

# Funding quality pre-kindergarten slots with Philadelphia's new 'sugary drink tax': simulating effects of using an excise tax to address a social determinant of health

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## Abstract

**Objective:** Philadelphia passed a 1.5-cent-per-ounce sweetened beverage tax (SBT). Revenue will fund 10 000 quality pre-kindergarten slots for poor children. It is imperative to understand how revenue from SBT can be used to fund programmes to address education and other social determinants of health. The objective of the present study was to simulate quality pre-kindergarten attendance, educational achievement and sugar-sweetened beverage (SSB) consumption among Philadelphia children and adolescents under six intervention scenarios: (i) no intervention; (ii) 10 000 additional quality pre-kindergarten slots; (iii) a 1.5-cent-per-ounce SBT; (iv) expanded pre-kindergarten and 1.5-cent-per-ounce SBT; (v) a 3-cent-per-ounce SBT; and (vi) expanded pre-kindergarten and 3-cent-per-ounce SBT.

**Design:** We used an agent-based model to estimate pre-kindergarten enrolment, educational achievement and SSB consumption under the six policy scenarios. We identified key parameters in the model from the published literature and secondary analyses of the Panel Study of Income Dynamics – Child Development Supplement.

**Setting:** Philadelphia, Pennsylvania, USA.

**Subjects:** Philadelphia children and adolescents aged 4–18 years.

**Results:** A 1.5-cent-per-ounce tax would reduce SSB consumption by 1.3 drinks/week among Philadelphia children and adolescents relative to no intervention, with larger effects among children below the poverty level. Quality pre-kindergarten expansion magnifies the effect of the SBT by 8%, but has the largest effect on moderate-income children just above the poverty level. The SBT and quality pre-kindergarten programme each reduce SSB consumption, but primarily benefit different children and adolescents.

**Conclusions:** Pairing an excise tax with a complementary programme to improve a social determinant of health represents a progressive strategy to combat obesity, a disease regressive in its social patterning.

**Keywords**  
Social determinants of health  
Health policy  
Health disparities  
Beverage tax  
Education and health

Local governments are increasingly considering excise taxes on sugar-sweetened beverages (SSB) to address the obesity epidemic<sup>(1)</sup>. By 2010, twenty states had implemented differential state-level sales taxes on SSB relative to other foods, with SSB sales taxes averaging 3.5 percentage points higher than other foods<sup>(2)</sup>. Excise taxes on SSB have also been proposed by cities, but have largely met resistance<sup>(1,3)</sup>. The main exception until very recently is Berkeley, California, which passed a penny-per-ounce (i.e. US fluid ounces; 1 US fl oz = 29.57 ml) tax on SSB in 2014<sup>(4)</sup>. In the previous year, SSB taxes were also passed by the cities of San Francisco and

Oakland in California, Boulder in Colorado, and Philadelphia in Pennsylvania.

Several economists have sought to understand the extent to which changes in the price of SSB yields changes in consumption. Specifically, a review of estimates of the 'own-price elasticity' of soda and other sweetened beverages suggests that, on average, a 1% increase in price is associated with a decrease in consumption of between 0.8 and 1.0% among adults<sup>(5)</sup>. While many studies have examined the price elasticity of SSB among adults<sup>(6)</sup>, few have examined the effect of price changes on SSB consumption among children and adolescents<sup>(2,7)</sup>. The studies that have been

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conducted have almost exclusively used data for either adults or household-level purchasing. The primary exceptions are studies by Fletcher and colleagues (2010) and Sturm and colleagues (2010). Fletcher *et al.* found that a 1% increase in the soft drink tax rate is associated with a decrease of approximately 25 kJ (6 kcal) from soft drinks consumed per day among children and adolescents. In contrast, Sturm *et al.* found that changes in the price of soda, sports drinks and sweetened juices had little to no impact on consumption among most children and adolescents<sup>(2)</sup>. Notably, they found that price increases were associated with significant reductions in consumption among children from low-income households.

An important aspect of imposing SSB taxes is that the revenue can be used to fund health-enhancing policies and interventions. In tobacco control, for example, excise taxes on cigarettes have been used by multiple states to fund prevention and cessation efforts<sup>(8,9)</sup>. In their study, Sturm *et al.* argued that the greatest benefit of SSB taxes may come 'from the dedication of the revenues they generate to other obesity prevention efforts rather than through their direct impact on children's consumption of soda'<sup>(2)</sup>. Despite the high potential of this 'two-pronged' approach, there is a dearth of research regarding the combined effects of both imposing an excise tax on SSB sales and using revenue from that tax to fund interventions beneficial for health.

