sup>
Diabetes	Relative risk of incident diabetes of 1.42 (1.19 to 1.69) per additional 250ml serving per day for adults and children	Imamura et al. <sup>20</sup>
Dental caries	Increase in number of decayed, missing, or filled teeth of 0.008 (0.002 to 0.014) per person for every additional 10g of sugar consumed per day.	Bernabé et al. <sup>33</sup>

SSB, sugar sweetened beverage

**Table 4.** Reduction in equivalised\* volume of sugar sweetened beverage consumed with each scenario [95% uncertainty interval]

Age and sex group	Reduction in mean equivalised volume of sugary drink consumed (ml per person per day)					
	Reformulation		Price change		Change in market share	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Boys, 4-10	61.7	11.2	34.5	12.4	<del>38.652.1</del>	<del>-3.82.3</del>
Boys, 11-18	137.6	25.0	77.0	27.7	<del>86.0116.2</del>	<del>-8.65.2</del>
Men, 19-64	71.0	12.9	39.7	14.3	<del>44.460.0</del>	<del>-4.42.7</del>
Men, 65+	24.0	4.4	13.4	4.8	<del>15.020.2</del>	<del>-1.50.9</del>
Girls, 4-10	51.9	9.5	29.1	10.4	<del>32.543.9</del>	<del>-3.22.0</del>
Girls, 11-18	93.2	17.0	52.1	18.7	<del>58.378.7</del>	<del>-5.83.5</del>
Women, 19-64	49.7	9.0	27.8	10.0	<del>31.141.2</del>	<del>-3.11.9</del>
Women, 65+	23.5	4.3	13.2	4.7	<del>14.719.9</del>	<del>-1.50.9</del>
Average	58.5 [54.5 to 62.6]	10.7 [10.0 to 11.4]	32.7 [30.3 to 35.3]	11.8 [10.9 to 12.7]	3649.64 [345.97 to 3862.34]	-3.62.2 [-312.86 to -316.42]

\*where equivalisation results in the same sugar intake for each equivalised unit of sugar sweetened beverage.

**Table 5.** Reduction in the number of obese individuals following each scenario (% reduction in number obese) [95% uncertainty interval]

Age and sex group	Reduction in number of obese individuals (% of obese individuals)					
	Reformulation		Price change		Change in market share	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Boys, 4-10	29227 (10.4%)	5524 (2.0%)	16689 (6.0%)	6095 (2.2%)	<del>24859</del> <del>18592 (6.68.9%)</del>	<del>-19111159 (-</del> <del>0.70.4%)</del>
Boys, 11-18	31793 (6.0%)	5907 (1.1%)	17987 (3.4%)	6521 (1.2%)	<del>2006626953</del> <del>(3.85.1%)</del>	<del>-20331236 (-</del> <del>0.40.2%)</del>
Men, 19-64	25582 (0.5%)	4663 (0.1%)	14324 (0.3%)	5149 (0.1%)	<del>1600521609</del> <del>(0.34%)</del>	<del>-1596972</del> <del>(0.0%)</del>
Men, 65+	3002 (0.2%)	547 (0.0%)	1680 (0.1%)	603 (0.0%)	<del>2535.1877</del>	<del>-187114 (0.0%)</del>

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					(0-12%)	
Girls, 4-10	16455 (8.9%)	3097 (1.7%)	9374 (5.0%)	3418 (1.8%)	<del>13984-10447</del> (5.67-5%)	<del>-1070649</del> (-0.60-4%)
Girls, 11-18	17581 (4.8%)	3257 (0.9%)	9930 (2.7%)	3595 (1.0%)	<del>14896-11081</del> (3.04-1%)	<del>-1120681</del> (-0.30-2%)
Women, 19-64	17328 (0.3%)	3157 (0.1%)	9700(0.2%)	3487 (0.1%)	<del>14636-10839</del> (0-23%)	<del>-1081658</del> (0-0%)
Women, 65+	3415 (0.2%)	622 (0.0%)	1911 (0.1%)	697 (0.0%)	<del>2884-2135</del> (0-12%)	<del>-213130</del> (0-0%)
Total	144383 (0.9%) [5102 to 306743]	26774 (0.2%) [1276 to 63806]	81594 (0.5%) [3588 to 182669]	29555 (0.2%) [1379 to 69804]	<del>122355-91042</del> (0.68%) [ <del>4839</del> 4289 to <del>276243</del> 204903]	<del>-92115599</del> (-0.10%) [ <del>-42190</del> 22776 to <del>58809-</del> 485]

**Table 6.** Reduction in the number of cases of diabetes per year following each scenario (reduction in incidence per 100,000 person-years) [95% uncertainty interval]

Age and sex group	Reduction in number of incident cases of diabetes per year (reduction in incidence per 100,000 person-years)					
	Reformulation		Price		Change in market share	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Boys, 4-10	71 (2.6)	13 (0.5)	40 (1.5)	15 (0.5)	<del>4560</del> (1.62-2)	<del>-53</del> (-0.21)
Boys, 11-18	224 (7.5)	44 (1.5)	131 (4.3)	49 (1.6)	<del>14592</del> (4.86-4)	<del>-159</del> (-0.53)
Men, 19-64	8364 (43.5)	1585 (8.2)	4783 (24.9)	1749 (9.1)	<del>53277118</del> (27.637-0)	<del>-549333</del> (-2.81-7)
Men, 65+	2539 (49.4)	469 (9.1)	1431 (27.8)	517 (10.1)	<del>15982150</del> (31.141-8)	<del>-16098</del> (-3.11-9)
Girls, 4-10	52 (2.0)	10 (0.4)	29 (1.1)	11 (0.4)	<del>3344</del> (1.2-1.7)	<del>2-3</del> (-0.1)
Girls, 11-18	223 (7.8)	43 (1.5)	128 (4.5)	47 (1.7)	<del>143190</del> (4.96-7)	<del>-159</del> (-0.53)

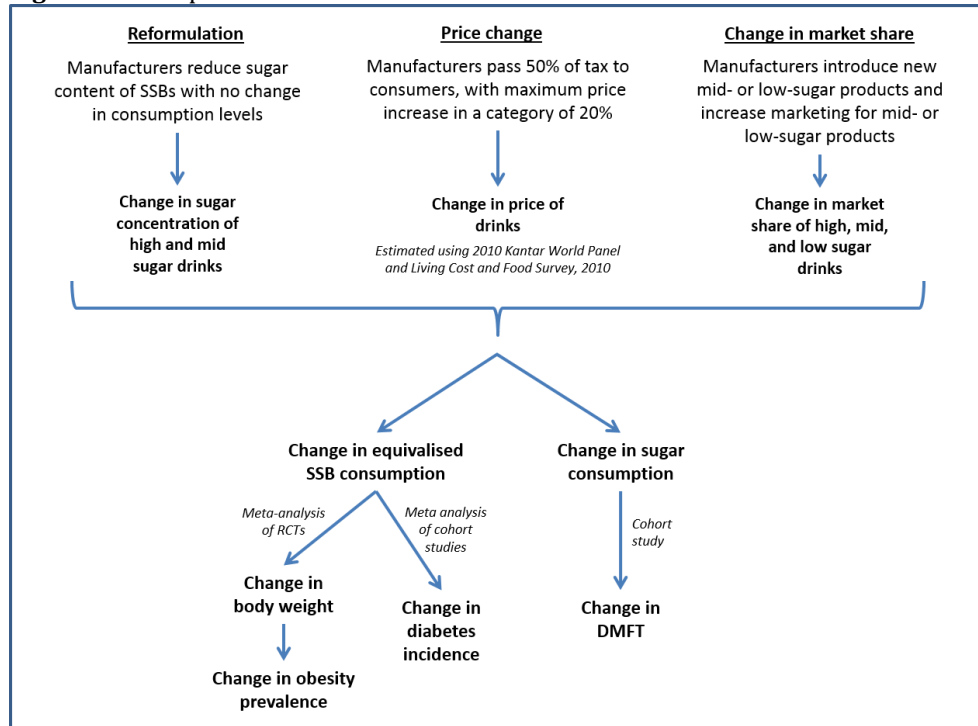
Women, 19-64	5192 (26.7)	972 (5.0)	2950 (15.1)	1073 (5.5)	<del>32894408</del> <del>(16.922.6)</del>	<del>-336204 (-</del> <del>1.71.0)</del>
Women, 65+	2429 (38.8)	448 (7.2)	1369 (21.8)	495 (7.9)	<del>15282056</del> <del>(24.432.8)</del>	<del>-154994 (-</del> <del>2.51.5)</del>
Total	19094 <del>(31.1)</del> [6920 to 32678]	3584 <del>(5.8)</del> [1289 to 6466]	10861 <del>(17.7)</del> [3899 to 18964]	3955 <del>(6.4)</del> [1420 to 7085]	<del>152816218</del> <del>(19.7)</del> [5665 4414 to <del>2178528739</del> ]	<del>-1238751 (-2.0)</del> [-23594686 to - <del>4555859</del> ]

