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The caries-related cost and effects of a tax on sugar-sweetened beverages

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ABSTRACT

Objectives: While taxes on sugar-sweetened beverages (SSBs) have frequently been proposed to reduce non-communicable diseases like obesity and type 2 diabetes, relatively little is known about the caries-related impacts of SSB taxation. We assessed the effect of a 20% ad valorem tax on SSBs on dental caries and related treatment costs, specifically taking into account that consumers may switch from SSBs to other (non-taxed) sugar-containing drinks.

Study design: Cost-effectiveness analysis.

Methods: A tooth-level Markov model was developed to evaluate the cost and effects of SSB taxation. Tax-related changes in sugar consumption were calculated using available evidence on SSBs price and cross-price elasticities, thereby taking changes in drinks consumption behaviors into account. The model was used to establish lifetime disease-free tooth years, caries lesions prevented, caries-related treatment costs avoided, tax revenues, and administrative costs (reference case: the Netherlands). Deterministic and probabilistic sensitivity analyses were performed to address uncertainties.

Results: A 20% SSB taxation would result in an average of 2.13 (95% uncertainty interval [UI] 2.12–2.13) caries-free tooth years per person and, on population level, prevention of 1,030,163 (95% UI 1,027,903–1,032,423) caries lesions. The intervention was found to save an aggregate total of € 159.01 (95% UI 158.67–159.35) million in terms of dental care expenditures. The estimated lifetime tax revenues (€3.49billion) were larger than the administrative costs for taxation (€37.3 million).

Conclusions: Our results show that SSB taxation may substantially improve oral health and reduce the caries-related economic burden. Benefits would be the greatest for younger age groups.

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Introduction

Dental caries remains one of the largest public health concerns of the 21st century, and it affects more than 2.5 billion people worldwide.[1] Beyond high repercussions on quality of life and social functioning, it implies a considerable economic burden to society.[2] Excessive intake of sugar is a major risk factor for caries development.[3] For prevention of sugar-related diseases (including caries), the World Health Organization (WHO) recommends that sugar intake should not exceed 10% of total energy intake and should ideally be no more than 5% of total energy intake.[4]

Sugar-sweetened beverages (SSBs) are one of the main sources of added sugars and have become more and more affordable throughout the last two decades.[5] Considering the adverse effects of SSBs, this raises serious public health concerns, and several interventions have been proposed to reduce SSB consumption. Fiscal policies, mainly additional ad valorem taxation, have increasingly been advocated for and are already implemented in various settings worldwide.[6] Some studies have demonstrated the positive impacts of such a health policy strategy on obesity and diabetes in terms of health benefits, reduced treatment costs, and fewer productivity losses.[7–10] So far, however, little is known about the caries-related impacts of SSB taxation and about the extent to which the effects of SSB taxation may be influenced by consumers replacing SSBs by other (non-taxed) sugar-containing drinks. Therefore, the purpose of the present study was to assess the potential caries-related effects of introducing a 20% ad valorem tax on SSBs.

Methods

We assessed, from a societal perspective, the potential health economic impact of introducing a 20% ad valorem tax on SSBs with respect to occurrence of dental caries and associated treatment costs. Using a Markov decision-analytic model, SSB taxation was compared with the current standard of no SSB taxation. Markov models are stochastic state-transition models that enable synthesis and analysis of the published evidence, considering benefits, harms, and costs to support decision-making under conditions of uncertainty.[11] As shown in Fig. 1, we assumed that the SSB taxation will result in increased market prices, which will subsequently result in changed demands for SSB (price elasticities). This will lead to changes in sugar consumption and consequent reduction in caries increment. In addition, tax revenues will be generated. SSBs were defined to include liquids with added sugar, that is, carbonated drinks, soft or isotonic drinks, fruit drinks, and diluted syrups.

