Taxing Volume, Targeting Sugar: The Impact of Sugar-Sweetened Beverage Excise Taxes on Outcomes Associated with Taxed and Untaxed Characteristics*

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Abstract

This paper develops a framework to understand how excise taxes affect outcomes related to both taxed characteristics of a product and associated, untaxed characteristics. The empirical analysis examines volumetric excise taxes on sugar-sweetened beverages (SSBs); while the tax is levied on volume, a primary objective of these taxes is to reduce sugar intake. Using national high-frequency retail scanner data and a staggered adoption synthetic difference-in-differences approach, we study the impacts of volumetric taxes across the US on prices and purchases of volume and sugar from SSBs. First, we find volumetric taxes disproportionately increase the price of larger-volume products, increasing the average price per ounce by 4.4% (24.6%) for products in the smallest (largest) product size quartile. Second, we show a specific excise tax generates an equivalent tax rate on taxed and untaxed characteristics within a product. Finally, we find that volumetric taxes in the US led to (i) larger overall reductions in volume (-36.2%) compared to grams of sugar (-31.0%) purchased from SSBs, and (ii) smaller increases in the average price per ounce (26.5%) compared to the average price per gram of sugar (40.7%). We show the gap in tax-induced relative reductions in volume versus sugar is plausibly driven by consumer substitution to products with higher sugar concentrations. The findings have important implications for specific excise tax structures, which should consider heterogeneity across products in both taxed and untaxed characteristics of interest.

JEL: I12, I18, H30, Q18

Keywords: specific excise tax, sugar-sweetened beverage, nutrition, sugar, synthetic difference-in-differences

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1 Introduction

Although taxes are often motivated by fiscal objectives, they are commonly used to achieve non-fiscal goals. "Sin" goods, such as tobacco, alcohol, and junk food, generate negative consumption externalities and internalities, which have prompted policymakers to consider taxation schemes focused on regulating this class of products (Hines Jr 2007; Chaloupka, Powell and Warner 2019). These taxes can take various forms. Specific taxation, a particularly prevalent form of excise taxes, are levied on a per-unit basis on one or more specific characteristics of a product. Specific excise taxes are simple to administer for this class of goods, because sin goods tend to feature characteristics that are labeled and can be directly targeted.[1] However, imposing specific excise taxes on one or more product characteristics may result in unintended changes in outcomes associated with other, untaxed characteristics of the product.

This paper develops a framework to understand how specific excise taxes affect outcomes related to both the taxed characteristics of a product and the associated, untaxed characteristics. We aim to address two important questions about the economic impacts of specific excise taxes. First, how does the quantity of taxed characteristic in a product affect the tax burden of a specific excise tax? We define the absolute tax burden as the total tax, in dollars, levied on an individual good, and the relative tax burden as the absolute tax burden divided by the price of a taxed good. Second, more generally, how do specific excise taxes affect outcomes associated with untaxed characteristics of interest?

The empirical analysis examines volumetric excise taxes on sugar-sweetened beverages (SSBs) implemented in the United States. Studies have found strong associations between consumption of sugar and adverse health outcomes including diabetes, obesity, and heart disease (McGuire 2016). Moreover, evidence from experimental settings featuring laboratory

[1] Examples include alcoholic concentration of a beverage, volume of liquid in vaping products, and milligrams of THC in cannabis products. Specific taxes are also levied on goods not typically considered as sin goods, such as an excise tax per gallon of gasoline, per ton sold or used of hazardous chemicals (i.e., Superfund chemical excise taxes), and taxes on airline travel, which are a mix of ad valorem and specific.

rats has shown sugar and sweetness to be as or more addictive than highly addictive drugs such as cocaine and heroin (Lenoir et al. 2007; Ahmed, Guillem and Vandaele 2013). SSBs make up the largest source of added sugar in the average American adult diet, representing nearly one-quarter of all added sugar intake (USDA and HHS 2020).[2] As a result, taxes on SSBs have become increasingly popular globally, with over 100 nations currently levying some form of an SSB tax (Hattersley and Mandeville 2023).

