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ARTICLE

The effects of a sugar-sweetened beverage tax: moving beyond dental health outcomes and service utilisation

P. Marcin Sowa[1]* and Stephen Birch[1,2]

[1]Centre for the Business and Economics of Health, The University of Queensland, St Lucia, Queensland, Australia and
[2]Centre for Health Economics, University of Manchester, Manchester, UK
*Corresponding author. Email: m.sowa@uq.edu.au

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Abstract

Despite considerable academic and policy interest in the taxation of sugar-sweetened beverages (SSBs), its extra-health implications remain largely unexplored. We investigated the impact of an SSB tax on school absenteeism due to improved dental health, in a framework that accounted for the distribution of the benefit. We designed a quantitative, decision-analytic model that synthesised existing evidence in the areas of dental epidemiology, public health and economics, and simulated causal mechanisms that lead to changes in school attendance in Australian children and adolescents aged 6–17, in a tax vs no tax scenarios. Introducing a 20% sales tax on SSBs would result in a 0.73% (95% confidence interval: 0.38; 1.10), or 4684 (2412; 7071) days per year nationwide, reduction in school absences attributable to dental health reasons. While positive impacts would be seen across the board, the distribution of benefit was favourable towards boys, older teens and those from lower socio-economic status. Our study highlights the need for, and the viability of, quantifying distributions of direct and indirect consequences of public health policy. Despite modest effect size, the equity profile of SSB tax, the long-lasting benefits of educational gains, and potential synergies with other interventions, make it an attractive option for policymakers to consider.

Key words: Dental health; school attendance; sugar-sweetened beverages; tax policy

1. Introduction

Excessive discretionary consumption of sugars has been linked to a rapid rise in the prevalence of non-communicable diseases in both developing and developed countries (World Health Organization, 1990). Proving more difficult to control than smoking and tobacco, in part due the necessary nature of food consumption, sugar has been high on the policy agenda concerning diet, nutrition and chronic disease prevention (Nishida *et al*., 2004). A number of areas have been identified as key to curbing free sugars consumption, including demand and supply side controls. Of all available measures the idea of a sugar levy has gained the most traction, which has been attributed to a successful record of taxation in reducing alcohol and tobacco consumption, and perhaps also due to its conceptual simplicity (Lustig *et al*., 2012). A sugar levy solution, targeting primarily sugar-sweetened beverages (SSBs), has been promoted by the World Health Organization on the grounds of its effectiveness being well-evidenced and, judging by most adopter countries' experience, its feasibility in terms of design and implementation (World Health Organization, 2016). This has resulted in a considerable international uptake of this policy measure (Backholer *et al*., 2016a).

Global economic impacts of dental disease have been estimated at US$298 billion (direct treatment costs) and US$144 billion (indirect costs) in 2010 (Listl *et al.*, 2015), with the upward trend calling for systemic responses (Kassebaum *et al.*, 2017). In spite of this, relative to other non-communicable diseases, dental health is a late addition to the debate on the merits of SSB taxation (World Health Organization, 2015). This is surprising in light of the widely recognised association between sugar consumption and dental health, and a possible reflection of both the lingering perception that oral health plays a peripheral role in overall well-being (Leake and Birch, 2008) and the fact that the role of oral health professionals in shaping SSB tax policy has so far been limited (Hagenaars *et al.*, 2021). While caries is sometimes referred to as a multifactorial disease, sugar is in fact the sole primary factor in the cariogenic process, with other factors reduced to the role of sugar effect modifiers (Sheiham and James, 2015). This is in contrast to obesity, for example, which has been shown to have more complex causes (Brand-Miller and Barclay, 2017). Consequently, the case for targeting sugar consumption as a risk factor is stronger in dental health than in other, more studied conditions. The issue has been increasingly recognised and dental health-oriented research emerging since 2016 (Schwendicke *et al.*, 2016; Briggs *et al.*, 2017; Sowa *et al.*, 2018; Jevdjevic *et al.*, 2019) now forms an important constituent of our understanding of the potential SSB tax effects, complementing the previously documented health benefits of reducing obesity, heart disease, hypertension, stroke, diabetes, osteoarthritis, cancer and other non-communicable conditions (Veerman *et al.*, 2016). Although it has to be noted that the modelled impacts of SSB tax vary considerably between studies, which may be attributable to the lack of standard modelling approaches, the uncertainty of input parameters, and idiosyncratic assumptions underlying each model.