### ***Philadelphia's sugary drink tax and quality pre-kindergarten proposal***

The Mayor of Philadelphia recently proposed a 3-cents-per-ounce excise tax on SSB. In a compromise, the City Council passed a 1.5-cent-per-ounce tax on both SSB and diet beverages<sup>(10)</sup>. This sweetened beverage tax (SBT) is projected to generate \$US 91 million per year in revenue<sup>(11)</sup>. Much of this revenue has been earmarked for an expansion of publicly funded, quality pre-kindergarten slots for low- and moderate-income Philadelphia children. Use of SBT revenue to support early childhood education and other public investments (e.g. improvements to public parks and recreation centres) is widely viewed as a reason the tax passed after failed previous attempts in 2010 and 2011<sup>(10)</sup>.

SBT revenue will be used to create an additional 6500 quality pre-kindergarten slots, a supplement to 3500 quality slots that are expected to be added via other state and local funding. Seventy-six per cent of 3- and 4-year-old Philadelphia children live in low- and moderate-income households that meet eligibility thresholds for publicly funded pre-kindergarten programmes. However, there are not enough publicly funded quality pre-kindergarten slots to meet this demand and less than half of those eligible are actually enrolled<sup>(11)</sup>. The addition of 10 000 quality slots would reduce this gap by nearly 60%.

The pre-kindergarten programme is designed to not only increase access to pre-kindergarten among low- and moderate-income children, but also to improve

pre-kindergarten quality relative to existing, publicly funded pre-kindergarten programmes. Expanded slots are to be implemented exclusively by pre-kindergarten providers that meet quality standards, children will participate for  $\geq 8$  h/d throughout the year, and wages of pre-kindergarten teachers will increase substantially.

### ***Quality pre-kindergarten***

Pre-kindergarten attendance and pre-kindergarten quality impact children's educational achievement<sup>(12-14)</sup>. Barnett (2011) reviewed pre-kindergarten programmes and found that Head Start attendance had little impact on children's academic achievement at grade 5. In contrast, participation in the more resource-intensive Perry and Abecedecian programmes, which have more demanding curricula, lower student-to-teacher ratios and more rigorous teacher requirements than many pre-kindergarten programmes, is associated with relatively large and long-lasting effects on children's achievement. For example, achievement was 0.33 SD higher among Perry participants at age 14 years relative to a comparison group, and 0.50 SD higher among Abecedecian participants from ages 8 to 21 years relative to a comparison group<sup>(12)</sup>. In a meta-analysis of 123 pre-kindergarten programmes, Camilli and colleagues (2010) found that measures of children's achievement were 0.23 SD higher in those who attended pre-kindergarten relative to those who did not. Camilli *et al.* found additional increases of 0.25 SD for participants in programmes that provided direct instruction and 0.19 SD for programmes that did not offer social services<sup>(14)</sup>. These heterogeneous effects highlight the importance that publicly funded pre-kindergarten programmes, such as the one being considered in Philadelphia, focus on improving pre-kindergarten quality.

### ***The present study***

The SBT is a potentially important tool to address children's health disparities via its direct effect on SSB consumption, as well as via the effect of the pre-kindergarten programme on educational achievement and attainment among Philadelphia children from low- and modest-income households. Education is an important social determinant of both childhood and adult health outcomes, and is interrelated to other social determinants such as employment status, occupation and income<sup>(15-17)</sup>.

We sought to evaluate the impact of the proposed SBT and pre-kindergarten programme on SSB consumption among children and adolescents. In particular, we are interested in understanding the independent effects of the SBT and pre-kindergarten programme, as well as the combined effects of both. We developed an agent-based simulation model (ABM) that projects educational outcomes and SSB consumption behaviour among Philadelphia children and adolescents. We estimated the effects of the SBT, both at the 1.5-cents-per-ounce level that passed and the 3-cents-per-ounce level originally proposed by the

Mayor, and pre-kindergarten programme on all children and adolescents, as well as separately by race/ethnicity and for children and adolescents from low-income (i.e.  $\leq 100\%$  of the federal poverty level (FPL)) and modest-income (i.e.  $\leq 300\%$  FPL) households.