**Table 7.** Reduction in number of decayed, missing, or filled teeth (DMFT) per year following each scenario (reduction in number of DMFT per 1,000 person-years) [95% uncertainty interval]

Age and sex group	Reduction in number of DMFT per year (reduction in number of DMFT per 1,000 person-years)					
	Reformulation		Price		Change in market share	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Boys, 4-10	12735 (4.6)	2318 (0.8)	7022 (2.6)	3376 (1.2)	<del>809610481</del> <del>(2.93.8)</del>	<del>-741376 (-</del> <del>0.30.1)</del>
Boys, 11-18	31040 (10.3)	5650 (1.9)	17268 (5.7)	7015 (2.3)	<del>1996725937</del> <del>(6.68.6)</del>	<del>-19221069 (-</del> <del>0.60.3)</del>
Men, 19-64	102477 (5.3)	18654 (1.0)	56909 (3.0)	23776 (1.2)	<del>6579285414</del> <del>(3.44.4)</del>	<del>-62823445 (-</del> <del>0.30.1)</del>
Men, 65+	9239 (1.8)	1682 (0.3)	5081 (1.0)	2554 (0.5)	<del>59247688</del> <del>(1.21.5)</del>	<del>-563306 (-</del> <del>0.10.0)</del>
Girls, 4-10	10225 (3.9)	1861 (0.7)	5645 (2.2)	2640 (1.0)	<del>64968409</del> <del>(2.5(3.2)</del>	<del>-593299 (-</del> <del>0.20.1)</del>
Girls, 11-18	19977 (7.0)	3637 (1.2)	11099 (3.9)	4610 (1.6)	<del>128086622</del> <del>(4.55.8)</del>	<del>-1216660 (-</del> <del>0.40.2)</del>
Women, 19-64	72625 (3.7)	13220 (0.7)	40270 (2.1)	17240 (0.9)	<del>4651660350</del> <del>(2.43.1)</del>	<del>-43972370 (-</del> <del>0.20.1)</del>

Women, 65+	11056 (1.8)	2013 (0.3)	6086 (1.0)	3029 (0.5)	<del>71199249</del> <del>(1.14.4)</del>	<del>-688385</del> (-0.1)
Total	269375 (4.4) [82211 to 470928]	49036 (0.8) [14929 to 85630]	149378 (2.4) [45231 to 262013]	64240 (1.1) [19643 to 112371]	<del>172718224150</del> <del>(2.83.7)</del> [65231 47919 to 294499411793]	<del>-164018911</del> [- 0.3(0.1) [- 6365628037 to - 460482642]

**Figure 1.** Conceptual model



DMFT, decayed missing or filled teeth; SSB, sugar sweetened beverage; RCT, randomised controlled trial

## A health impact assessment of the UK soft drinks industry levy: a comparative risk assessment modelling study

Adam D M Briggs, Oliver T Mytton, Ariane Kehlbacher, Richard Tiffin, Ahmed Elhussein, Mike Rayner, Susan A Jebb, Tony Blakely, Peter Scarborough

### Supplementary material: Description of the modelling process

#### Modelling price change

The effect of a price change on purchases of SSBs and on complementing and substituting drinks was modelled using own- and cross-price elasticities. Own-price elasticities describe how purchases of a good change due to a price increase, and cross-price elasticities describe the effect of the price change on other goods. For example, if bread has an own price elasticity of -1.0 and a cross price elasticity with butter of -0.2 and of 0.1 with cereal, a 10% increase in the price of bread will result in 10% less bread, 2% less butter (butter is a complement) and 1% more cereal (cereal is a substitute) being purchased.

Conditional own- and cross-price elasticities were estimated for 25 food and drink categories; supplementary figure 1 shows these categories and illustrates the demand system hierarchy. Demand systems 1 to 5 were estimated using 2010 [Living Costs and Food Survey \(LCF\)](#) data and using an Almost Ideal Demand System (AIDS)<sup>1,2</sup> with infrequency of purchase<sup>3</sup> which assumes that censoring arises because households consume from stock. [Adding up, symmetry, homogeneity and concavity are imposed in the estimation. Because the covariance matrix is singular we drop one of the share equations, obtaining estimates that are invariant to which equation is dropped.](#)<sup>4</sup> Food categories are aggregated using the EKS quantity index<sup>5,6</sup> which is a multi-lateral version of the superlative Fisher Ideal index, and is used to compute the implicit price index. A superlative index offers some mitigation towards the concerns over the potential endogeneity of prices.<sup>7</sup> The LCF data are a cross-section of 5,236 households which are chosen using multi-stage stratified random sampling. Data on 270 categories of food expenditures and quantities purchased for consumption at home are collected from each household over a two week period using food diaries and these periods are distributed across the year for different households.

For the estimation of the elasticities of concentrated and regular mid- and high- sugar drinks (demand systems 6 and 7), we used selected product codes from the 2010 Kantar World Panel UK data, [a panel of 30,000 households demographically representative of Great Britain](#). These data are collected over 52 weeks and we therefore used an AIDS with double hurdle model that assumes censoring arises because households prefer to not purchase a given drink. [Quantities in the Kantar data were aggregated using an EKS quantity index<sup>4,5</sup> to compute the implicit price index used in the AIDS.](#) Estimation was carried out using Markov chain Monte Carlo methods where the Gibbs sampler draws 10,000 samples sequentially from the conditional posterior distributions after a burn-in of 2,000. The conditional elasticities of the seven demand systems were combined to obtain unconditional elasticities which allow for expenditure to vary within all food and drinks categories.<sup>8</sup> [The own and cross-price elasticity estimates was used to estimate the change in consumption of each drink category by multiplying the elasticity matrix with the price changes modelled. The percentage change in price is estimated by applying the proposed levy rates to expenditure of each taxed drink category in LCF, 2014.](#) See supplementary table 1 for price elasticity matrix.

We assumed that the price elasticities apply uniformly across the population whereas in reality individuals may respond differently to the price rise based on their age, baseline consumption, and socio-economic group.<sup>9,10</sup> [Furthermore, price elasticities are estimated using data containing price variations which are smaller than the price increases modelled. Therefore greater price increases have greater uncertainty surrounding the estimated responses of households.](#)

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#### Modelling health outcomes

[We estimate the effect of changing SSB and sugar consumption on obesity prevalence in the UK, and on annual diabetes incidence and incidence of decayed, missing, and filled teeth \(DMFT\).](#)

Baseline drink consumption was taken from [LCF, the 2014 Living Costs and Food Survey \(LCF\)](#).<sup>11</sup> Drinks were categorised into milk, water, fruit juice, soft drinks regular low calorie, soft drinks regular not low calorie, soft drinks concentrated low calorie, soft drinks concentrated not low calorie, tea and coffee, other beverages, beer, wine, and other alcohol. Regular soft drinks include carbonates, energy drinks, and fruit juice with added sugar.

The LCF divides SSBs into *soft drinks concentrated, not low calorie*, and *soft drinks regular, not low calorie*. In order to estimate the effect of the levy on mid-sugar drinks, these categories were split into high-sugar and mid-sugar drink categories using the following method. The volume purchased and sugar concentration of each of the *not low-calorie soft drink* categories is reported by the LCF. The volume purchased for each of the mid-sugar categories was estimated by assuming that the concentration of sugar in drinks in the high-sugar category is 10g sugar/100ml and in the mid-sugar category is 6.5g sugar/100ml, which is supported by an analysis of Kantar World Panel Data.<sup>12</sup> Using these data, the ratio of high- to mid-sugar drink volume purchased for each of regular and concentrated drinks was calculated and applied to the volume of *not low-calorie soft drinks* purchased thereby estimating the baseline volume of each of mid-sugar drinks and high-sugar drinks.

The volume purchased within some drinks categories in the LCF is considerably lower than industry reported sales data [from the British Soft Drinks Association \(BSDA\)](#).<sup>13</sup> Therefore, as with previous studies,<sup>14</sup> purchases of fruit juice, water, regular soft drinks and concentrated soft drinks were initially adjusted upwards based on 2015 industry reported total volume sales.<sup>13</sup> Volume consumed was assumed to be the same as that purchased minus wastage estimated for carbonated soft drinks, bottled water, fruit juice, and concentrated soft drinks by the Waste and Resources Action Programme (WRAP), [a survey of approximately 1,800 households in the UK with detailed measurement of weight and types of and drink waste](#).<sup>15</sup>

[As the LCF reports at the household level, a](#) Age and sex specific estimates of drinks consumed were derived by dividing the ~~total volume of SSBs~~ total purchased ~~per person in the LCF according to the~~ relative consumption of each drink category [by age and sex](#) reported by The National Diet and Nutrition Survey rolling programme, 2008/09-2011/12 (NDNS).<sup>16</sup> [The NDNS is a four day diary of food consumption for both children and adults and the 2008/09 – 2011/12 data are based on data collected for over 6,000 participants.](#)

We have assumed there is no excess health risk associated with artificially sweetened beverages (ASBs). While we note that some studies have reported that ASBs are associated with obesity and type 2 diabetes in prospective studies many authors suggest these associations may be due to reverse causation and there is no strong plausible biological explanation for an aetiological association.<sup>17,18</sup> However we note that ASBs are linked to enamel erosion, and the harm associated with this has not been modelled.<sup>19</sup>

[In comparison to Data from BSDA- 2015 suggest that the market share of low- middle-, and high-sugar drinks is 58%, 6%, and 36% respectively, cdata compared to our estimates from; LCF 2014 of 0 data suggest the market share of low , mid , and high sugar drinks is 50%, 17% and 33% respectively.](#) Therefore for scenarios 5 and 6, baseline volumes of [concentrated and non-concentrated](#) soft drinks consumed were adjusted to fit BSDA reported 2015 market shares. The new market shares described in table 1 [of the manuscript](#) were then compared to this new baseline. The concentration of sugar in each category and their prices were assumed to remain the same.