Target population and time horizon

We were interested in the effects on permanent dentition; therefore, those aged younger than 6 years were not included. The model was designed with reference to the Dutch population aged 6–79 years in 2016, thereby aiming at simulations which can be considered relevant for the context of high-income countries. The composition of the population, stratified by age and sex, was retrieved from Statistics Netherlands.[12] The demographic characteristics are comparable to other Western European countries. The model was run for a lifetime-horizon (i.e. until the 2016 Dutch population reached mean life expectancy). We chose to model the Dutch population as the Netherlands is the third country in the world with highest sugar consumption.[13] Only 10% of the Dutch children have sugar intake below the WHO recommended value.[14] Furthermore, preventable oral disorders belong to 10 health problems responsible for the most disability in the Netherlands.[15] In 2015, costs of dental health care in the Netherlands exceeded € 3.75bn.[2]

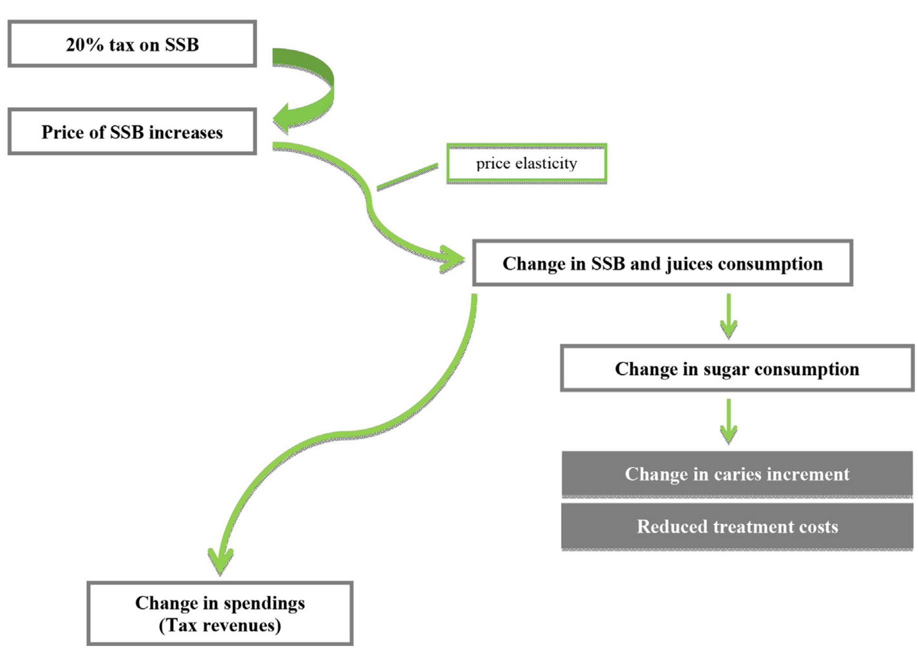

Fig. 1 – Conceptual model of the SSB taxation and its effects. SSB, sugar-sweetened beverage.

SSB consumption in the Netherlands and (cross-) price elasticities

Beverages consumption data were extracted from the Dutch National Food Consumption Survey.[14] This survey collected periodical data on food consumption and nutrition status for a representative sample of people living in the Netherlands. The data were obtained at an individual level, which allowed us to derive population-representative consumption estimates for different age groups (6–8, 9–18, 19–50, and 51–79 years) (Appendix Fig. A1). Non-alcoholic beverages of interest were divided into two groups: (1) fruit juices (not subject to SSB taxation) and (2) SSBs (subject to taxation): diluted syrups, carbonated, soft, or isotonic drinks. After estimating the change in volume of beverages consumption due to taxation, changes in sugar intake were calculated according to beverages sugar content provided by the Dutch Food Composition Database (NEVO-online version 2016/5.0).[16]

Because there were no estimates of own and cross-price elasticities available for SSB consumption in the Netherlands, we primarily relied on estimates of price elasticities as available from a meta-analysis (Appendix).[10]

Outcome

We estimated the number of caries lesions prevented and caries-free tooth years gained. Caries-free tooth year represents a year spent without caries experience per tooth. Additionally, we calculated the avoided treatment costs, the administrative costs of SSB taxation, and tax revenues (see below for more details).

Modeling

We developed a tooth-level Markov state-transition model to evaluate the cost and effects of SSB taxation on caries and oral health care (Fig. 2). Transition patterns were adjusted according the Dutch clinical routine and implemented in the model. We applied a 6-month cycle length, assuming that dental check-ups would take place every 6 months.[17] In case a need for treatment is determined during diagnostic assessment, we assumed that the required treatments are carried out immediately. Hence, the required treatment is always provided at the start of a new state.