## Methods

### Overview

The model is an ABM built using AnyLogic 7. The model environment is in continuous GIS (geographic information system) space. Each simulation runs in discrete time with each time step equivalent to 1 d. The ABM includes several interrelated processes: (i) initialization of the environment and population; (ii) pre-school assignment; (iii) educational achievement; (iv) SSB consumption; and (v) intervention scenarios. In brief, the model environment and population reflect observed data regarding the distribution and student population characteristics of public and private schools in Philadelphia, as well as sociodemographic characteristics of Philadelphia neighbourhoods. Pre-school assignment is based on the existing number of slots in the various quality pre-kindergarten programmes in Philadelphia (i.e. child does or does not participate in a quality programme). Academic achievement is projected based on parameters derived from secondary analyses of the Panel Study of Income Dynamics – Child Development Supplement (PSID-CDS), as well as the relevant literature regarding the effect of quality pre-kindergarten participation on achievement. SSB consumption is also calculated based on PSID-CDS. We use the model to examine six intervention scenarios: (i) no intervention; (ii) expanded pre-kindergarten, (iii) 25% sugary drink tax (SBT); (iv) expanded pre-kindergarten and 25% SBT; (v) 50% SBT; and (vi) expanded pre-kindergarten and 50% SBT. These percentages are the rough equivalent of the 1.5-cents-per-ounce and 3-cents-per-ounce taxes<sup>(18,19)</sup>. Outcomes include pre-kindergarten participation, academic achievement and mean SSB consumption stratified by race/ethnicity (white, black and Latino) and income level.

Below, we provide details regarding prediction of educational achievement and SSB consumption, evaluation of outcomes, key assumptions, sensitivity analyses and validation. The online supplementary material, Supplemental File 1, provides further details regarding initialization of the population and environment in the ABM; the current landscape of publicly funded pre-kindergarten programmes in Philadelphia; the process for assigning agents in the model to pre-kindergarten slots; the implementation of intervention scenarios; the rationale, sources and values for model parameters; sensitivity analyses; and secondary analyses of PSID-CDS.

### Predicting educational achievement and sweetened beverage consumption

The ABM simulates children's educational achievement based on their pre-kindergarten attendance and sociodemographic

characteristics including gender, age, race/ethnicity, household income and parents' educational attainment. Similarly, we estimate each child's average SSB consumption based on his/her pre-school attendance, educational achievement, sociodemographic characteristics, and a random component representing between-person variation in SSB consumption. Each week, the SSB consumption of each child varies slightly around this average based on a random component that represents within-child 'week-to-week' variation driven by random processes and circumstances.

To develop prediction equations for academic achievement, we estimate the relationship between sociodemographic characteristics and achievement directly, using multiple linear regression models and data from the PSID-CDS. To estimate most parameters predicting average soda consumption, we again use data from the PSID-CDS. Since PSID-CDS lacks data regarding soda taxes in the communities in which participants reside, we use parameters from Sturm *et al.*<sup>(2)</sup>. Our use of estimates from Sturm *et al.* has several advantages. In contrast to many studies of the own-price elasticity of demand of SSB<sup>(7,20,21)</sup>, Sturm *et al.* estimated the effect of taxes from a longitudinal study of children and adolescents combined with state-level data on differential tax rates on SSB. They also estimated SSB elasticities separately among poor children, which aligns with our interest in examining differences in SSB consumption across racial/ethnic and income-based strata. To understand the extent to which our choice of parameters regarding the effect of the tax may drive model outcomes, we employ parameter variation experiments (see 'Sensitivity analyses' section below) using a range of parameters from the literature.

Parameter values for predicting educational achievement are given in the online supplementary material, Supplemental Table 1; parameter values for calculating SSB consumption, as well as their sources, are given in Supplemental Table 2.

### Evaluation of outcomes

The primary outcome in which we are interested is children and adolescents' weekly SSB consumption. For each of the six intervention scenarios, we compare mean model outcomes across twenty simulation runs. To assess changes over time, we present the difference between mean SSB consumption among the entire population of children and adolescents both at baseline and after 18 years of elapsed time. The relatively long time frame is necessary because in scenarios that include the universal pre-kindergarten programme, only the 'new' 4-year-old children added to the model each year are enrolled in pre-kindergarten slots subsidized by the SBT. Thus, it takes at least 14 years for children to 'age through' the model, such that all age cohorts were exposed to the intervention.