Conceptually, the existing literature on SSB taxation has two key shortcomings. One is its focus on the burden and cost of disease, leaving effects on productivity largely unexplored. Interestingly, even reports dedicated to economic benefits of taxing SSBs focus primarily on the cost-savings from health care averted and tax revenue, as opposed to actual economic productivity (Brownell *et al.*, 2009; Long *et al.*, 2015). This is problematic from the policy assessment perspective because a large part of the welfare gain is missing from the evaluation picture (Birch and Donaldson, 1987), and especially true in the area of dental health that so far has not been linked to indirect economic outcomes. Secondly, insufficient attention has been given to the equity aspect of SSB policies (Backholer *et al.*, 2016b). Recent attempts to account for the distributional effects again focused on obesity-related diseases (Moreland *et al.*, 2015; Lal *et al.*, 2017) but an assessment of the equity aspects of SSB tax policy impacts on dental health is still lacking.

The objective of this study was to address both shortcomings and to demonstrate that the health, social and equity consequences of the policy can be integrated within a single framework. Building upon this framework, we developed a quantitative decision-analytic model that synthesised pivotal evidence with the end goal of informing policy decisions in all three dimensions (dental health, school attendance, equity). Our study capitalised on recent literature reviews documenting associations of dental health with educational outcomes (Ruff *et al.*, 2018; Rebelo *et al.*, 2019), which incited the question of how a sugar levy would impact school attendance by children and adolescents, and enabled its quantitative modelling. Our working premise was that, to the extent that sugar consumption is a determinant of dental health, its reduction would lead to better dental health and, in turn, to improved educational outcomes.

2. Methods

The framework comprised of three modules (Figure 1) representing a chain of causal mechanisms: (1) the effect of change in SSB product price on consumption, (2) the effect of changing discretionary sugar consumption on caries accumulation and (3) the effect of changing dental health on school absenteeism. We implemented this framework by adopting a decision-analytic

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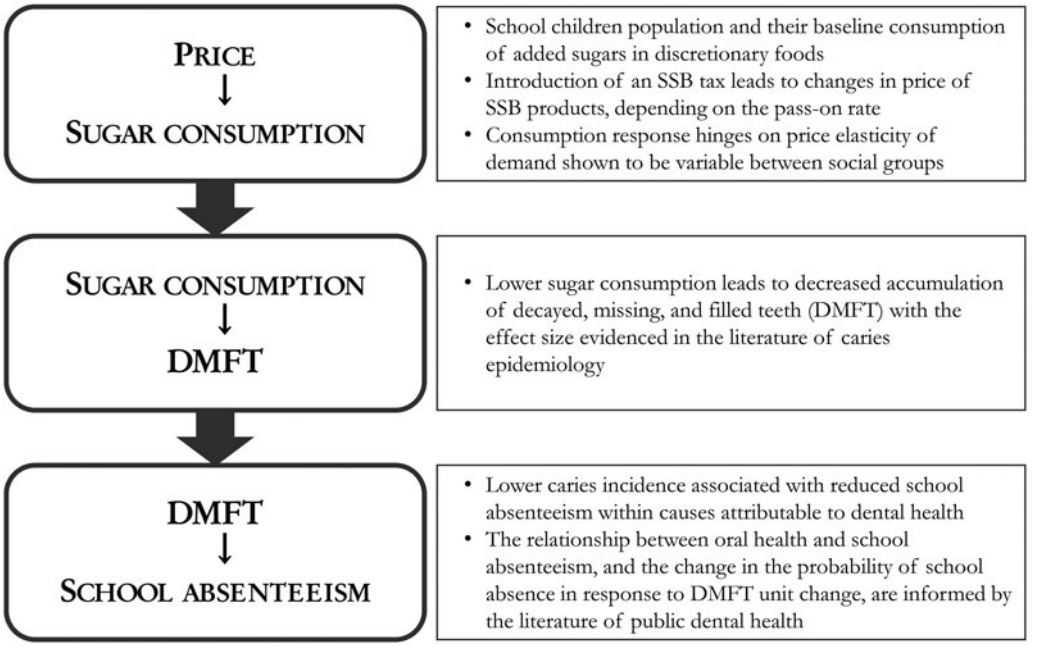

Figure 1. Conceptual framework and model structure.

approach that is well-suited for decisions in the prevention of disease, the modelling of which depends on combining data from different research areas, requires transferring and extrapolating results between settings, places and populations, and involves complex and uncertain outcomes (Siebert, 2003). The purpose of the model was to generate incremental educational and health outcomes reflecting changes in a tax scenario relative to the status quo, while allowing for disaggregation in sub-groups defined by age, sex and socio-economic status (SES).