Probabilities

Transition probabilities among the different Markov states were derived from literature (Appendix Table A1). We assumed that the cohort starts in the caries-free state, and in case of developing caries within a standard dental visit every 6 months, restoration would be the only possible treatment. Repairment of the original restoration was defined as partial replacement involving only one surface. Replacement of restoration was assumed to generate one additional treated surface.[18] Endodontic re-treatment was not considered within our model. An individual-level perspective generated through a simple aggregation of the tooth-level model was adjusted for the time of permanent teeth eruption and the impact of declining number of teeth over the life course.[19,20]

The data on caries incidence were obtained from the publicly available open-source platform of the Institute for Health Metrics and Evaluation.[15] The relationship between the amount of consumed sugar and caries was derived from the 11-years long Finnish longitudinal study.[21] We calculated the 6-month probability of caries development per tooth for every 10 g of sugar additionally consumed on a daily basis (Appendix).

Cost

Costs for different treatment modalities were extracted from the national price list for dental services.[22] Additionally, the dental technician fee was added to the dental costs for crown

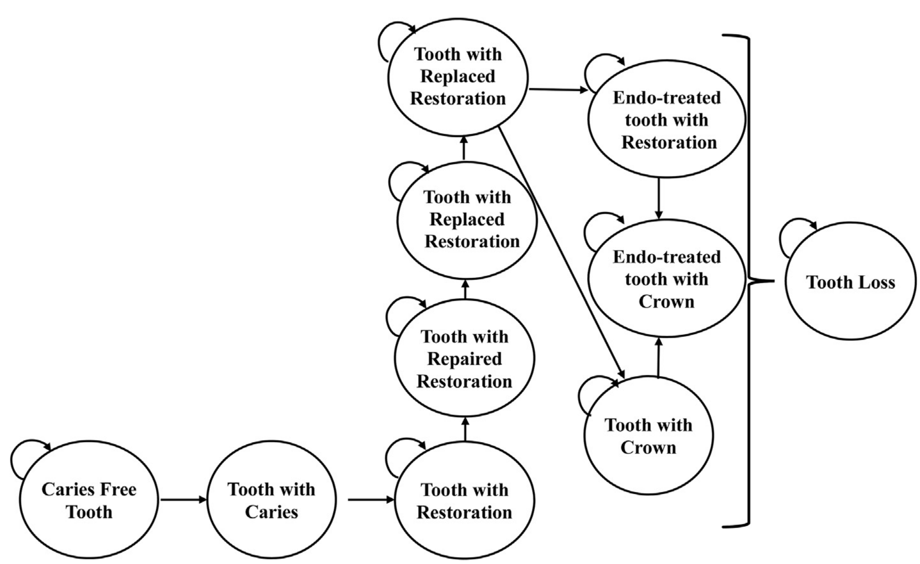

Fig. 2 – Conceptual framework of the Markov model—tooth exposure to caries and dental health care. Arrows indicate possible transitions between Markov states (states of a tooth within the restorative cycle) represented by the circles. However, for better readability not all possible options are included. The full transition list is provided in Appendix (Table A1).

based on the price list of a large University Policlinic in the Netherlands (Table 1). Tax revenues of a potential ad valorem tax on SSBs were calculated based on estimated consumption under taxation and 2015 beverage consumer prices.[23] The latter were accumulated to the baseline year by adjusting for inflation rates. Calculations were performed for the life-time horizon of the current Dutch population. Sensitivity checks were performed to account for different levels in price elasticities of demand. According to Dutch average administrative cost of tax collection, administrative expenditures were assumed to be 1.07% of tax revenues from the SSB taxation.[24]

Discounting of future health outcomes and costs

Following the guideline for economic evaluation in health care in the Netherlands, future costs were discounted at 4%, and future health effects were discounted at 1.5%.[25]

Sensitivity and scenario analyses

In our model, we considered uncertainty in several input parameters, i.e. disease incidence, sugar content in beverages of interest, transition probabilities, and dental treatment costs (Appendix). To determine the extent of the uncertainty, we employed Monte Carlo simulation using 5000 iterations. This allows estimating the means and 95% uncertainty intervals (UI). In the base case, we used mean values for the price and cross-price elasticity for SSB and fruit juices reported in the literature. Additionally, deterministic sensitivity analysis was performed to address the uncertainty in relationship between caries incidence and the amount of sugar consumed using lower and upper bound for caries incidence reduction (Appendix).