### Model assumptions

We make a number of key assumptions in the model that are important to consider. One assumption is that publicly

funded pre-kindergarten slots are filled by randomly selecting participants from the pool of all children who meet the eligibility criteria. This selection mechanism assumes that children and parents do not have a preference for certain types of publicly funded slots over others, and that selection is random and not driven by the social, economic, geographic or other characteristics of children, parents or schools. While this assumption may not be tenable, its effects on our findings are likely minimal because we evaluate outcomes across all children within each racial/ethnic- or income-based stratum rather than among individual children. A further set of assumptions is that the effects of the SBT and quality pre-kindergarten programme will be similar to those observed in the relevant literature<sup>(2,12,13)</sup>. As described above, we use results presented in Sturm *et al.*<sup>(2)</sup> regarding the effect of SBT on SSB of children and adolescents. Similarly, we assume that participation in a pre-kindergarten programme subsidized via the SBT will improve children's educational achievement scores by 0.50 sd. We consider this a realistically optimistic scenario based on effect sizes of quality pre-kindergarten programmes in the literature<sup>(12,13)</sup>, but it is probably a larger effect than public pre-kindergarten programmes currently in place in Philadelphia. This assumption is based on recommendations made by a commission charged with creating an implementation plan for the expanded quality pre-kindergarten programme, which includes provisions that should improve quality of the new SBT-funded programme by, for example, improving quality standards, increasing teacher pay and implementing a minimum time requirement for children who participate in the programme (i.e.  $\geq 8$  h/d and  $\geq 260$  d/year). Since our main findings are a direct result of this set of assumptions, we conduct sensitivity analyses to understand how findings would vary based on different effect sizes of the SBT (on sweetened beverage consumption) and expanded quality pre-kindergarten programme (on children's educational achievement).

### Sensitivity analyses

Since our main findings are directly influenced by assumptions regarding the effect sizes of the SBT (on sweetened beverage consumption) and expanded quality pre-kindergarten programme (on children's educational achievement), we conducted sensitivity analyses to understand how findings would change under different effect size assumptions. Our approach to sensitivity analyses was to identify a reasonable range of parameters from the published literature and conduct 'one-at-a-time' local sensitivity analysis by essentially re-running simulations with parameter values at the upper and lower bounds of this range. In the online supplementary material, Supplemental Table 3, we provide effect sizes from the literature regarding the impact of participation in quality pre-kindergarten programmes on academic achievement. In Supplemental

Table 4, we provide effect sizes from the literature regarding the effect of SSB taxation on SSB consumption, as well as from the literature regarding own-price elasticities of demand of SSB. All sensitivity analyses were conducted 'one at a time' within the context of a base model that included implementation of a 25% tax on SSB and the pre-kindergarten intervention funded by the SBT. We ran twenty replications of five iterations of the model, with parameter values for each iteration provided in Table 3.

### Validation

To help establish face validity of the model (i.e. that 'baseline' results produced by the model are reasonable), we present simulated outcomes from the ABM as well as 'observed' outcomes based on data from child and adolescent participants in the 2010 and 2012 Southeastern Pennsylvania Household Health Survey (SPHHS). SPHHS is a repeated cross-sectional survey with a range of health and social data on a representative sample of children, adolescents and adults in Philadelphia<sup>(22)</sup>.

### Results

In Table 1, we present simulated outcomes from the ABM as well as soda consumption and pre-kindergarten data from the 2010 and 2012 SPHHS. In general, outcomes at the population level align reasonably well between the ABM and SPHHS data, but less well for subgroups defined by race/ethnicity and household income. Mean weekly soda consumption in the ABM was 8.9 drinks/week, compared with 9.2 drinks/week in SPHHS. Similarly, 53% of children and adolescents in the model attended some type of pre-kindergarten, compared with 65% in SPHHS. In general, the ABM predicted higher soda consumption for whites than observed in the SPHHS data, but lower consumption for blacks and those in poor households and households with income  $\leq 300\%$  FPL. Pre-kindergarten

**Table 1** Mean weekly sugar-sweetened beverage (SSB) consumption and pre-kindergarten (Pre-K) attendance, stratified by race/ethnicity and household income, for agent-based model (ABM) predictions and data from the Southeastern Pennsylvania Household Health Survey (SPHHS)