We considered two possible educational outcomes, school performance and school attendance, whose strong association with oral health was established in two independently carried out meta-analyses (Ruff *et al.*, 2018; Rebelo *et al.*, 2019). In assessing the usefulness of this evidence towards modelling we noted that the former was more complex in terms of its determinants, and subject to considerable international heterogeneity of educational systems and methods. Furthermore, the evidence linking dental health to school performance reflected a wide range of educational outcome metrics including single and multi-component tests across a variety of subjects, final grades and other measures of achievement. These complex determinants and heterogeneity of outcomes were problematic from the modelling standpoint. In comparison, school attendance (or absenteeism) is a more uniform outcome measure that has a similar meaning, i.e. a day of schooling (lost), regardless of any systematic differences between jurisdictions internalised in the meta-analyses. Consequently, attendance and absenteeism lent themselves better to modelling of SSB tax impact on education outcomes, where the effect size of the response had to be quantified. The analysis is conservative in so far as it does not include any reductions in presenteeism associated with the SSB tax.

The model population was defined as primary and secondary school children and adolescents in Australia, ages 6–17 years. The population, which represented 3,539,676 individuals in 2016 (Australian Bureau of Statistics, 2016a), was modelled as 72 cohorts defined by single year age groups (12), sexes (2) and SES groups (3). The latter were defined as the bottom 20%, middle 60% and top 20%, mirroring definitions from key sources of data and evidence required to inform the model (Sharma *et al.*, 2014; Australian Bureau of Statistics, 2016b).

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The baseline daily intake of added sugars in discretionary foods, and their proportion attributable to SSB consumption, was sourced from the Australian Health Survey (Australian Bureau of Statistics, 2016b). Changes in price reflected the assumed tax rate and pass-on rate. In line with the larger part of existing literature, we defined our intervention as a 20% sales tax imposed on SSB products. The pass-on rate was assumed to be 100% in the base case, with other values to be explored in scenario analyses. The change in discretionary sugar consumption as a response to price increase was modelled using SES-specific Australian estimates of the price elasticity of demand for SSBs (Sharma *et al.*, 2014) that accounted for the switching between types of SSBs in response to their changing price levels. However, in line with its assumed scope, it allowed no substitution of SSBs by other sugar-containing beverages that did not meet the Australian Health Survey definition of an SSB, which includes fruit and vegetable juices and drinks, cordials and soft drinks including flavoured mineral waters, but excludes milk (Australian Bureau of Statistics, 2016b).

In our model, decayed, missing and filled teeth (DMFT) served as a single dental health outcome variable reflecting the sum of deciduous and permanent dentition. Baseline DMFT and its accumulation in the status quo scenario were based on dental health outcomes reported in Australian minors (Chrisopoulos *et al.*, 2016). The dose response of incident DMFT to unit reductions of sugar intake was from a longitudinal study in Finland (0.1 [95% confidence interval (CI): 0.04; 0.15] DMFT per 10 g of sugar consumed daily) (Bernabé *et al.*, 2016) and applied to the underage population after consideration of extensive supporting evidence (Armfield *et al.*, 2013; Moynihan and Kelly, 2014; Sheiham and James, 2015; Peres *et al.*, 2016; Hardy *et al.*, 2018).

Australian Curriculum, Assessment and Reporting Authority (ACARA, 2019) provided information on baseline school absenteeism. Days of schooling lost due to dental health-related reasons were determined from overall school absence statistics (Hancock *et al.*, 2013), the proportion of absences due to any illness (Hancock *et al.*, 2018) and an informed assumption regarding the proportion of days missed because of illness that was attributable to dental pain (Jackson *et al.*, 2011).

Modelling school absence as a function of dental health required us to perform a premodelling study in order to establish the gradient of risk as a function of DMFT. The systematic literature reviews (Ruff *et al.*, 2018; Rebelo *et al.*, 2019) reported the mean odds ratios (ORs) of missing school by those with poor oral health, relative to normal health, as 1.57 and 1.43, respectively. Based on epidemiological evidence on the functional relationship between DMFT and the probability of experiencing dental pain (Slade, 2001), we assumed the OR of missing school to scale linearly with worsening oral health status. While the assumption of a linear relationship would have been problematic in a microsimulation model, it was likely to be appropriate for a cohort-level study. Accounting also for the observed distribution of DMFT in the poor oral health group, we determined that the OR of missing school due to dental health would increase by 0.149 with each additional DMFT.

We incorporated uncertainty surrounding key model parameters through normal distributions for those estimates where means and standard deviations were reported (sugar consumption, sugar impact on caries incidence, probability of school absence), or a triangular distribution with a ±10% range where standard deviations were not available (price elasticity, baseline caries accumulation, proportion of absences due to dental reasons). The impact of uncertainty on model outcomes was explored by performing a Monte-Carlo simulation of 2000 cycles, which provided the 95% uncertainty intervals around base case estimates.