Owing to high uncertainty around the Dutch (Western European) preferences for SSB beverages (price elasticity) and fruit juices (cross-price elasticity), we examined alternative scenarios, replacing the abovementioned mean values with lower and upper bounds. Scenario 1 reflects the strongest possible reaction of the Dutch population to taxation. Own price elasticity of −3.87 for SSBs and cross-price elasticity for fruit juices of 0.14 were used in the simulation. The least elastic demand for SSB was evaluated in Scenario 2, taking the upper values for price elasticity and cross-price elasticity from the literature (−0.69 for SSBs and 1.45 for fruit juices) as input parameters in our model. To compare the impact of uncertainties in different parameters on the outcomes of interest (number of caries lesions prevented, amount of caries-free tooth years gained, and amount of treatment costs avoided), we created Tornado diagrams as a graphical presentation of sensitivity of our results.

All analyses were performed using the TreeAge Pro Healthcare Module 2017 software (TreeAge Software, Inc., Williamstown, MA).

Results

In the base case scenario, introducing the 20% SSB taxation would prevent development of 1,030,163 (95% UI 1,027,903–1,032,423) caries lesions (Table 2), which comprises an absolute reduction of 0.55% as compared with the current situation. On a person level, each individual in the population will on average benefit with 2.13 (95% UI 2.12–2.13) caries-free tooth years. With a lifetime horizon, a total of € 159.01 (95% UI 158.67–159.35) million caries-related treatment cost will be saved on a population level. For boys aged 6–12 years, the intervention would be most beneficial with 162,213 (95% UI 161,095–163,330) caries lesions prevented and 6.17 (95% UI 6.14–6.20) millions of caries-free tooth years gained. In girls and women, the benefits in terms of caries-free tooth years per person are lower as compared with boys and men, 1.64 and 2.61 caries-free tooth years, respectively. The estimated lifetime tax revenues (€3.49bn) were larger than the administrative costs for tax collection (€37.30million).

The deterministic sensitivity analysis showed that the model was highly sensitive for caries reduction input values. Fig. 3 shows the number of caries lesion prevented, ranging from 313,516 for the lowest reported caries incidence reduction to 1,549,627 for the highest reported value. Avoided treatment costs ranged from €49.84 million to €238.83 million (Fig. 4), and the total amount of caries-free tooth years ranged from 12.86 million to 48.19 as shown in Fig. 6.

In the alternative scenario with lower values for SSB price and cross-price elasticity (scenario 1, −3.87 for SSB and 0.14

Table 1 – Costs per dental intervention (€)[a].

Course of treatment	Cost (€)	Course of treatment	Cost (€)
Examination	20.44	Replace 2-surface restoration	95.74
1-Surface restoration	71.54	Replace 3-surface restoration	114.57
2-Surface restoration	84.99	Replace more than 3-surface restoration	114.57
3-Surface restoration	95.74	Endodontic th + restoration	359.3
More than 3-suface restoration	114.57	Endodontic th + crown[b]	948.64
Repair 1-surface restoration	71.54	Crown[b]	632.37
Repair 2-surface restoration	71.54	Crown replacement[b]	659.26
Repair 3-surface restoration	71.54	Crown recementation	21.51
Repair more than 3-surface restoration	71.54	Extraction	55.4
Replace 1-surface restoration	84.99		

[a] Nederlandse Zorgautoriteit, Tandartstarieven 2017.
[b] Radboudumc Department of Dentistry.

Table 2 – Oral health benefits and treatment costs avoided owing to 20% SSB taxation, lifetime horizon, mean values for price elasticities, and mean value for caries incidence reduction (95% uncertainty level).