Finally, the model is static meaning that we do not estimate the effect of scenarios on disease over time and have not incorporated current disease or risk factor trends. Results therefore relate to 2014 disease incidence and prevalence rates.

#### *Modelling obesity*

The relationship between SSB consumption and body weight was derived following a [random effects](#) meta-regression of randomised controlled trials describing the change in body weight following change in volume of SSBs consumed. No published meta-regressions exist and therefore a search of the literature was completed in Medline and four trials were identified and combined, two in children<sup>20,21</sup> and two in adults.<sup>22,23</sup> Based on these data, we assumed a linear relationship between body weight and SSB consumption; for every additional 100ml of SSB consumed per day, we assumed 0.09kg (-0.11 to 0.29) of additional weight in adults and 0.45kg (0.24 to 0.66) in children. Weight increases were then converted into change in body mass index (BMI) using age and sex specific measures of height and weight from the Health Survey for England (HSE, assumed to apply to the UK population).<sup>24</sup> Overweight and obesity in children was defined as being above the 91<sup>st</sup> and 98<sup>th</sup> centile respectively for weight based on sex specific Royal College of Paediatrics and Child Health growth charts.<sup>25</sup> [For both of the childhood studies included in the meta-analysis, body weight was recorded one year after the introduction of the intervention.](#) Overweight and obesity in adults was defined as a body mass index (BMI) of 25-30kg/m<sup>2</sup> and >30kg/m<sup>2</sup> respectively. [For the adult studies included in the meta-analyses, body weight was recorded six months after introduction of the intervention.](#)

We assumed that the effect of changing SSB consumption on diabetes and dental caries would be the same in adults and children whereas we assumed different effect sizes among adults when modelling obesity. The

differences in effect size reported by trials estimating the effect of SSB consumption on weight gain may in part be due to the adult trials reporting after six months whereas the trials in children reported at 1 year post intervention.<sup>20-23</sup> The adult trials used may under-report the potential total weight loss, meaning our obesity results are conservative. Results estimate the number of obese individuals in 2014 had the population been consuming SSBs as modelled in each scenario rather than current consumption. We repeated the obesity estimates using Christiansen and Garby's energy balance equation, which estimates significantly greater falls in obesity prevalence (as used by Briggs et al., see supplementary table 3).<sup>26,27</sup> Hall and Jordan's dynamic model estimates a two-fold greater loss of weight than we estimate after six months (but with further weight loss to be expected if the calorie change is maintained), again suggesting that we may be conservative in our estimates.<sup>28</sup>

#### *Modelling diabetes*

We assumed a relative risk of 1.42 (95% confidence interval: 1.19 to 1.69) per 250ml SSB serving for diabetes incidence, based on the results of a random effects meta-analysis of 17 prospective cohort studies with median follow up ranging from 3.4 years to 21.1 years.<sup>18</sup> This estimate was unadjusted for obesity as obesity is on the causal pathway between SSB consumption and type 2 diabetes. We assumed no relationship between artificially sweetened beverages and type 2 diabetes. It was assumed that the same relative risk applies equally to both adults and children. Baseline incidence of diabetes by age and sex was taken from Holden et al.<sup>29</sup>

#### *Modelling dental caries*

We were unable to identify data to estimate the dose-response of SSB consumption on dental caries. We therefore assumed that for every additional 10g sugar consumed per day there would be 0.008 (0.002 to 0.014) extra ~~decayed, missing, and filled teeth~~ (DMFT) per person in a given year. This estimate was from an 11 year-long longitudinal study of sugar consumption and oral health in Finnish adults controlling for a variety of confounders including socio-economic status and tooth brushing habits, the time for DMFT to manifest from a change SSB consumption was not observed.<sup>30</sup> Change in sugar consumption was estimated across all drinks consumed and not only change in SSB consumption. We assumed that there was no substitution from drinks to food when estimating the change in sugar consumption.

#### *Uncertainty analysis*

We conducted a Monte Carlo analysis with 5000 iterations to quantify the uncertainty in the modelled results due to uncertainty around the model parameters. In each iteration, the model parameters were drawn randomly from a specified distribution and the six scenarios were modelled using this random set of model parameters. Results for the iteration were saved, and uncertainty intervals for the results were based on the 2.5<sup>th</sup> and 97.5<sup>th</sup> percentiles of the results across the 5000 iterations. Uncertainty around the following parameters were included in the analysis: baseline consumption of drinks categories estimated by the LCF; volume of sales of drinks categories estimated by the BSDA; percentage of waste of food categories estimated by WRAP; sugar drink consumption by age and sex estimated by the NDNS; diabetes incidence by age and sex estimated by Holden et al.;<sup>29</sup> height and weight by age and sex estimated by the HSfE; own price elasticities for the soft drinks categories; and the parameters associating changes in sugar or sugar drink consumption and DMFT, diabetes incidence (drawn from the literature), and obesity prevalence (drawn from the literature) (bespoke meta-analyses of two randomised controlled trials for both children<sup>20,21</sup> and adults),<sup>22,23</sup> Due to heterogeneity of study design we conducted random effects meta-analyses, therefore the parameters are averages of results reported in the literature, weighted by the inverse of the standard error. For most of these ~~categories~~ parameters, the prior distributions ~~of the parameters~~ were estimated using data from the source material. This was not possible for some of the parameters, where there are no published estimates of the ~~ir~~ uncertainty ~~of the parameters~~. In these cases, we categorised our confidence in the data source as either 'confident' or 'moderately confident'. For data sources categorised as 'confident' (data from LCF, BSDA, Holden et al.) we used normal distributions with the published estimate as the mean and set the standard deviation as 5% of the mean. For those categorised as 'moderately confident' (data from WRAP), we set the standard deviation as 10% of the mean.

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Due to unknown covariance between own-price and cross-price elasticities, we were unable to conduct a full probabilistic uncertainty analysis of the uncertainty due to the price elasticity matrix. The analysis conducted here is likely to capture most of this uncertainty (since the own-price elasticities drive most of the price effects from the price elasticity matrix) but some uncertainty associated with price change will be underestimated.

#### **References**

- 1 Deaton AS, Muellbauer J, Deaton A, Muellbauer J. An Almost Ideal Demand System. *Am Econ Rev* 1980; **70**: 312–26.
- 2 Department for the Environment Food and Rural Affairs. Family Food 2010. London, 2011.
- 3 Tiffin R, Arnoult M. The demand for a healthy diet: estimating the almost ideal demand system with