We explored the impact of specific model inputs on the outputs by performing one-way deterministic sensitivity analyses on the assumed tax and pass-on rates, the DMFT incidence in response to change in sugar consumption, the price elasticity of demand and the proportion of absences due to dental health. Furthermore, we investigated two additional scenarios: (1) the possibility that teenagers respond to change in price separately, and differently, from their households, and (2) the impact of water fluoridation on the effects of SSB tax policy.

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The first scenario was informed by a study of teenagers' pocket money (Edwards, 2014). The study reported that by 12–13 years of age 62% of the group have had some disposable sums of money, and 38% were receiving pocket money on a regular basis. Pocket money did not depend on the SES of the family, and the amounts gave sufficient purchasing power to alter patterns of SSB consumption if unsupervised. We found no data compatible with our model on SSB-specific purchasing patterns, however results reported by Markowitz and Tauras (2006), which demonstrated price-inelastic demand for cigarette and alcohol participation by teenagers, provided reference values to inform our scenario analysis.

The second scenario relied on evidence of the interaction between sugar consumption and community water fluoridation (CWF), in terms of DMFT outcomes (Armfield *et al.*, 2013). The study reported no apparent effect on DMFT in children aged 5–10, but demonstrated that lifetime exposure to CWF reduced DMFT in those aged 11–16 who were on the higher end of the sugar consumption spectrum. In Australia, access to fluoridated water varies across states and territories (National Health and Medical Research Council, 2017). We used the Armfield *et al.* sample of underage individuals from South Australia, Victoria, Tasmania and Queensland as an approximation of exposure to CWF in Australia. Accordingly, our base model represented a situation in which 55% of individuals had >50% lifetime exposure to CWF. The scenario analysis explored two counterfactuals: CWF exposure in all or none of the population. Model input parameters and their sources are summarised in Table 1.

3. Results

Compared to no tax, a 20% sales tax on SSB would lead to a 0.73% (95% CI: 0.38; 1.10) reduction in the number of days lost due to dental reasons (Table 2). In absolute terms, this corresponded to 4684 (2412; 7071) lost days of schooling averted nationwide. The change in DMFT, an intermediate model output, was a per-person reduction of 0.046. A larger share of the benefits would accrue in boys, with the benefit ratio of 1.61 days absence averted for every day of absence averted in girls, and a DMFT reduction of 0.055 per boy, compared to 0.036 in girls. Looking at the distribution of the benefits in socio-economic groups, for every day of absence averted in the high SES group there would be 2.12 and 2.99 days absence averted in the middle and low SES, respectively. This pattern was also reflected in the percentage reductions from baseline absenteeism. The dental health benefit was similar in the middle and low SES groups, a reduction of 0.05 DMFT per person, which was greater than 0.029 among high SES.

Further disaggregating by age and sex (Figure 2) revealed that the educational benefit would generally (although not monotonously) be greater in higher age groups, increasing from 4.3% of all days absence averted at age 6 to 14% at age 17. The boys' share of benefits also tended to increase with age, from 55% in 6 year olds to 67% in 17 year olds.

Varying the tax and pass-on rates showed a linear input–output dependency (Table 3). This was expected because, everything else being equal, the tax rate and the pass-on rate are in fact two components of a single factor: the effective tax rate faced by the consumer. While each SES group had its own price elasticity of demand, changing the effective tax rate equally across all groups translated into proportional reductions in absenteeism averted. These reductions were 2342 and 7027 days in the 10 and 30% tax scenarios, respectively. Assuming different levels of sugar-to-DMFT responses showed non-linear scaling, with a 20% decrease (increase) in the effect size resulting in a 7% decrease (increase) in averted days of schooling lost.

Using alternative estimates of price elasticity of demand served to validate our approach. The sensitivity analysis suggested the base model was well within the range determined by low (−0.95; change from base case: −17%) and high (−1.299; +13%) values found in the published literature (Cabrera Escobar *et al.*, 2013; Etilé and Sharma, 2015). The model showed moderate sensitivity to the assumed proportion of absences caused by dental health. Modifying the base case assumption of 2% to 1.5% and 2.5% resulted in the days of absence averted being 24% lower and 26% higher, respectively.