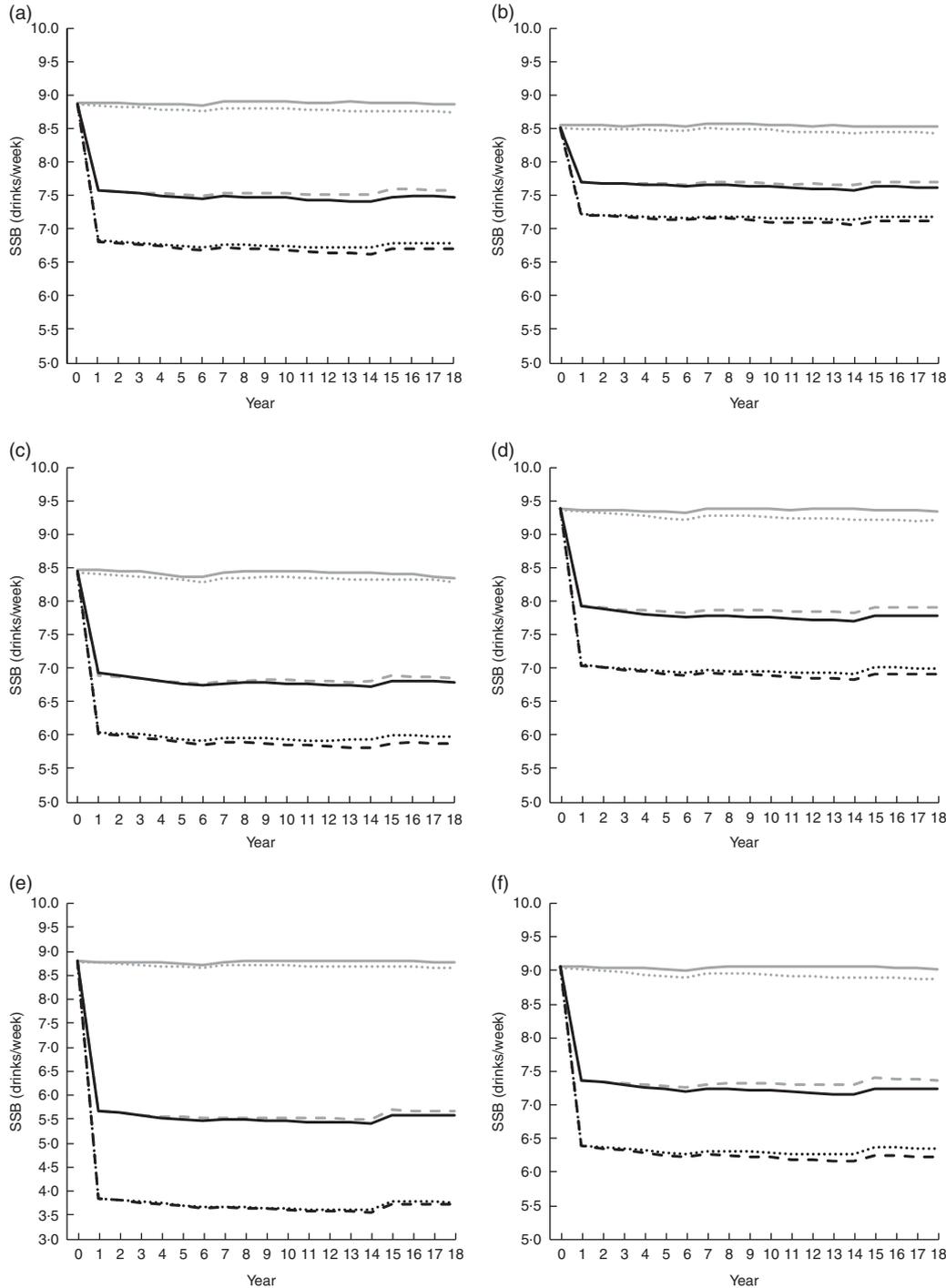
	Mean SSB (drinks/week)		% Attending Pre-K	
	ABM	SPHHS	ABM	SPHHS
Total	8.90	9.24	52.7	61.3
Race/ethnicity				
White	8.55	7.27	52.8	64.7
Black	9.40	10.64	52.9	60.1
Latino	8.47	8.29	52.6	61.0
Household income				
$\leq 100\%$ FPL	8.80	11.19	66.5	47.9
$\leq 300\%$ FPL	9.06	10.55	47.3	49.7

FPL, federal poverty level. Soda consumption is measured in mean SSB drinks/week and data are from the 2010 SPHHS; Pre-K attendance data are from the 2012 SPHHS and refer to  $\geq 12$  h Pre-K/week.

attendance rates were also lower among all racial/ethnic groups in the ABM relative to the SPHHS data.