Population	Caries lesions prevented (total)	Caries-free tooth years (per person)	Caries-free tooth years (total, million)	Treatment costs avoided (million €)
Boys & men				
Boys aged 6–12 years	162,213 (161,095–163,330)	9.07 (9.03–9.11)	6.17 (6.14–6.20)	23.83 (23.73–23.93)
Men aged 13–18 years	103,270 (102,941–103,598)	5.82 (5.80–5.83)	3.64 (3.63–3.65)	15.90 (15.86–15.95)
Men aged 19–35 years	197,449 (196,819–198,079)	3.42 (3.40–3.44)	6.16 (6.13–6.19)	32.32 (32.20–32.44)
Men aged 36–55 years	134,201 (132,873–135,530)	1.33 (1.32–1.35)	3.16 (3.12–3.20)	20.23 (20.00–20.46)
Men aged 56–79 years	45,929 (45,662–46,195)	0.32 (0.32–0.32)	0.68 (0.67–0.69)	5.46 (5.42–5.51)
Girls & women				
Girls aged 6–12 years	101,068 (100,329–101,806)	6.35 (6.31–6.38)	4.12 (4.10–4.14)	16.12 (16.05–16.20)
Women aged 13–18 years	62,371 (62,173–62,570)	3.70 (3.69–3.71)	2.21 (2.21–2.22)	10.05 (10.01–10.08)
Women aged 19–35 years	13,622 (123,244–124,001)	2.22 (2.21–2.23)	3.92 (3.90–3.94)	20.47 (20.40–20.55)
Women aged 36–55 years	77,446 (76,523–78,369)	0.78 (0.77–0.79)	1.84 (1.81–1.87)	11.94 (11.78–12.10)
Women aged 56–79 years	22,594 (22,464–22,725)	0.15 (0.15–0.15)	0.33 (0.33–0.34)	2.69 (2.67–2.71)
Total	**1,030,163 (1,027,903–1,032,423)**	**2.13 (2.12–2.13)**	**32.25 (32.18–32.31)**	**159.01 (158.67–159.35)**

SSB, sugar-sweetened beverage.

for fruit juices), taxation would yield 7.52 (95% UI 7.51–7.54) caries-free tooth years per person (Fig. 5) and prevent 4.09 (95% UI 4.09–4.10) million caries lesions (Appendix Table A2). SSB taxation would subsequently result in a saving of €603.17 (95% UI 601.92–604.43) million dental healthcare expenditures on a population level. Assuming a high reduction in demands for SSB as a response to increased taxes, tax revenues will amount to €1.03 billion with €11.00 million of administrative costs.

Even in case of a very strong preference for SSBs and a less elastic demand (–0.69 for SSB and 1.45 for fruit juices), as depicted in scenario 2, taxation appears to be a cost-saving intervention resulting in 0.81 (95% UI 0.80–0.81) caries-free tooth years per person, 350,694 (95% UI 349,658–351,730) caries lesions prevented, and €59.44 (95% UI 59.27–59.27) million as averted caries-attributable treatment costs (Appendix Table A3). With this reaction to SSB taxation, the tax revenues will be €3.96 billion, whereas the administration of taxation will be €42.42 million.

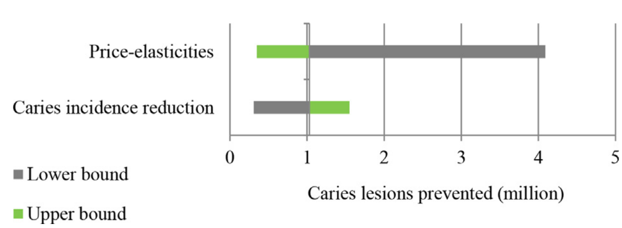

Fig. 3 – Tornado diagram. The bars indicate the effect of different input values for price elasticities and caries incidence reduction on the number of caries lesions prevented.

Discussion

The findings of our study show that a total of 1,030,163 (95% UI 1,027,903–1,032,423) caries lesions could be prevented with SSB taxation, while gaining a total of 32.25 (95% UI 32.18–32.31) million of caries-free tooth years. The introduction of SSB taxation could potentially reduce caries-related dental expenditures by € 159.01 (95% UI 158.67–159.35) million over a lifetime horizon. The estimated lifetime tax revenues (€3.49 billion) were estimated to be larger than the administrative costs for taxation (€ 37.3 million).