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Table 1. Summary of model inputs

Parameter	Value	Source
Base model		
School children population size, *n*	3,539,676	Australian Bureau of Statistics (2016a)
Baseline consumption of added sugars, g/day	Boys: 14–36.9	Australian Bureau of Statistics (2016b)
	Girls: 12–18.3	
Pass-on rate	100%	Assumption
Price elasticity of demand for SSBs, point estimate	Low SES: 1.18	Sharma *et al.* (2014) (weighted by product type)
	Medium SES: 1.19	
	High SES: 0.86	
Baseline DMFT	0.13–2.63 by age/sex	Chrisopoulos *et al.* (2016)
DMFT response per gram of sugar per 10 g of sugar consumed daily, mean (95% CI)	0.1 (0.04; 0.15)	Bernabé *et al.* (2016)
Overall school attendance, %	88.6–93.3 by age/sex	ACARA (2019); Hancock *et al.* (2013)
Proportion of absence due to illness, %	51	Hancock *et al.* (2018)
Share of dental pain in all illness, %	2	Assumption based on Jackson *et al.* (2011)
Odds of school absence due to poor oral health, mean (95% CI)	1.57 (1.08; 2.05)	Rebelo *et al.* (2019)
	1.43 (1.24; 1.63)	Ruff *et al.* (2018)
Probability of missing school due to occurrence of tooth pain, ΔOR/ΔDMFT	0.149	Based on Slade (2001)
Scenario analyses		
Teenagers with disposable income	62% or 38%	Edwards (2014)
Teenagers' own price elasticity of demand for SSB	0.3 or 0.5	Assumption based on Markowitz and Tauras (2006)
Relative effect of SSB on DMFT in ages 11–16 weighted by SSB consumption, no-CWF vs CWF ratio	1.29	Based on Armfield *et al.* (2013)

DMFT, decayed, missing and filled teeth; SES, socio-economic status; CWF, community water fluoridation; SSB, sugar-sweetened beverage; CI, confidence interval; OR, odds ratio.

Allowing for teenagers' own inelastic responses to SSB price change revealed the considerable potential of this factor to dampen the policy effects. In the more extreme case of highly inelastic demand for SSB among teenagers, we found that absenteeism averted was 46% lower than in the base scenario in which teenagers responded accordingly to their households' preferences. In a moderate case where the independent demand was slightly less inelastic, and disposable income available in fewer teenagers, we found a 21% reduction in the policy effect compared to the base case.

Finally, exploring policy interactions suggested that SSB tax policy is relatively more effective (+11% reduction in absenteeism) in the absence of CWF, and relatively less effective (−9%) where all individuals have exposure to CWF. This made sense because caries prevention offered by CWF lowers the baseline risk, reducing the marginal reductions from other interventions. The reverse is also true: in the absence of CWF exposure, the advantages of other public health interventions such as SSB tax become more pronounced.

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Table 2. Days of schooling lost due to dental reasons, year 1

			Δ (days)		Δ (%)			
Group	No tax	Tax	Mean	95% CI[a]	Mean	95% CI	Benefit ratio[b]	Δ DMFT[c] per person
Total	642,585	637,901	−4684	(−7071; −2412)	−0.73	(−1.10; −0.38)	Ref.	−0.046
Sex								
Girls	310,042	308,308	−1734	(−2636; −895)	−0.56	(−0.85; −0.29)	Ref.	−0.036
Boys	332,543	329,593	−2950	(−4458; −1522)	−0.89	(−1.34; −0.46)	1.61	−0.055
Socio-economic								
Bottom 20%	168,111	166,757	−1354	(−2052; −706)	−0.81	(−1.22; −0.42)	2.99	−0.050
Middle 60%	371,358	368,480	−2878	(−4372; −1,485)	−0.78	(−1.18; −0.40)	2.12	−0.050
Top 20%	103,116	102,664	−452	(−694; −231)	−0.44	(−0.67; −0.22)	Ref.	−0.029

[a]Uncertainty intervals from a Monte-Carlo simulation of 2000 cycles.
[b]Absenteeism averted (days) relative to the reference group, adjusting for group size.
[c]Decayed, missing and filled teeth (deciduous and permanent teeth combined).