- infrequency of purchase. *Eur Rev Agric Econ* 2010; **37**: 501–21.
- 4 Barten AP. Maximum likelihood estimation of a complete system of demand equations. *Eur Econ Rev* 1969; **1**: 7–73.
- 5 Elteto O, Koves P. On a problem of index number computation relating to international comparison. *Statisztikai Szle* 1964; **42**: 507–18.
- 6 Szulc B. Indices for multiregional comparisons. *Prz Stat* 1964; **3**: 239–54.
- 7 Diewert WE. Exact and superlative index numbers. *J Econom* 1976; **4**: 115–45.
- 8 Edgerton DL. Weak Separability and the Estimation of Elasticities in Multistage Demand Systems. *Am J Agric Econ* 1997; **79**: 62–79.
- 9 Tiffin R, Kehlbacher A, Salois M. The Effects of A Soft Drink Tax in the UK. *Health Econ* 2015; **24**: 583–600.
- 10 Finkelstein EA, Zhen C, Nonnemaker J, Todd JE. Impact of targeted beverage taxes on higher- and lower-income households. *Arch Intern Med* 2010; **170**: 2028–34.
- 11 Office for National Statistics. Family Spending: 2015. A report on the Living Costs and Food Survey 2014. London, 2015.
- 12 Oxford Economics. The economic impact of the soft drinks levy. Oxford, 2016  
[http://www.britishtsoftdrinks.com/write/MediaUploads/Publications/The\\_Economic\\_Impact\\_of\\_the\\_Soft\\_Drinks\\_Levy.pdf](http://www.britishtsoftdrinks.com/write/MediaUploads/Publications/The_Economic_Impact_of_the_Soft_Drinks_Levy.pdf).
- 13 British Soft Drinks Association. Leading the Way. Annual report 2016. London, 2016.
- 14 Ma Y, He FJ, Yin Y, Hashem KM, MacGregor GA. Gradual reduction of sugar in soft drinks without substitution as a strategy to reduce overweight, obesity, and type 2 diabetes: a modelling study. *Lancet Diabetes Endocrinol* 2016; **4**: 105–14.
- 15 Quested T, Ingle R, Parry A. Household Food and Drink Waste in the United Kingdom 2012. Banbury, 2013.
- 16 Public Health England. National Diet and Nutrition Survey: Results from Years 1 - 4 (combined) of the Rolling Programme (2008/2009 – 2011/12). London, 2014.
- 17 Pereira MA. Sugar-sweetened and artificially-sweetened beverages in relation to obesity risk. *Adv Nutr* 2014; **5**: 797–808.
- 18 Imamura F, O'Connor L, Ye Z, *et al*. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: systematic review, meta-analysis, and estimation of population attributable fraction. *BMJ* 2015; **351**: h3576.
- 19 Nadimi H, Wesamaa H, Janket S-J, Bollu P, Meurman JH. Are sugar-free confections really beneficial for dental health? *Br Dent J* 2011; **211**: E15.
- 20 de Ruyter JC, Olthof MR, Seidell JC, Katan MB. A trial of sugar-free or sugar-sweetened beverages and body weight in children. *N Engl J Med* 2012; **367**: 1397–406.
- 21 Ebbeling CB, Feldman HA, Chomitz VR, *et al*. A randomized trial of sugar-sweetened beverages and adolescent body weight. *N Engl J Med* 2012; **367**: 1407–16.
- 22 Maersk M, Belza A, Stødkilde-Jørgensen H, *et al*. Sucrose-sweetened beverages increase fat storage in the liver, muscle, and visceral fat depot: a 6-mo randomized intervention study. *Am J Clin Nutr* 2012; **95**: 283–9.
- 23 Tate DF, Turner-McGrievy G, Lyons E, *et al*. Replacing caloric beverages with water or diet beverages for weight loss in adults: main results of the Choose Healthy Options Consciously Everyday (CHOICE) randomized clinical trial. *Am J Clin Nutr* 2012; **95**: 555–63.
- 24 Health and Social Care Information Centre. Health Survey for England 2014. London, 2015.
- 25 Royal College of Paediatrics and Child Health. School age charts and resources. 2015.  
<http://www.rcpch.ac.uk/improving-child-health/public-health/uk-who-growth-charts/school-age-2-18-years/school-age-charts-an>.
- 26 Christiansen E, Garby L. Prediction of body weight changes caused by changes in energy balance. *Eur J Clin Invest* 2002; **32**: 826–30.
- 27 Briggs ADM, Mytton OT, Kehlbacher A, Tiffin R, Rayner M, Scarborough P. Overall and income specific effect on prevalence of overweight and obesity of 20% sugar sweetened drink tax in UK: econometric and comparative risk assessment modelling study. *BMJ* 2013; **347**: f6189.
- 28 Hall KD, Jordan PN. Modeling weight-loss maintenance to help prevent body weight regain. *Am J Clin Nutr* 2008; **88**: 1495–503.
- 29 Holden SH, Barnett AH, Peters JR, *et al*. The incidence of type 2 diabetes in the United Kingdom from 1991 to 2010. *Diabetes Obes Metab* 2013; **15**: 844–52.
- 30 Bernabé E, Vehkalahti MM, Sheiham A, Lundqvist A, Suominen AL. The Shape of the Dose-Response Relationship between Sugars and Caries in Adults. *J Dent Res* 2016; **95**: 167–72.



**Supplementary table 1. Price elasticity matrix**

	Dairy & Eggs	Meat & Fish	Fats & Starches	Fruits & Nuts	Veg	Milk	Water	Fruit Juice	SD conc, diet	SD conc, regular	SD conc, mid-range	SD diet	SD regular	SD mid-range	Tea & Coffee	Other beverages	Beer	Wine	Other alcohol
Dairy & Eggs	-0.534	0.000	-0.004	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.003	0.000	-0.003	0.000	0.000	0.002	0.000
Meat & Fish	0.000	-0.633	-0.005	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.003	0.000	-0.003	0.000	-0.002	-0.015	-0.001
Fats & Starches	0.000	-0.003	-0.564	0.000	0.000	-0.005	0.000	0.000	0.000	-0.002	-0.002	-0.002	-0.016	-0.002	-0.016	0.000	0.001	0.010	0.001
Fruits & Nuts	0.000	0.000	0.001	-0.809	0.000	0.002	0.000	0.000	0.000	0.001	0.001	0.001	0.006	0.001	0.006	0.000	-0.003	-0.021	-0.002
Veg	0.000	-0.002	-0.004	0.000	-0.503	-0.003	0.000	0.000	0.000	-0.001	-0.001	-0.001	-0.008	-0.001	-0.008	0.000	-0.001	-0.004	0.000
Milk	0.000	0.000	-0.005	0.000	0.000	-0.971	0.000	0.000	0.000	0.003	0.002	0.002	0.018	0.002	0.017	0.000	0.002	0.017	0.002
Water	0.000	0.000	-0.001	0.000	0.000	0.017	-0.835	0.000	0.000	0.001	0.001	0.001	0.010	0.001	-0.041	0.000	0.001	0.005	0.000
Fruit Juice	0.000	0.000	-0.004	0.000	0.000	0.014	0.000	-0.977	0.000	0.004	0.002	0.004	0.026	0.004	0.024	0.000	0.002	0.013	0.001
SD conc, diet	0.000	0.000	-0.003	0.000	0.000	0.000	0.000	0.000	-0.940	0.103	0.068	0.010	-0.008	-0.001	0.007	0.000	0.001	0.009	0.001
SD conc, regular	0.000	0.000	-0.004	0.000	0.000	0.001	0.000	0.000	0.004	-0.881	-0.023	0.017	0.045	0.006	0.010	0.000	0.002	0.014	0.001
SD conc, mid-range	0.000	0.000	-0.004	0.000	0.000	0.001	0.000	0.000	0.005	-0.049	-0.879	0.018	0.046	0.007	0.011	0.000	0.002	0.015	0.001
SD diet	0.000	0.000	-0.006	0.000	0.000	0.001	0.000	0.000	0.000	-0.003	-0.002	-1.013	0.016	0.002	0.016	0.000	0.003	0.022	0.002
SD regular	0.000	0.000	-0.006	0.000	0.000	0.001	0.000	0.000	-0.001	-0.013	-0.009	0.003	-0.952	0.004	0.015	0.000	0.003	0.020	0.002
SD mid-range	0.000	0.000	-0.006	0.000	0.000	0.001	0.000	0.000	-0.001	-0.013	-0.009	0.003	0.035	-0.976	0.015	0.000	0.003	0.020	0.002
Tea & Coffee	0.000	0.000	-0.005	0.000	0.000	0.010	0.000	0.000	0.000	0.006	0.004	0.006	0.044	0.006	-0.938	-0.002	0.002	0.017	0.002
Other beverages	0.000	0.000	-0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.002	0.001	0.001	0.011	0.001	0.099	-0.680	0.001	0.004	0.000
Beer	0.000	-0.002	0.003	0.000	0.000	0.005	0.000	0.000	0.000	0.002	0.001	0.002	0.015	0.002	0.015	0.000	-1.009	0.015	0.002
Wine	0.000	-0.003	0.005	0.000	0.000	0.007	0.000	0.000	0.000	0.003	0.002	0.003	0.022	0.003	0.021	0.000	0.000	-1.008	-0.001
Other alcohol	0.000	-0.002	0.003	0.000	0.000	0.005	0.000	0.000	0.000	0.002	0.001	0.002	0.015	0.002	0.015	0.000	0.003	0.000	-0.934

SD, soft drink; conc, concentrated

**Supplementary table 2. Baseline SSB consumption from NDNS years 1-4**

Age and sex group	Sugar drink consumption (ml/d)
Boys, 4-10	139
Boys, 11-18	310
Men, 19-64	160
Men, 65+	54
Girls, 4-10	117
Girls, 11-18	210
Women, 19-64	112
Women, 65+	53

SSB, sugar sweetened beverage; NDNS, National Diet and Nutrition Survey

**Supplementary table 3. Change in obesity prevalence using an energy balance equation**

Scenario	Change in number of obese individuals
<u>1: Reformulation best case</u>	<u>908773 (502697 to 1203852)</u>
<u>2: Reformulation worst case</u>	<u>168549 (96762 to 229847)</u>
<u>3: Price change best case</u>	<u>484621 (272800 to 651200)</u>
<u>4: Price change worst case</u>	<u>206642 (112800 to 282900)</u>
<u>5: Market share best case</u>	<u>592034 (324255 to 791264)</u>
<u>6: Market share worst case</u>	<u>-59925 (-33520 to -83278)</u>