In Fig. 1, we present mean weekly soda consumption under the six intervention scenarios, among all children and adolescents, by race/ethnicity and by poverty status.

In all simulations, interventions are implemented at the end of the first year. In general, soda consumption is greater among blacks than among whites and Latinos, both at initialization and post-intervention in all scenarios. Thus, soda consumption disparities both exist and persist in all scenarios.



**Fig. 1** Mean weekly sugar-sweetened beverage (SSB) consumption among all children and adolescents (a), and stratified by race/ethnicity (b, white; c, Latino; d, black) and household income (e,  $\leq 100\%$  of the federal poverty level (FPL); f,  $\leq 300\%$  FPL), from agent-based model predictions in the six intervention scenarios (—, no intervention; ·····, expanded pre-kindergarten, - - -, 25% sugary beverage tax (SBT); — — —, expanded pre-kindergarten and 25% SBT; - · - · - ·, 50% SBT; - · - · - ·, expanded pre-kindergarten and 50% SBT)

The results presented in Fig. 1 clearly demonstrate large decreases in SSB consumption among all racial/ethnic groups in scenarios with the SBT, with the magnitude of change larger in scenarios with a 50% tax than a 25% tax. For example, mean SSB consumption among black children and adolescents decreased from 9.4 drinks/week at model initialization to roughly 7.9 drinks/week upon implementation of a 25% tax and 7.0 drinks/week upon implementation of a 50% tax. Results also demonstrate that SSB consumption is slightly lower in scenarios that include the pre-kindergarten intervention compared with similar scenarios that lack the intervention.

Figures 1(e) and (f) present outcomes among poor children and adolescents as well as those in households with income  $\leq 300\%$  FPL. In general, scenarios that include the SBT demonstrate a larger decrease in SSB consumption among the poor than the non-poor. This makes sense, as the literature suggests the effect of excise taxes on SSB is strong for poor children and adolescents and near zero for the non-poor (and parameter values in the model reflect this)<sup>(2)</sup>.

In Table 2, we present mean changes between initialization and year 18 in weekly SSB consumption and pre-kindergarten attendance among all children and adolescents, as well as racial/ethnic- and income-based strata. Among the entire population, we find that soda consumption will decrease by 1.3 drinks/week with a 25% SBT and 1.4 drinks/week with a 25% SBT and pre-kindergarten. Thus, the pre-kindergarten programme increases the effect of the 25% tax by 7.7%. The 'value added' by the pre-kindergarten intervention is particularly large among children and adolescents with income  $\leq 300\%$  FPL: the 25% SBT reduces consumption by 1.68 drinks/week without the pre-kindergarten programme, but by 1.82 drinks/week with the programme (an additional 8.3%). The value added by the pre-kindergarten programme is somewhat smaller among the poor. For all children and adolescents, we find large reductions in SSB consumption in scenarios that include the SBT, as well as small but consistent additional reductions associated with the pre-kindergarten programme.

In Table 3, we present results of sensitivity analyses. In general, the sensitivity analyses yield results that make sense intuitively. Model outcomes are relatively insensitive to changes in the parameter regarding the effect of the SBT-funded pre-kindergarten programme on children's academic achievement. This insensitivity makes sense, because changes in children's achievement should not be expected to drive large-scale changes in SSB consumption, specifically. Rather, the importance of achievement is that it is associated with a range of social outcomes (e.g. educational attainment) which, in turn, drive a range of health outcomes across the life course. The sensitivity analyses also suggest that model outcomes are quite sensitive to changes in the effect of the amount of an SSB tax on SSB consumption. This is purely mechanical, as we

**Table 2** Mean changes in weekly sugar-sweetened beverage (SSB) consumption and pre-kindergarten (Pre-K) attendance in six intervention scenarios