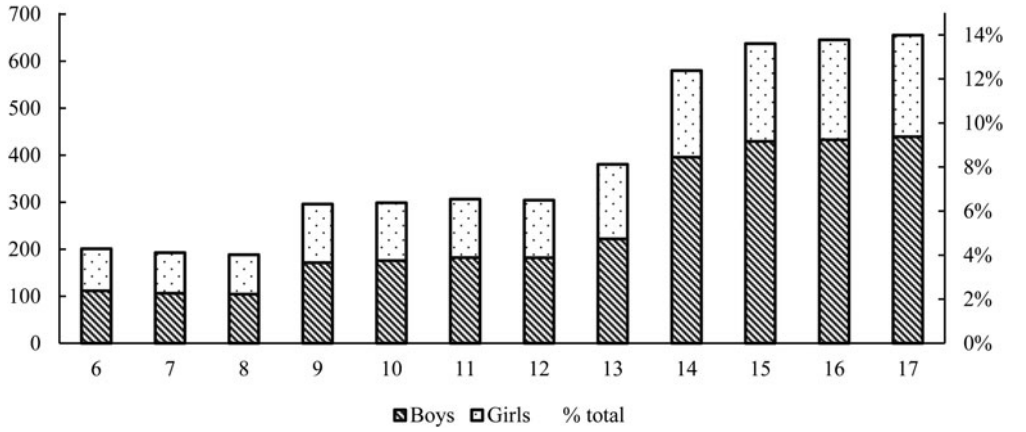

Figure 2. Disaggregation of benefit (total days of absence averted) by age.

4. Discussion

Attending school is the central aspect of human development during childhood and adolescence and an important determinant of productivity during school years and beyond. While determinants of school attendance are multiple and complex, health (including oral health) places highly among them. The odds of missing school are compounded for those from lower SES households, because of correlated risk factors, which makes targeting determinants that are modifiable through policy measures particularly attractive. Improving our understanding of this nexus of public policy, health, SES factors and productivity was the broad motivation behind this study. Combining available evidence in a decision-analytic model demonstrates how a sugar levy can reduce absenteeism by way of improving dental health. Although reducing absenteeism may not be a primary or direct objective of SSB taxation, but merely a by-product, this effect should nonetheless feature among criteria influencing policy decisions. Moreover, it represents a realised benefit of improved oral health which may not be the case for estimates of health care costs averted from reduced treatment needs, as supply driven health care systems simply redirect available supply to other activities (Birch *et al.*, 2007).

The full marginal benefit of increasing school attendance is difficult to quantify because it involves a number of interacting terms that produce multiplicative outcomes. The positive relationship between educational attainment and later-life productivity, as approximated by higher wages, is well established; moreover, the marginal returns to education may also be higher in disadvantaged groups than average returns in the population as a whole (Card, 1999). At the same time, increasing educational attainment leads to improved health behaviours, resulting in better health status, manifested in a number of ways including a greater number of productive days (Cutler and Lleras-Muney, 2010). Furthermore, additional days of schooling yield cognitive development gains, which are also higher in low SES children, meaning that increases in attendance can increase the yield from further attendance (Ready, 2010). More specifically for oral health outcomes, a recent study established a causal relationship between the duration of schooling and edentulism at older age, showing that additional investment in education produces improved oral health later in life (Matsuyama *et al.*, 2019). Consequently, investing in children's education is a rare example of policy that simultaneously promotes efficiency and equity, as opposed to trading-off one objective for another (Heckman, 2011). This complex interaction of marginal benefits further extends to health, because the health of deciduous teeth affects permanent dentition (Skeie *et al.*, 2006). Although most of the supporting evidence is based on greater increments than the plausible individual effects of an SSB tax, and the effect size of small

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Table 3. Results of scenario analyses

Scenario	Mean days of absence averted	Change from base case	
		Days	%
Base case	−4684	Ref.	Ref.
Tax rate			
10%	−2342	2342	−50
30%	−7027	−2342	+50
Pass-on rate			
50%	−2342	2342	−50
80%	−3747	937	−20
120%	−5621	−937	+20
Price elasticity of demand			
−0.95 (Etilé and Sharma, 2015)	−3873	812	−17
−1.299 (Cabrera Escobar *et al*., 2013)	−5295	−611	+13
Assumed proportion of absences due to dental health			
1.5%	−3540	1145	−24
2.5%	−5896	−1212	+26
DMFT response to change in sugar consumption			
−20%	−4361	323	−7
+20%	−5007	−323	+7
Teenagers' price elasticity of demand for SSB			
0.3 in 62% of teenagers age 12+	−2538	2146	−46
0.5 in 38% of teenagers age 12+	−3679	1006	−21
Water fluoridation			
Not available	−5179	−494	+11
Available to all	−4280	405	−9

incremental gains may be difficult to quantify or demonstrate as marginally important, they are nonetheless likely to be substantial, especially at the cohort level, due to the cumulative nature of health and education. Based on the existing body of knowledge, marginal gains in early life health and education will have flow-on effects to later life, influencing health directly and indirectly through health behaviours, cognitive ability, productivity and the stock of healthy days.