To our knowledge, this is the first study to assess the potential benefits of SSB taxation on dental care, taking into account short- and long-term consequences of taxation and the whole caries treatment cycle until potential tooth loss. The major strength of this study is the use of country-specific data for beverages consumption and caries incidence, stratified by age and sex. Moreover, to estimate taxation-related changes in sugar consumption, we

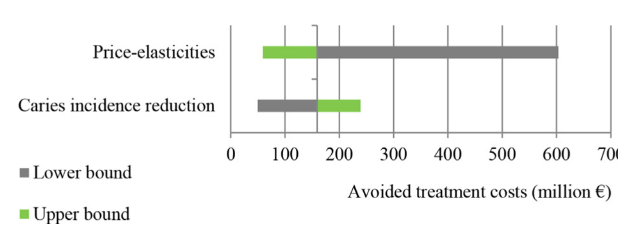

Fig. 4 – Tornado diagram. The bars indicate the effect of different input values for price elasticities and caries incidence reduction on avoided treatment costs.

Fig. 5 – Tornado diagram. The bars indicate the effect of different input values for price elasticities and caries incidence reduction on the amount of caries-free tooth years gained per person.

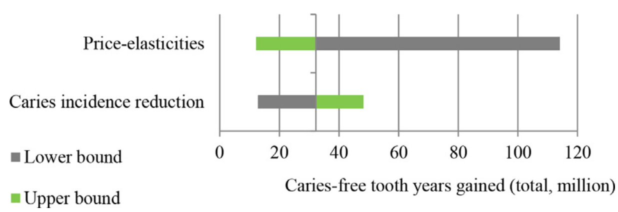

Fig. 6 – Tornado diagram. The bars indicate the effect of different input values for price elasticities and caries incidence reduction on the total amount of caries-free tooth years.

accounted for reduced SSB intake and potential substitution with fruit juice. To arrive at more precise estimates, tooth eruption time and a specific tooth loss trajectory were incorporated in the model.

Some potential limitations should also be discussed. First, country-specific estimates for SSB price and cross-price elasticities were not available. However, the range of values reported in the literature was employed and evaluated in alternative scenarios. Second, owing to lack of more detailed evidence, possible substitution with sugar-containing foods was not considered. Therefore, we should be aware that the magnitude of the effect of SSB taxation is highly dependent on people's behaviors affecting absolute sugar intake. Price elasticities for SSBs and fruit juices were derived from panel-based data, mostly containing purchases for at-home consumption. Hence, in case of strong consumers' preferences for SSBs within away from home markets (e.g. restaurants), total sugar intake as assumed in our study might be underestimated. Another important consideration to be taken into account are meal deals that could diminish the price difference and motivate consumers to select high-sugar products, which they perceive as the most expensive alternative, maximize the cost-benefit ratio of the purchase.[26] This could particularly affect the amount of health benefits we estimated for children and the population under the age of 18 years as they are the most frequent consumers of combo meals.[27] A SSB tax may potentially induce a reduction in drink waste, as suggested by Smith et al.[28] Yet, this effect has not been quantified. In our study, we assumed a constant ratio between the purchased and consumed amount of SSBs. Further research should address the uncertainty around people's preferences, substitution patterns with sugar-containing beverages and foods. Third, we assumed the same sensitivity to taxation across the whole population. With this assumption, potential differences within educational or income groups are neglected. Low socio-economic households possibly have higher reductions in purchasing SSBs reflecting the differential taxation impact, as found in a recent study by Colchero et al.[29] In case the differential taxation impact is absent, the SSB taxation would be regressive imposing the highest burden on the economically most vulnerable citizens. Fourth, societal changes will likely result in availability of alternative drinks with reduced or no added sugar. It implies that the effect of SSB taxation will not be constant over the entire life course, as presupposed in our study. Finally, our results are simulation-based, and all inputs for beverage consumption and costs are based on Dutch data. The consumption of SSBs and fruit juices in the Netherlands is, however, comparable to consumption in United Kingdom, Ireland, Germany, France, Spain, Portugal, and Australia.[30] The price elasticities for SSBs and fruit juices that we used for our simulation were pooled through a meta-analysis that was based on several studies performed in different high-income settings. Therefore, these estimates are also applicable to the abovementioned countries.[31] Healthcare prices, administrative costs of taxation as well as tax revenues may also differ across countries. In addition, disease-related parameters (e.g. caries incidence) for the Netherlands are similar to the rest of the Western European countries or Australia.[15] Taking into account the aforementioned extent of generalizability of input parameters, simulations for these countries would most likely yield similar results with regard to health benefits in Australia and Western Europe. In contrast, sugary drinks consumption is higher in the United States and Canada, thus analyses with country-specific parameters for these settings are likely to produce different results. However, given the detailed presentation of the model and its input parameters, those interested can straightforwardly assess the transferability of the cost estimates to their specific situation.