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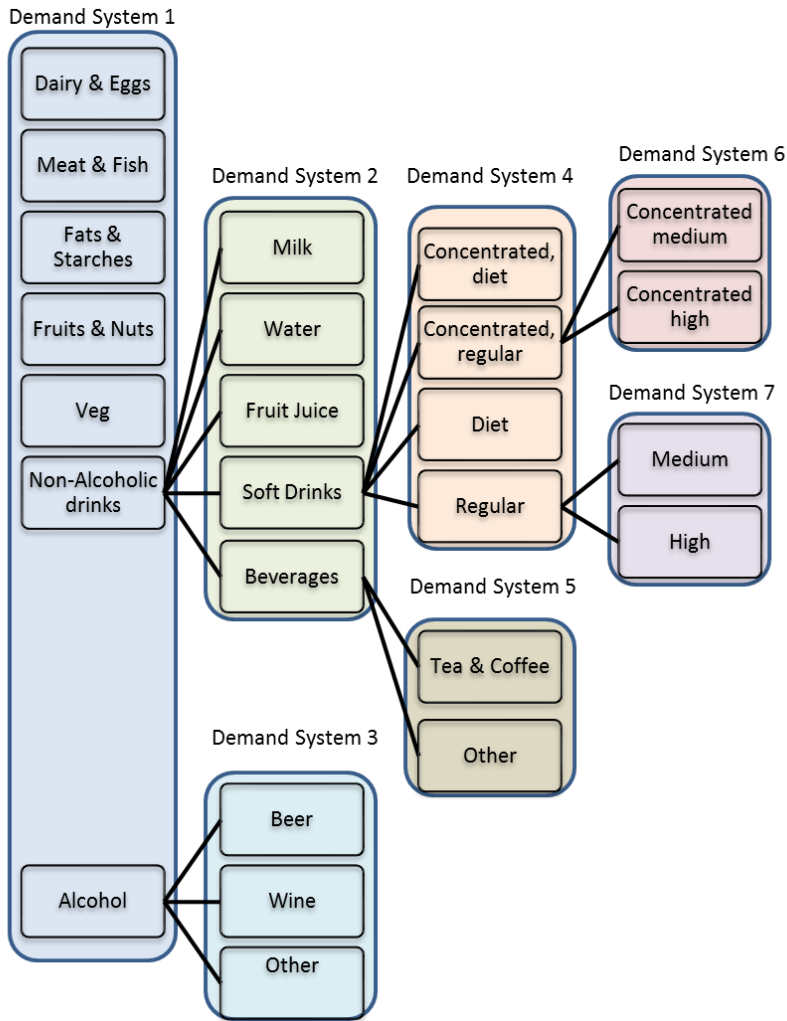
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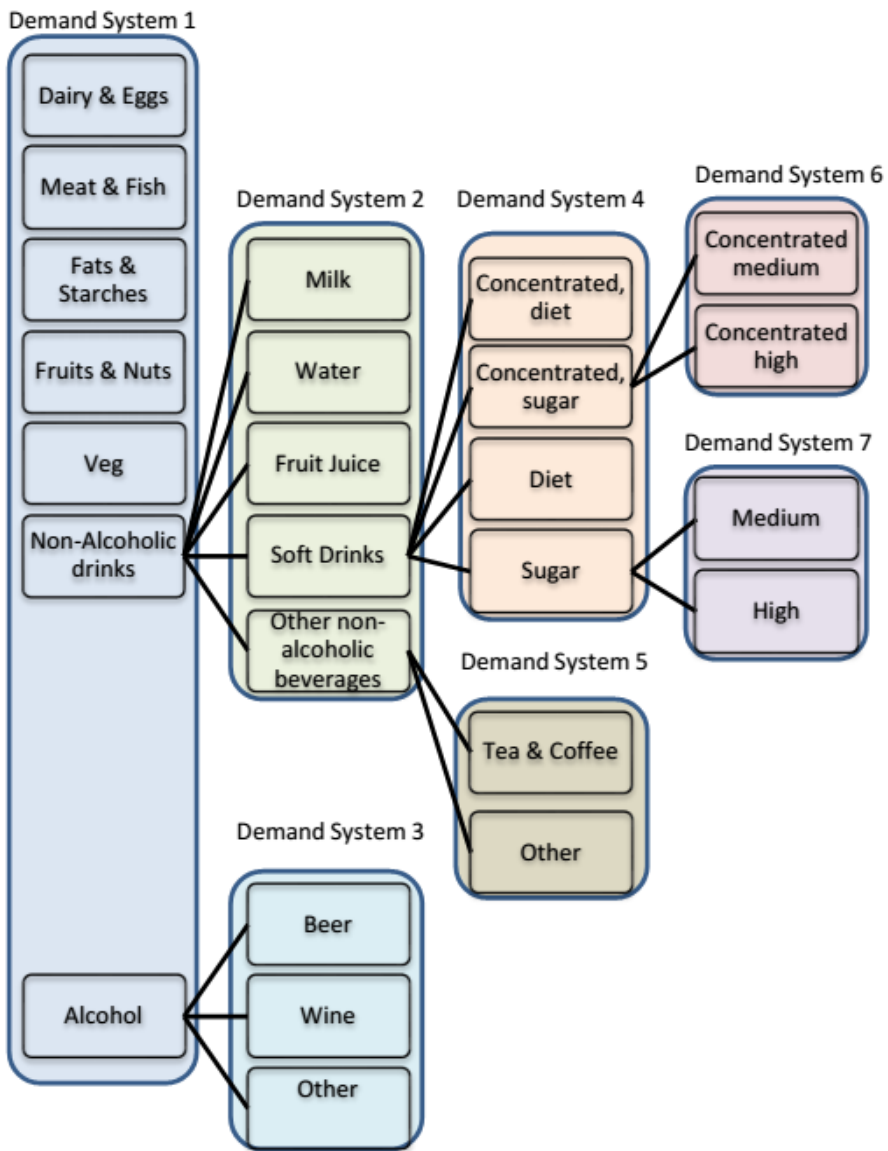
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**Supplementary figure 1.** Demand system hierarchy for economic modelling





Response to reviewers

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Title: A health impact assessment of the UK soft drinks industry levy: a comparative risk assessment modelling study

*Many thanks to the reviewers for their extremely thoughtful and positive comments. Please find our responses below (in italics throughout).*

*In addition to the changes made, you will note that the numbers for the market share scenarios have changed slightly. This is due to a small error identified in our modelling when running the sensitivity analyses. The error does not change the ranking of the scenarios, however it does change scenario 6 (worse case for change in market share) from having small positive health outcomes to small negative health outcomes. This reinforces the message that an increase in mid-sugar drink market share needs to come from high-sugar drink consumers rather than low-sugar drink consumers. We have made minor changes to the text throughout to reflect this change in the results.*

Reviewer #1:

This manuscript presents a risk assessment modelling study of the UK soft drinks industry levy. The aim of the levy is to reduce the population's exposure to sugar in order to reduce risks of dental caries, obesity and type 2 diabetes. The modelling study is performed to estimate the health effects of future changes in product reformulation, price, and market shares. Product reformulation represents the best scenario, and this results in 144000 fewer cases of obesity, 19000 fewer cases of diabetes, and 269000 fewer cases of dental caries. The uncertainty intervals are, however, wide and the methodology is unclear. I have a few comments on this.

First two major points.

1. The structure of the model, causal relationships, and underlying assumptions can be described more clearly. The used statistical and epidemiological techniques need to be presented in more detail to facilitate the reader's critical interpretation of the presented findings.

*We have added redrafted the 'health impact modelling' section of the methods to include a description of comparative risk assessment modelling methods and to better guide the reader through the main steps of the model. The detail of the model has also been updated in the supplementary material, including providing greater detail on the data sources.*

2. Please describe especially how the inferential uncertainty of the included parameters has been taken into account in the modelling. For example, Table 3 describes the used parameters and their confidence intervals, but it is unclear whether the information refers to meta-analysis results from fixed effects models (estimating a common effect) or from random effects models (estimating an average effect), see e.g. Riley RD, Higgins JPT, Deeks JJ. Research Methods & Reporting: Interpretation of random effects meta-analyses. Br Med J 2011;342:d549, which has consequences for the modelling results.

*We have updated the section titled 'Uncertainty analysis' in the methods section of the manuscript and in the supplementary material to provide more general information about how the Monte Carlo analysis was conducted. We have also updated this section to specify that the meta-analysis results for the body weight modelling were conducted using random effects meta-analyses.*

Then some minor points.

3. The data incorporated into the model can be described more clearly.

*We have updated the supplementary material throughout to give a clearer description of model parameters and data inputs.*

4. Has sensitivity analyses been performed in order to evaluate structural uncertainty?

*We note that the design of the paper (modelling best and worst cases for each scenario) could be described as sensitivity analyses. In addition, in order to test key model assumptions, we have conducted new sensitivity analyses to test the effect of changing the level of pass-through of taxes in the price change scenarios and to change the method of modelling change in body weight in adults (from the meta-analysis of RCTs to equations linking kcal intake and body weight).*

5. Has heterogeneity been evaluated, e.g. by separate modelling in different subgroups?

*Heterogeneity of different subgroups has not been evaluated and is beyond the scope of this paper. For many population subgroups, data availability is poor and would add extra uncertainty to what already are uncertain results. We also think that it would add too much complexity to a paper that is intended to inform policy and as such benefits from relative simplicity – any subgroup analysis would exponentially increase the number of results presented (which already stand at 6 scenarios and 3 disease outcomes). We have added a sentence on this to the limitations section of the discussion.*

Reviewer #2:

This is an important and timely contribution which attempts to model the potential impact of the first tiered sugar sweetened beverage levy approved anywhere. The UK government recently closed a consultation period and will only set out detailed legislation in the Finance Bill 2017, with implementation expected from April 2018 onwards. Sugar sweetened beverage taxes are one of the major policy options under study for preventing obesity, both for their potential direct effects on consumption, as well as the effects of use of revenue for prevention or other purposes, and were recently endorsed by the WHO. Evaluation results to date are limited, with the strongest data from Mexico, some from France and Hungary, and from the small city of Berkeley, CA in the US.