The global uptake of sugar levy policies has been increasing, driven among other things by the World Health Organization consensus regarding their effectiveness (World Health Organization, 2016). Evidence is emerging on how aspects of implementation, such as framing and salience, may affect its effectiveness (Cornelsen and Smith, 2018), and there are some encouraging lessons learnt from its various implementations in geographically and culturally diverse jurisdictions (Backholer *et al*., 2016b). Despite their variety, non-alcoholic beverages are a dichotomous category comprising SSBs and non-SSBs, all of which are considered non-necessities. These characteristics make them amenable as policy targets, and a tax levy has the potential to provide benefits that, compared to other policies, are broader ranging, more readily achieved, and complementary.

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In practical terms, the jury is still out on the effectiveness of taxation in tackling the sugar problem, and in particular on its role in a broader package of policy responses. In conditions with multiple determinants, such as obesity, the effect size on health outcomes has been shown to be small when tax was the only policy, despite the argument of reducing sugar consumption being conceptually compelling (Kaiser *et al.*, 2013; Maniadakis *et al.*, 2013). In Australia, the prevalence of obesity has been rising despite declining SSB consumption, which suggests factors other than SSB consumption are in play (Brand-Miller and Barclay, 2017). This is also true for other non-communicable diseases that have many determinants other than sugar contributing to their burden (GBD 2017 Diet Collaborators, 2019). Still, while increasing prices of sugary products might be only one of many required responses, and insufficient in itself, its relative importance might be greater in achieving improvements in dental health. That is because, relative to other diseases, the aetiology of dental disease justifies sugar consumption as a sole factor, and its reductions as a policy goal.

Options other than tax might exist and complementary policies are required in order to target and optimise the effectiveness of an overall policy response (Pomeranz, 2012). Strong links of child food-related behaviours to parental practices, with availability and modelling being two main mechanisms of influence (Yee *et al.*, 2017), suggest that relying on SSB tax as the sole mechanism is likely to be insufficient. We illustrate this in our pocket money scenario in which teenagers have their own, price-inelastic response to change in product price. The complexity of child-level, interpersonal and environmental determinants (Mazarello Paes *et al.*, 2015), and the lack of effective primary care interventions (Dooley *et al.*, 2017), mean that the challenge of designing a comprehensive policy package will be formidable. Ideal policies complementary to SSB tax, which addresses the affordability component of accessibility, would be those that reduce the other components of SSB accessibility, that is availability and acceptability (McIntyre *et al.*, 2009), and incentivise switching to non-sugary alternatives (Cobiac *et al.*, 2017). Rather than eliciting specific choices, these policies should aim to contribute to creating environments that facilitate healthy behaviours (Cornelsen *et al.*, 2015).

Similar to obesity, the dental health benefits from SSB tax will depend on a number of contextual factors influencing its effectiveness (Jou and Techakehakij, 2012). One such dental-specific factor is CWF, another major dental public health strategy that has proven safe, effective and cost-effective (Petersen and Lennon, 2004). Our results indicate that because the two policies aim to achieve the same goal of improving dental health, their combined effect is less than the sum of individual effects. Still, the policies are complementary in that they address two independent aspects of the cariogenic process: reducing sugar intake on the one hand, and protecting against the effects of sugar consumption on the other. The gains from one policy in the presence of another are still considerable, and the advantages of SSB tax go beyond dental health in preventing other non-communicable conditions.

Accounting for social benefits stemming from improvements in health that result from SSB taxation has so far not been achieved, and remains an important task from the standpoint of evidence-informed policymaking. Modelling social benefits expands the perspective beyond health care and fiscal impacts to incorporate a social investment component. In doing so, it adds new arguments to be used in the sugar policy debate, and may in particular provide additional leverage for achieving industry co-operation and self-regulation. Studies prior to the recent wave of SSB tax implementations showed no evidence of self-regulation or public–private partnership ability to limit the harmful effects of consumption of unhealthy commodities. This was in contrast to selected regulation and market intervention policies that were shown to be effective at prevention (Moodie *et al.*, 2013). More recent experiences demonstrated that tax policies can be used to compel the industry response in reformulating or promoting products that contain lower sugar content (Blecher, 2015). For example, the UK's SSB tax design was successful at incentivising reformulation on announcement, prior to the policy coming into effect (Scarborough *et al.*, 2020). In Australia, industry resistance and ability to counteract policies

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have been identified as key regulation challenges alongside food standards and labelling, availability and the use of economic incentives (Davoren *et al.*, 2014). Industry resistance takes the form of research manipulation, lobbying and procrastination (Sheiham and James, 2015), counterarguments based on fragmented and incomplete information, or lacking evidence (Backholer and Martin, 2017), and using free-trade agreements to protect against the effects of state intervention (Jones, 2016). Linking sugar consumption to social consequences in children and adolescents, with potential lifelong effects, may offer strong arguments in building a broader coalition around the goal of rationalising sugar consumption. This is especially important because SSBs are in part a cultural phenomenon, and one gladly cultivated by the industry. The consumption choices that individuals make are not independent from marketing efforts, which promote associations between SSB and food consumption, and broader social activity (Soares, 2016), making it an important area for policymakers to consider.