Our results are in agreement with previous studies that have shown the reduction in caries incidence and decayed, missing, or filled teeth (DMFT) increment due to SSB taxation.[9,32,33] Though, none of the studies accounted for any further consequences of caries except the restoration placement. Sowa et al. estimated that SSB taxation in Australia would result in 3.9 million units of DMFT averted and €0.43 billion in cost saved over 10 years.[33] Nevertheless, in their study, they did not consider potential substitution with sugar-containing beverages not subjected to taxation. Schwendicke et al. reported 0.75 million of caries lesions prevented and avoided treatment costs of €0.8 billion over a 10-year horizon in Germany.[32] A specific novelty of our study is that the effects on oral health are illustrated by the total number of caries lesions prevented and caries-free tooth years gained. Considering these two outcomes, we were able to analyze the effect of taxation on oral health in a more comprehensive way taking into account patterns from clinical practice. By postponing caries onset and entering the restorative cycle in the later stage in life, more invasive treatments could be avoided and consequently lead to prevention of tooth loss.

Clinical prevention and dental treatment severely affect both the financial capacity of individuals and already limited healthcare budgets. Moreover, these interventions are not affordable to all people in need. Improvements in oral health are most likely to be achieved through population-based interventions. In our study, we considered only the effects on oral health and even then SSB taxation appears to be a cost-saving intervention. That could be a good starting point for future dialogs with health policy-makers. Thereby, it could also be highlight that—independent of arguable cost savings due to lower treatment needs in response to SSB taxation—reduced caries burdens would be beneficial in terms of reducing absence from work and school. To arrive at the more precise estimation of overall potential impact of taxation, all diseases with a common risk factor should be included. However, several implementation challenges should be considered. Policy-makers might be reluctant to introduce SSB taxation because of high uncertainties or absence of empirical evidence. In addition, such an intervention can be seen as an intrusion in individual autonomy to make choices and contribute to the mistrust of true intention of taxation.[34] Briggs et al. have shown that the industry response is of substantial importance for the actual SSB tax effect.[9] However, its exact reaction cannot be precisely predicted. Currently, available evidence from natural experiments suggests that the industry could opt for reformulation of products by reducing the amount of sugar in high- and mid-sugar drinks as done by Lucozade Ribena Suntory and Tesco when tiered taxes are introduced.[35,36] Based on the findings from a UK modeling study, this scenario would result in the highest amount of health benefits gained.[9] Similarly, producers could aim for innovation by developing new versions of sugar-free alternatives and shifting their marketing strategies toward healthier brands.[37] This may eventually reduce sugar consumption even further. However, recently estimated cross-price elasticities for regular soft drinks and their diet versions have shown that these products are rather complements than substitutes.[38] Also note that both regular and diet sodas may imply risks of dental erosion.[39] In addition, the effects of SSB taxation could be offset by price increases for other drinks. Dependent on setting, the impact of SSB taxation could potentially also be diminished by cross-border shopping. For example, a recent study has shown that after a tax was introduced in Berkeley, California, SSB purchases increased by 7% in surrounding regions without this fiscal policy.[40] All important determinants should be considered through engagement of relevant stakeholders to secure that maximum of health benefits is achieved.

In conclusion, our model shows that SSB taxation may substantially improve oral health and reduce the caries-related economic burden.

Authors statements

Ethical approval

None sought.

Funding

None declared.

Competing interest

The authors declare no potential conflicts of interest with respect to the authorship and publication of this manuscript.

Author contribution

M.J. had full access to all the data used in this study and takes responsibility for the integrity of the data and accuracy of its analysis. M.J. and A.T. contributed to design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; M.R. contributed to interpretation, drafted, and critically revised the manuscript; S.L. contributed to design, interpretation, drafted, and critically revised the manuscript. All authors read and approved the final manuscript.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2019.02.010.