The specific study appears generally well conceived and models three relevant potential industrial responses to the levy - reformulation for which tiered taxation offers an innovative incentive, price changes - the traditional route of sin tax impact, and market shifts between low, medium and high sugar beverages. It looks at 3 health outcomes of the scenarios - effects on obesity, diabetes and tooth decay. The study omits a fourth obvious possibility of industry response, which is market shifts to smaller bottles and cans, or other portions which pay less tax but may have higher price per ounce, a strategy which is already being seen in some places in the US. The paper would be strengthened by inclusion of a portion size model, or should explain why it was omitted.

*We are aware of the reduction in portion size is not explicitly modelled despite being mentioned by the Chancellor as a potential industry response. We discussed this at length between the authors as there are significant challenges to modelling portion size reduction. There are questions as to which drinks change size and by how much. If we were to assume cans change from 330ml to 250ml, this*

*requires at least some data on the proportion of soft drink bought by size (presently we use Living Cost and Food Survey data which tells us the volume of soft drink purchased but not how much is purchased in different quantities). Then there is the question about whether reduction in portion size should be modelled as with reformulation (i.e. that people do not change their purchasing behaviour, but consume less because less is being sold) or whether it should be modelled using an econometric method (i.e. a drop in portion size is equivalent to a price increase per ml of drink and consumers respond accordingly). If it is the former, then this will tell us nothing beyond what the reformulation scenario tells us. The latter approach appears to go against conventional wisdom that reducing portion size will reduce consumption by 'stealth', although it seems plausible that there will be some compensatory behavioural response. In reality there is probably a mix of both patterns, the magnitude of which is unknown.*

*We therefore decided that instead the change in portion size change is captured by the change in market share, however, we had not stated this clearly in the paper (it was mentioned briefly in the third paragraph of the introduction). We have therefore changed the methods section to reflect this. This basis for this is that if the aim is to only reduce consumption of high sugar drinks and vendors reduce the sizes of high sugar drinks it may shift people towards lower sugar alternatives and this can be seen in the same light as using marketing/availability to change people to lower sugar alternatives.*

The most important limitation is the extent of the many assumptions used and their impact on the models, which pushes them to conservative estimates, particular for price impacts, which may constrain the validity of the hierarchy of impact, but might not change the order. The overall suggestion that the potential impact of reformulation is greater than the likely impact of price elasticity or marketing shifts is important and argues for the tiered model of taxation - or for direct regulation of sugar content.

*We have added to the 'modelling price change' section of the supplementary data two sentences stating that uncertainty in household responses to changing prices is greater with larger modelled price increases.*

Specific comments include:

(page numbers refer to PDF pages not bottom of page numbers)

Abstract: The time frame for changes in obesity is unclear, whereas it is specified for diabetes and tooth decay.

*This is because the obesity is modelled as a change in the steady state population of obese individuals rather than as a change in incident rate. We have added 'in the UK' to the abstract to try and emphasise that this is the final reduction in the obese population. We have changed the 'health impact modelling' section of the methods to reflect this, and clarified this in the first paragraph of 'estimating health outcomes' and in the 'modelling obesity' section of the supplementary data. We have also added an explanation of a comparative risk assessment model to the beginning of the methods to make it clear that this is a cross-sectional model.*

Page 3 paragraph 1: The UK is not unique in proposing a tiered levy, this was also proposed to the US Congress in the Sweet Act in the 2015-2016 session where the tax was directly proportional to the grams of sugar. It is unique in moving forward on the proposal. Similar comment for Page 6 paragraph 2.

*We have altered the text accordingly.*

Page 6 paragraph 2: as mentioned, while the authors cite portion size reduction as an objective of the tax, they do not model it, which is surprising as it would otherwise seem to fit well with the approach taken. Previous modeling for the UK by McKenzie Global Institute (Overcoming Obesity: an Initial Economic Analysis, November 2014) concluded that changes in portion size of foods, followed by reformulation, would have the greatest potential impact on obesity.

*McKinsey estimated the health impact of incremental reductions in the portion sizes of packed goods by 1-5%, including a ban on supersized goods, and the data are focused predominantly on the US market where portion sizes tend to be much larger than in the UK. It is unlikely within the pre-packaged soft drinks market that small incremental portion size changes could happen due to the infrastructure around the vending industry and bottle/can manufacturing. Instead step-wise falls in portion size are more likely. As such, this remains a very challenging thing to model in isolation, hence see previous response above.*

Page 6 paragraph 3: Authors state that pass-through of a tax cannot be mandated. Is that correct legally? An excise tax such as this is simplest and more difficult to mandate pass-through but other approaches could be used.

*This is our understanding from conversations with HM Treasury.*

Page 6 paragraph 5: The timeframe for the analysis should be made clear here - e.g. we modeled the impact of one year of the levy had it been implemented in 2013, on 2014 outcomes, or whatever best summarizes the model.

*Change made.*

Page 7 paragraph 5: I was somewhat surprised by the very conservative assumptions on tax pass-through. While published results to date are in the range described (or slightly above for carbonated beverages where pass-through has been complete), even the optimistic scenario combined a 50% pass-through with an absolute 20% cap, even though the tax on high sugar was described as 75% and 31%. This seems excessively conservative and likely to reduce the estimated effects of price changes in relationship to other responses. While most soda taxes to date have not tested these higher levels there is no reason. I am aware of to assume that producers and distributors would completely fail to pass on the larger proportion, if there is the authors should justify it. This has not been the case in cigarette taxation for example, where taxes comprise the bulk of the price in some jurisdictions. It might be appropriate for the high effect scenario not to cap the percentage before calculating the partial pass-through, even if assuming a partial pass-through of 50% - I believe that is one of the columns in the table now.

*We discussed this at length and there is no data to guide us either way. As such, we made a decision to cap the potential price increase at 20% as within the soft drink market, this is the largest price increase that has been seen elsewhere. Although other countries have passed the tax on at around 100%, their absolute tax rates are much lower than that being proposed in the UK (we have added a sentence to the methods 'scenarios' to make this clear). We agree that there is significant uncertainty in industry response and that this is a novel tax structure. Therefore, we have added a 100% pass through as a sensitivity analysis and included this in the results section and discussion. It should be noted that the greater the price increase, the greater the uncertainty in how price elasticities reflect true household response. We have added a note on this to the 'modelling price change' section of the supplementary material.*



Page 9 paragraph 2-3: Obesity impacts lack a timeframe - per year for example, here and throughout.

*We have made changes to the methods and supplementary data to clarify that there is no specific timeframe to the obesity scenario, and in the strengths and limitations section there is already a comment on the time period over which we would expect weight changes to take place.*

Page 10 paragraph 3: To uncertainties I would add "extent of price pass-through". Would also note that the uncertainty in regard to the relationship between SSB consumption and health outcomes, in general and specifically at different ages.

*We have added that we have not estimated uncertainty from pass-on rate (although we have added a sensitivity analysis estimating a 100% pass-on), and we have added that we could not model child-specific estimates of how SSBs affect DMFT and diabetes due to lack of data. Uncertainty in the overall relationship between SSB consumption and health is already included in the uncertainty intervals as mentioned at the beginning of the paragraph in question.*

Page 10 paragraph 5: You also state that you have not "modeled a temporal component." However the studies on which the risks assessments were based all involved some period of observation, this should be addressed more clearly in the supplemental methods and here.

*The supplementary data and discussion already include that the periods of observation for the effect on body weight are 6 and 12 months for adults and children. The meta-analysis of the relationship between diabetes incidence and SSB consumption is from a range of cohort studies across a range of median observation periods between 3 and 21 years. Equally the relationship for DMFT was over 11yrs however the effect from SSBs on DMFT could be any length of time within this period. As these are not intervention trials, it is not possible to use them to estimate the time to disease outcome from a given exposure. We have updated the discussion to include the range of median follow up from the diabetes meta-analysis, and the supplementary data has been updated to reflect this point as well. However, we have not updated the main text to say the length of follow up for the dental caries cohort study as it would be misleading to suggest that it would take 11 years for a change in SSB habit to reduce SSB consumption.*

Page 11 paragraph 1: Here you state that using your model a 100% pass-through would have surpassed the effects of scenario 1. Do you mean 100% pass through with no capping of the percentage or 100% with the true percentages of the levy? If the former than using the true percentages of the levy, even with lower pass through, might surpass scenario 1, which would change the conclusions.