	Mean SSB (drinks/week)						% Attending Pre-K						
	Intervention scenario						Intervention scenario						
	None	Pre-K	25% SBT	50% SBT	Pre-K & 25% SBT	Pre-K & 50% SBT	None	Pre-K	25% SBT	50% SBT	Pre-K & 25% SBT	Pre-K & 50% SBT	
Total	-0.04	-0.12	-1.30	-2.08	-1.40	-2.17	-0.40	21.78	-0.57	-0.45	21.67	-0.45	21.84
Race/ethnicity													
White	-0.02	-0.08	-0.81	-1.32	-0.88	-1.38	-0.29	19.12	-0.57	-0.46	18.71	-0.46	18.81
Black	-0.06	-0.16	-1.49	-2.38	-1.62	-2.47	-0.51	22.33	-0.59	-0.45	22.35	-0.45	22.58
Latino	-0.12	-0.15	-1.56	-2.44	-1.66	-2.58	-0.21	23.43	-0.51	-0.58	23.30	-0.58	23.41
Household income													
$\leq 100\%$ FPL	-0.04	-0.12	-3.12	-5.00	-3.21	-5.07	-0.69	19.24	-0.96	-0.81	19.33	-0.81	19.23
$\leq 300\%$ FPL	-0.05	-0.17	-1.68	-2.69	-1.82	-2.82	-0.50	28.69	-0.56	-0.49	28.65	-0.49	28.72

SSB, sweetened beverage tax; FPL, federal poverty level. Statistics refer to the mean difference in outcomes between years 0 and 18, across twenty simulation runs. Pre-K attendance refers to the percentage of children of pre-school age children who attend  $\geq 12$  h Pre-K/week.

**Table 3** Sensitivity analyses to understand how projected sugar-sweetened beverage (SSB) consumption among Philadelphia children and adolescents in low-income households varies based on key model parameters

	Parameters		Model outcome
	SSB tax rate on SSB consumption	SBT-funded Pre-K on achievement	Change in weekly SSB consumption (drinks/week)
Iteration no.			
1	-0.142	0.23	-3.17
2	-0.142	0.63	-3.25
3	0	0.50	-0.79
4	-0.30	0.50	-5.21
5	-0.45	0.50	-6.47

SBT, sweetened beverage tax; Pre-K, pre-kindergarten; FPL, federal poverty level.

'SSB tax rate on SSB consumption' refers to the effect of a 1 percentage point increase in the SBT on SSB consumption among poor children (i.e.  $\beta_{TR} | \text{child}=\text{poor}$ ) from Eq. (4) in the online supplementary material, Supplemental File 1).

'SBT-funded Pre-K on achievement' refers to the effect of SBT-funded quality pre-kindergarten participation on a child's achievement (i.e.  $\beta_p$  from Eq. (2) in Supplemental File 1, given that the child attended one of the Pre-K slots funded by the SBT).

'Weekly SSB consumption' refers to the mean difference in outcomes between years 0 and 18, across twenty simulation runs.

All outcomes are for children from households with annual income  $\leq 100\%$  FPL.

varied the value over a relatively large range and the amount of Philadelphia's SBT tax is high (i.e. 25%).

## Discussion

In the present study, we used an ABM to simulate plausible effects associated with the SBT and related pre-kindergarten programme in Philadelphia. We found that implementing an SSB tax at the level proposed in Philadelphia would achieve a substantive reduction in children's and adolescents' SSB consumption. This research is largely consistent with previous simulation studies and price elasticity research, which has generally found that price increases associated with an SSB tax would lower consumption<sup>(2,6,18,23,24)</sup>. Our results suggest that impact of the SBT is likely to be most pronounced among low-income children and adolescents. This is due to price elasticity estimates suggesting that poor children and adolescents are much more sensitive to price changes in SSB than the non-poor<sup>(2)</sup>. Because a large proportion of Philadelphia children and adolescents live in households with income below the poverty line<sup>(25)</sup>, the SBT will have a population-level impact despite only small changes in SSB consumption among the non-poor.

We also found that the pre-kindergarten programme will reduce SSB consumption among the entire population of poor children and adolescents by an average of about 0.1 drinks/week, a 'bonus' equivalent to 7 to 8% of the total effect size beyond what would be gained from implementing the 1.5-cent-per-ounce SBT alone. Furthermore, since education is a social determinant associated with a wide range of outcomes, the pre-kindergarten

programme is likely to have positive effects that extend beyond SSB consumption<sup>(26)</sup>.

Interestingly, we found that the 'value added' of the pre-kindergarten programme was larger in magnitude among children and adolescents with annual income  $\leq 300\%$  FPL than among those in poor households. This is likely because children in households with income between 101% and 300% FPL are the most likely to benefit from the pre-kindergarten programme; Philadelphia has a large number of Head Start slots exclusively available to children below 100% FPL<sup>(11)</sup>. Different groups may ultimately benefit most from the SBT *v.* the pre-kindergarten programme: SSB consumption among poor children will fall most due to the tax, because they are most sensitive to price changes, while children in households above but near the FPL will benefit most from the pre-kindergarten intervention.