The central contribution of our study is in its novel framework, which integrates outcomes that go beyond health and health care utilisation, paving the way for exploring broader social impacts of SSB tax policy. In an application of the framework, we simulate cohort-specific determinants of absenteeism: SSB consumption, response to SSB price change, observed DMFT and its accumulation rate, and the baseline probability of missing school associated with reasons related to dental health. This approach is more comprehensive than mechanistically applying a fixed or proportional policy effect to baseline absenteeism in order to obtain group-specific outcome. Limitations of our study revolve around the nature of its model design. The purpose of decision analytic modelling is to simulate what can be expected, based on the combined pool of relevant evidence, in order to support policy decision making. This is not meant to replace post-hoc evaluation or a reconciliation of empirical effects against predictions. Our study features a partial model approach that does not aim to simulate causes or evaluate consequences that go beyond its explicit scope. The model relies on input parameters from heterogeneous sources, in some cases representing distinct, foreign jurisdictions. Feasibility of the model required accepting minor misalignments in terms of definitions. For example, SES was defined at the household level for the price elasticity of demand for SSB, and at the school area level for the purposes of absenteeism. In order to reduce model complexity to a workable level, we made simplifying assumptions regarding school absences being equivalent to a full day, and occurring independently. The model is static in the sense that it does not reflect gradual uptake or an adjustment period. The 1-year results should therefore be interpreted as 1 year of policy in full effect, not the first year of implementation. The omission of the spatial dimension and special interest populations, such as indigenous populations and other high risks groups unrelated to SES, was dictated by insufficient data to inform this level of detail. Stratification by SES groups mitigated this problem somewhat.

The wide uncertainty intervals around mean effect estimates reflect the uncertainty of linking evidence in a modular model design. To some extent this illustrates a broader uncertainty of policy outcomes in a system where multiple individual and system-level factors influence the overall outcome. Still, the intermediate outcomes of our model (reduction in caries) validated well against recent studies. One study reported 0.55% decrease in DMFT in the SSB tax vs status quo scenario, which was similar to our model despite the fact that the study used a different modelling technique (a Markov model) and was designed for a different jurisdiction (the Netherlands) (Jevdjevic *et al.*, 2019). Our model prediction that the benefits would be higher in the lower SES groups confirmed previous results reported in Australia (Lal *et al.*, 2017). We were unable to validate the final (educational) outcomes due to the lack of prior research concerning social and economic implications.

The overall benefits and acceptability of an SSB tax policy, and a subsequent decision to implement it, will depend on a much wider variety of outcomes, factors and circumstances. Elements of the policy process, including a compelling statement of SSB tax aims, mobilisation of public support for the goal and ways of achieving it, building effective advocacy coalitions and leadership of

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the oral health profession, have been identified as factors critical for generating traction and enabling implementation (Hagenaars *et al.*, 2021). This study contributes a novel set of results and highlights the need for, and the feasibility of, accounting for the health, social and equity dimensions in evidence-informed policymaking, which may prove relevant to advancing the policy process. There are a number of possible extensions going forward. Social gains are underestimated in our study in that they omit reductions in presenteeism among children, and do not account for parents' use of time, which would be positively affected by lower absenteeism. Societal costs of dental visits and oral conditions have been shown to be considerable in terms of time loss and reduced normal activities, especially among disadvantaged groups (Gift *et al.*, 1992). Secondly, future model iterations should prioritise exploration of the interactions of SSB tax and complementary policies, in an attempt to identify a synergistic mix of strategies that optimises the overall effect while minimising drawbacks. Finally, obesity represents a major alternative pathway linking SSB tax to school absenteeism; its quantification would complement the results of our present study. Going beyond the children's cohorts, a model of adult productivity might be feasible, although more complex than the current model due to a wide range of activities and opportunity costs to consider.

5. Conclusion

Our framework extends the scope of the SSB tax debate from the immediate health gains, and their conditional direct cost implications, towards consequent social benefits which, as is the case with education, might have lifelong effects. It highlights the important role of dental health in this conversation and demonstrates the feasibility of accounting for direct and indirect consequences of an SSB tax in a single, quantitative, SES-stratified framework. Applying our model using available data indicates that the overall benefits would be small but not insignificant, and concentrated in lower socio-economic groups. The projected outcomes should be interpreted in addition to other, previously documented gains from taxation of sugary foods.

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Conflict of interest. The authors declare none.

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