*We have added in the 100% pass through (with no capping) as a sensitivity analysis.*

Page 11 paragraph 1: spelling error "energy."

*Thank you.*

Page 11 last paragraph: where you speak of uncertainty it may be useful to recognize more explicitly that in general these are conservative estimates both because of your estimates on pass-through and because they do not model the effects of the revenue use.

*We have not added this to this paragraph because we have been explicit in our model comparisons with other studies about how our pass-through rates differ (noting that this is for only two of our six*

*scenarios), and also the studies we are comparing to do not estimate the effect of revenue use (we acknowledge that we do not estimate the effect of revenue use in the final paragraph of 'strengths and weaknesses').*

Page 12 paragraph 3: The conclusion could benefit by noting the conservative nature of the estimates.

*We have added this to the 'interpretation and implications', highlighting the possibility of greater pass-on rates and of greater reformulation than modelled.*

Page 16 table 1: The description of the price change scenarios is not entirely clear. In 3 do you mean the tax is passed on solely to the taxed beverage (vs. 4 where it is spread across packaged beverages)?

*Yes, we have changed table 1 to make this clearer.*

Table 5 - specify time frame for obesity cases

*As explained, there is no timeframe for this, changes have been made throughout the text to help readers to interpret these data.*

Page 22 paragraph 1: Spell out LCF the first time it appears

*Change made, thank you.*

Page 23 paragraph 3-5: Here are you referring to a one year change in prevalence of obesity in 2014 or to newly incident cases? Do you mean the change you measured is for prevalent cases of obesity in 2014 had the tax been in effect for [x] period of time prior to that (as opposed to diabetes where you used incidence)? This should be clear in the main paper as well as the supplement for all outcomes.

*We have changed the text in the supplementary data and throughout the manuscript to make this clear.*

The childhood overweight and obesity measures are also conservative in numbers of cases as they use the UK recommended cut-points which differ from those in use in many other countries based on the 95th percentile for obesity in children.

*We were unaware of this, however we have not changed the text because our results apply to UK statistics.*

The stated assumption that the impact on diabetes and tooth decay will be the same in children and in adults is of some concern. Similarly the stated assumption that the relative risk for diabetes is the same in children is a weakness. Though without it likely would not be possible to estimate changes for children.

*As you state, we unfortunately do not have specific data for children to be able to estimate these effect sizes (we have added this to 'strengths and weaknesses').*

I was also unclear on how the cross-price elasticity was employed as opposed to the own price elasticity, although that reflect a non-economist background, it would be helpful to be explain more clearly to the reader.

*The effect of own-price and cross-price elasticities were applied using a matrix as is standard in this situation. This allows for both effects to be taken into account when estimating results. We have added this to 'Modelling price change' in the supplementary data.*

Reviewer #3:

I think this is a very timely and important paper.

Page 4 - para 2 - change 'levy will be introduced' to pending levy or 'levy may be introduced' or something along those lines as the levy has not gone through parliament yet

*Thank you, change made.*

Page 5 - para 4 - can you explain briefly in the text how the 'increase in price by 75% and high-sugar regular drinks by 31%' was worked out?

*We have added this to the end of the modelling price change section of the supplementary material.*

Page 7 - para 1 - can you convert the fall in average sugar content of SBB to sugars in grams and energy in calories? Quoting mls seems like an unusual way of reporting this finding.

*We have added the change in energy, we have not quoted the amount of sugar in order to be consistent as this is not reported throughout the manuscript.*

Page 7 - para 3 - impressive finding.

Reviewer #4: MAJOR COMMENTS

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> The analysis is generally sound (although I do have a number of questions and comments; see below). The range of outcomes (numbers of people with obesity, new cases of type 2 diabetes and dental caries) is limited and not justified in the paper, which is a weakness. The analysis is also limited to short-term effects and here again, not carried through to the full health impact. For instance, effects on heart disease, stroke, low back pain and osteoarthritis are not included, and hence the results give only part of the health benefits associated with SSB taxation. However, to have an impact on policy, this may not be a grave hindrance and I expect that this paper will be useful to inform the debate in the UK and elsewhere.

*Thank you for this comment. Our aim was to model the direct or proximal health effects of SSB consumption. SSB consumption is associated with dental caries and diabetes independently of body weight. SSB consumption is associated with raised BMI, and raised BMI is associated with a very wide range of health outcomes, for simplicity rather than represent all of these conditions, as others have done, we have modelled just to weight gain. We have changed the methods to indicate that we are modelling direct health impacts, and we have added to the 'strengths and weaknesses that we did not model long term health gains from falls in obesity.*

>

> P.5: Scenario 3 has a pass-on rate of 50% and a cap of the increase in price of maximum 20%. I find these choices overly cautious, not well supported by the available evidence, and unrealistic. True, in small Berkeley the tax does not seem to have been passed on in full, but in larger jurisdictions like Mexico or France, it has. The UK is more like the latter than the former. Moreover, I question whether the companies concerned could afford to absorb the tax. (It would be interesting to see how much this would depress profits, maybe the authors could add such an analysis if they prefer to stick to the current setting?)

*We agree that in other contexts pass through rates have been much closer to 100% than 50%, however the subsequent price changes have been much smaller due to lower absolute tax rates than is proposed in the UK (we have added a sentence to the methods 'scenarios' to make this clear). We discussed this at length among the authors as there is no precedent for the size of the proposed levy. We thought it was more realistic for producers not to give consumers such a price shock as would result from up to 70% price increases. However, in response to this comment and to comments from reviewer 1 we have added in a 100% pass through as a sensitivity analysis, and have mentioned this in the discussion. Also, as we responded to reviewer 2, it should be noted that the greater the price increase, the greater the uncertainty in how price elasticities reflect true household response. We have added a note on this to the 'modelling price change' section of the supplementary material.*

> P.7 & appendix: All scenarios give results for obesity that do not include 'no effect'. This is strange, given that Table 3 gives the increase in weight per 100ml of SSB for adults as 0.09 kg/m<sup>2</sup> with a 95% CI that spans from -0.11 to 0.29. Of course, such an uncertainty in the driving effect must translate to similarly broad uncertainty ranges in the results. The fact that it does not is due, I suspect, not only to the contribution of the more certain impact on children, but also to the use of independent draws for the distributions for the separate age (and sex) groups. In this, the eight groups ensure that the uncertainty is 'drowned out' by high and low estimates tending to balance. But this is an artefact: had the authors used a hundred age-sex groups, the uncertainty intervals would be very narrow. They should instead link the uncertainty in all adult age groups to one single draw to be consistent with the source study cited in Table 3, and likewise for the children.

*This is a good observation and the reviewer's explanation is partly correct. However, we do not make independent draws for different age and sex groups in the model, precisely to avoid the statistical artefact described by the reviewer. The fact that the uncertainty intervals for obesity do not cross zero is entirely due to the fact that the results for children 'drown out' the results for adults (as the reviewer suggests. This is not surprising since the effect size in children is five times bigger than for adults. We reran the uncertainty analyses restricted to adults only and produced the following results which include uncertainty intervals that overlap with zero:*

Scenario	95% Uncertainty Intervals for reduction in number of obese adults
1: Reformulation best case	(-58,341 to 162,559)
2: Reformulation worst case	(-10,592 to 29,839)
3: Price change best case	(-32,786 to 91,182)
4: Price change worst case	(-11,810 to 32,683)
5: Market share best case	(-35,545 to 101,443)
6: Market share worst case	(-10,090 to 3,562)

*We have added a comment to the results to clarify this.*

> Because this would result in 'insignificant' estimates and it seems rather unlikely that a reduction in SSB consumption would lead to an increase in body mass, this may prompt a re-think of the

decision to base this aspect of the analysis on the evidence of the two RCTs available, which as discussed in the appendix, are far from perfect. I would have more confidence in the approach previously used by the authors, that is, to use an energy balance to estimate the impact.

*We have conducted a sensitivity analysis where the results for adults are modelled using equations linking energy balance and body weight (as expected, these are significantly greater than when estimating the direct effect from SSBs). The results of the sensitivity analysis are reported in the supplementary data with reference to this in the methods and discussion of the manuscript. In the supplementary data we also discuss how our modelled obesity results compare against the gold standard of energy balance equations developed by Kevin Hall.*

> MINOR COMMENTS

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> P.9: Is it possible to comment on how dilutables are most likely to be taxed?

*It is stated by the government in their consultation that they would be taxed as drunk (i.e. once diluted). We have made this clear in the methods.*

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> Supplementary material:

> I am confused about the source of data for the baseline drink consumption data: was it the LCF or the NDNS, or if both, how were they combined? The text reads: "Baseline drink consumption was taken from the 2014 Living Costs and Food Survey (LCF)." But also: "Age and sex specific estimates of drinks consumed were derived by dividing the total purchased according to the relative consumption of each drink category reported by The National Diet and Nutrition Survey rolling programme, 2008/09-2011/12 (NDNS)." More explanation is needed.