Consideration should be given to advocacy organizations, media and members of the public who argue that the SBT is regressive because price increases represent a greater proportion of income among poor households<sup>(27,28)</sup>. While this is true, the complementary argument is that obesity, diabetes and other diet-related chronic diseases disproportionately impact the poor and thus are also regressive. Using a regressive policy to address regressively patterned diseases may thus be a common-sense approach. Furthermore, the benefits of the pre-kindergarten programme are progressive, as slots will be targeted towards low-income and other high-risk children<sup>(29,30)</sup>. These children typically experience worse educational quality and outcomes relative to others. Reducing the 'readiness gap' that separates low- and non-low-income children upon entry to kindergarten represents one strategy to reduce longer-term disparities in educational outcomes<sup>(12)</sup>.

We believe the present simulation-based study is very useful for informing policy debates regarding SSB taxes generally, as well as policy decisions regarding use of revenues from such taxes. SSB taxes passed in Philadelphia and Berkeley, California have explicitly allocated revenue towards programmes likely to impact health. As described by Gortmaker and colleagues (2017), the Berkeley City Council has allocated revenue from a recently implemented SBT to school and community programmes, many of which target low-income populations and include components to reduce diet-related chronic disease<sup>(31)</sup>. Other SSB taxes have been passed or are under consideration in cities that include San Francisco, Oakland, Boulder, Chicago and Seattle. Policy simulation research can play a role in helping policy makers to identify effective strategies for using tax revenue. This is particularly true for cities that implement SSB taxes over the next several years, since evaluation studies of programmes implemented in Berkeley, Philadelphia and other 'early adopter' cities will not yet be available.

The results of our sensitivity analyses underscore the need for further research to understand how implementation of large-magnitude SSB taxes impacts SSB consumption among children and others. The studies we

reviewed derived own-price elasticities of demand for SSB largely from state-level variation in differential tax rates on SSB<sup>(2,5–7)</sup>, which are much lower than those implemented in Philadelphia. Thus, applying these estimates to taxes of the magnitude passed in Philadelphia is admittedly extrapolating beyond the data, although there is little choice in this instance. Future evaluation studies of the larger SSB taxes in Berkeley, Philadelphia and other cities should be illustrative in this regard.

The current study has limitations that must be considered when interpreting its findings. First, our findings may reflect decisions in implementing the ABM. For example, parameter values in the ABM are based on our own secondary analyses of PSID-CDS data and values from the literature. Our use of own-price elasticity estimates from Sturm *et al.* has several advantages<sup>(2)</sup>. In contrast to many elasticity studies<sup>(7,20,21)</sup>, Sturm *et al.* estimated SSB elasticities using data from a longitudinal study of children and adolescents combined with state-level data on differential tax rates on SSB. They also estimated SSB elasticities separately among poor children, which aligns with our interest in examining differences in SSB consumption across racial/ethnic- and income-based strata.

Our findings regarding the impact of the pre-kindergarten programme on SSB consumption are also a function of our own analyses of data from PSID-CDS. These analyses (see online supplementary material) were subject to potential bias due to data limitations and sampling strategy of the original study. Specifically, we used a measure of weekly SSB consumption, which may not be as accurate as other methods (e.g. 24 h dietary recall). PSID-CDS also lacks measures of pre-kindergarten programme type (e.g. Head Start) and quality. A further limitation of our study is that we focus narrowly on SSB consumption. Clearly, compensatory behaviours may be important to assess. Currently, we lack the data to understand how children's pre-kindergarten attendance and educational achievement impact overall diets or consumption of a broader range of specific healthy and unhealthy food items.

In sum, we find that the SBT and pre-kindergarten programme to be implemented in Philadelphia will likely reduce SSB consumption. Interestingly, simulation results suggest that the tax will primarily impact low-income children, while expansion of quality pre-kindergarten will most greatly benefit modest-income children. The pairing of an excise tax on SSB with a complementary programme to improve a social determinant of health represents a progressive strategy to combat obesity and other diet-related chronic diseases, which are largely regressive in their social patterning.

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## Supplementary material

To view supplementary material for this article, please visit <https://doi.org/10.1017/S1368980017001756>

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