*We used LCF to estimate baseline per person SSB consumption in preference to NDNS as this is the same data source as used for our price elasticity estimates. LCF do not estimate consumption by age and sex so we therefore used estimates by age and sex from NDNS to weight the LCF consumption. We have changed the wording in the supplementary material to make this clearer.*

> "... baseline volumes of soft drinks consumed were adjusted to fit BSDA reported 2015 market shares" From where were they adjusted? Was this a major or a minor change from the LCF 2010 data?

*Volumes were adjusted from the LCF baseline. As reported in the text, LCF 2010 data suggest the market share of low-, mid-, and high-sugar drinks is 50%, 17% and 33% respectively. This compares to 58%, 6%, and 36% reported by BSDA (table 1). Proportional adjustments of concentrated and non-concentrated high, mid and low sugar SSBs were made such that the appropriate volumes were in each category to give the overall BSDA market share before scenarios 5 and 6 were modelled. We have updated the text to make this clearer.*

> How was obesity modelled? Was consumption and the translation to BMI made on individual records in the HSfE, or on aggregate measures? If (as I suspect) it's the former, did this take into account any population weighting that survey probably has?

*The obesity modelling was based on shifts in the distribution of BMI that were estimated from the raw HSfE data that were weighted for non-response using the derived variables from the HSfE dataset. We did not shift individual bodyweights – rather the estimated lognormal distribution of body weight for each age-sex group was shifted to the left or right according to the average change in body weight estimated by the scenario.*

Reviewer #5:

This is an important paper that provides a useful layout of some of the ways in which industry might respond to the proposed SSB tax in the UK. The analysis has many components, which seems appropriate in general, but require more clarification and consistency in terminology across them in order to minimize confusion for a very complex approach. There is also a need to add more discussion on a number of issues described below.

*In response to reviewer 1's concern about the transparency of the methods used and the assumptions made, we have made amendments to the methods section of the main paper and the supplementary material. We hope this resolves the reviewer's concerns about clarification of methods.*

1) There seems to be a contradiction on page 5 about whether the concentrates are being taxed at the rate of the manner in which they are bought or in the manner in which they are consumed (diluted). In the 3rd paragraph it's suggested that they are taxed based on the sugar content of the concentrated product itself: "and if the tax was entirely passed through to consumers, high-sugar concentrated drinks would, on average, increase in price by 75%". However in the next paragraph it says: "Tax rates were applied to concentrated drinks given their price per litre as drunk assuming a ratio of concentrate to water of 1:4 as used by the British Soft Drinks Association (BSDA)." Which is it (I think it's the latter)? And how does this change the simulation? Or am I not understanding what is meant in the 3rd paragraph?

*This is a misunderstanding. The tax is calculated based on the concentration of sugar after dilution (as consumed), and this would lead to a 75% price increase of the concentrated product.*

2) For the two reformulation scenarios, it is unclear why the authors would assume that the volume consumed would remain constant. If it's in order to have conservative estimates, please say so. One would expect that even with some reformulations, some beverages would still be subject to tax (perhaps lower tax, but taxed nonetheless) and depending on the degree of pass-through affect purchases.

*We accept that in reality a blended response combining a mixture of tax, reformulation and change in market share is most likely. However there is considerable uncertainty about the size of each response, for this reasons we chose to simulate three discrete categories of industry response in order to estimate possible effects on health. As we state in the discussion, is it likely that industry will respond with a combination of all three however this leads to huge array of possible scenarios and does not answer the question about how each type of response might affect health in isolation. We hope that the results will then be able to help guide the finer details of the levy and its subsequent introduction.*

3) Obviously reformulations might result in changes in the market share, but the authors have treated these as 2 separate responses. Clearly the consumer response also matters. There is a need to have a discussion about this in general.

*Please see response to comment 2. We have updated the introduction and discussion to make it clear that this is the aim of the manuscript.*

4) I found the description of the "equivalized SSB consumption" unclear. It might be useful to provide a short example in the text or the footnotes to Tables 4 & 5.

*We have added an example to provide clarity.*

5) What time-frame for the changes in purchases is being modeled? Are these expected to be immediate? Are they assuming those reductions are sustained?

*The model is cross-sectional and so compares a scenario with the changes in purchases to one without. There is no temporal component as explained in the supplementary material and outlines in the discussion. We have added more detail on comparative risk assessment models to the beginning of the methods in the manuscript, and added more detail about the possible timeframes around each health outcome in the supplementary material.*

6) Table 6 should have % reduction for the total row.

*Thank you. We have added the reduction in incidence per 100,000 person years to the final row.*

7) Modeling price changes

- What is the LCF data? It is only described later, but given that there is a 2014 version, why not use that rather than the 2010 version?

*We have used 2010 LCF data for the econometric modelled to be consistent with the 2010 Kantar data that we have available to us. We have added a description of the LCF data to the supplementary material.*

- Are the results in Supplemental table 1 based on models conducted on the Kantar data? I am confused about what level of data is available between LCF and Kantar!! And what was used for the demand system estimates to produce the price elasticities table!

*The results in table 1 are based on the model estimates of the demand systems where demand systems 1-5 are estimated using LCF data and demand system 6&7 are estimated using Kantar data. The LCF data contains 270 food and drink categories but the drink categories are rather broad (soft drink no sugar, soft drink sugar, soft drink concentrated sugar, soft drink concentrated no sugar). We use the Kantar data to further split up the sugary soft drink categories into different sugar content levels (demand system 6 and 7). The estimated coefficients for each demand system are used to compute the conditional elasticities for each demand system. The conditional elasticities of the different demand systems are then used to compute the unconditional elasticities using the method by Edgerton (1997). This ensures that food expenditure is allowed to vary between all food and drink categories.*

- In the censored AIDS models, did they apply restrictions (i.e., homogeneity and symmetry)? Often times endogeneity in the prices and expenditures are also an issue that is raised. Please briefly address these.

*We have added the following to the text: "Adding up, symmetry, homogeneity and concavity are imposed in the estimation. Because the covariance matrix is singular we drop one of the share equations, obtaining estimates that are invariant to which equation is dropped.(Barten, 1969) Food and drink categories are aggregated using the EKS quantity index (Elteto and Koves, 1964; Szulc, 1964), which is a multi-lateral version of the superlative Fisher Ideal index, and is used to compute*

*the implicit price index. A superlative index (Diewert, 1976) offers some mitigation towards the concerns over the potential endogeneity of prices."*

- Supplemental Figure 1 Demand system 2 should have the last category be "Other non-alcoholic beverages".

*We have amended this figure.*

- In the text "Regular" is used to distinguish between concentrates that require dilution to drink and ready-to-drink beverages. However in the demand system, it is used differently. This is confusing.

*In the figure we now differentiate between "diet" and "sugar" soft drinks.*

8) There are other critical information missing in the paper. I've noted them here:

- Are sweetened dairy-based beverages also subject to the same bands of sugar amounts given that they also contain intrinsic sugars (lactose?). Seems like it, but probably best to explicitly clarify.

*No, dairy based drinks are not subject to the levy and are not included in the modelling. This is mentioned in paragraph 2 of the 'Scenarios' section of the methods.*

- The justification for scenario 6 is a bit weak and needs more explanation (why this over assuming no change in market share).

*In discussion among the authors, we thought that no change in market share was unrealistic and that there was a possibility that new mid-sugar products may attract consumers away from low-sugar drinks depending on how they were marketed (Coca-cola Life being a possible example). This would then present a worse scenario than no change in market share as it could potentially harm health (as we found with our modelling). There are of course an infinite number of possible scenarios that we could have simulated and these were felt to be the most informative for illustrating the possible implications of the levy for health.*

- Uncertainty intervals: do they mean what has typically been called "confidence intervals"? I realize there may be some ongoing debate about the term "Confidence intervals", which may be why these authors choose to use the term "uncertainty intervals" instead. Please at least explain briefly why the use of this term and what it is meant to reflect and how it's different from confidence intervals (later in the paper there is a brief discussion on this, but I think it's not enough).

*We use 'uncertainty intervals' to distinguish them from confidence intervals that are derived from estimating sampling uncertainty. Here, we are following the lead of the Global Burden of Disease study, which has set the standards for much of the work in the comparative risk assessment modelling field.*

9) Given that manufacturers are likely already reformulating in anticipation of the UK SSB tax, what would this mean in terms of changes one would see between now and before the tax is even implemented. Are the potential effects of reformulation more immediate (possibly even pre-tax)? It may be useful to discuss the potential staggered responses by industry given the timeline of when the tax would be implemented. One would expect that the industry would likely use a combination



some of the scenarios tested, and also at different times. It might be good to add a discussion on this and what this might mean for the estimated health outcomes.

*Industry is clearly responding to the levy already through reformulation (we have altered the 'Interpretation and implications' section of the discussion to reflect this). We have not modelled a temporal component although it is likely (and is the intention of the government) that reformulation and changes to market share will precede the levy's introduction and any subsequent price change. These possible temporal effects are beyond the scope of this paper but do present an interesting discussion and one that should form part of any levy evaluation.*