While specific excise taxes on SSBs can in theory be levied on a number of different characteristics (e.g. calories, grams of sugar, etc.), in practice over 90% are levied on volume, primarily to simplify tax administration and reduce enforcement costs. Yet, volumetric SSB taxes are not designed to reduce volume intake per se; rather, they are targeted at reducing associated characteristics, principally sugar. Using a Monte Carlo simulation, Grummon et al. (2019) finds that taxing sugar content as opposed to volume could boost the health benefits associated with an SSB tax by approximately 30%, driven by anticipated substitution from high-sugar to low-sugar products. Empirically evaluating how specific excise taxes affect outcomes associated with both taxed and untaxed characteristics of interest is crucial for providing guidance to policymakers crafting new or modifying existing taxes.

Our framework offers several important insights regarding specific excise taxation, in particular as they apply to SSBs. First, we show that when tax pass-through rates are the same across product sizes, larger-volume products experience a higher relative tax burden under a volumetric excise tax compared to smaller products. This arises due to the relationship between non-linear pricing in volume versus a tax that is linear in volume. This has important implications for how well volumetric taxes may target sugar; we identify two primary channels that may account for this relationship. First, if larger products contain different sugar concentrations (sugar-per-ounce) than smaller ones, a volumetric tax could disproportionately affect sugar relative to volume purchased from SSBs. Second, a volumetric tax may lead consumers to substitute toward products with higher sugar concentrations to reduce the

[2]While many foods containing sugar may offer some nutritional value through other characteristics, calories from SSBs are considered "empty" in that they do not provide any nutritional value.

tax paid per gram of sugar from SSBs. Similar evidence has been shown in response to per-pack cigarette excise taxes, with consumers substituting toward higher-quality products as the relative prices across quality tiers decrease after the tax (Chiou and Muehlegger 2014). Our findings also suggest that these substitution patterns may be more prevalent among larger-volume products, which face a higher relative tax burden.

Using national high-frequency retail scanner data and a staggered adoption synthetic difference-in-differences (SDID) approach, we study the impacts of five city-level volumetric SSB taxes across the United States on prices and purchases associated with volume and sugar from SSBs. Our analysis offers three key findings. First, the relative tax burden of a volumetric tax increases significantly with product size. The average price per ounce increases 4.4% for products in the smallest size quartile, and 24.6% for products within the largest size quartile. Second, while a specific excise tax imposes a different absolute tax amount per unit of characteristic in a good, it applies an equivalent tax rate to all characteristics within the same product. In other words, while the absolute tax amount on a gram of sugar might differ from that on an ounce of volume within a given SSB product, both characteristics will experience the same relative price increase under a specific excise tax. This equivalence, however, does not hold when aggregating or averaging *across* different products due to differences in the composition of their characteristics and possible differences in pricing and tax pass-through.

Finally, we find that volumetric taxes in the US led to (i) larger overall reductions in volume purchased compared to sugar purchased from SSBs and (ii) smaller increases in the average price per ounce compared to the average price per gram of sugar in SSBs. Sales of volume and sugar from SSBs fell 36.2% and 31.0%, respectively, in response to a volumetric tax. The average price per ounce and average price per gram of sugar increased 26.5% and 40.7%, respectively. We provide empirical evidence that the gap between relative reductions in sugar vs. volume purchased from SSBs is plausibly explained by an increase in the sugar concentration of purchased SSBs across product sizes. An accompanying Monte Carlo analysis finds that attributing proportional changes in volume to those of sugar from SSBs in response to volumetric SSB taxes may lead to overestimates of averted externality and internality costs of approximately \$5.70 per person per year.

1.1 Existing Literature and Contributions

Excise taxes are considered a key regulatory tool in addressing market failures associated with the presence of negative externalities (Pigou 1924; Baumol 1972; Diamond 1973). They are present in many different markets, ranging from firearms and ammunition to transportation and energy. A large and economically important class of products that are subject to various excise tax structures are sin goods. Sin goods often feature specific characteristics that tend to generate not only consumption externalities, but also internalities related to their addictive nature and the challenges they pose for self-control (O'Donoghue and Rabin 2006; Allcott, Lockwood and Taubinsky 2019b; Chaloupka, Levy and White 2019; Li and Dorfman 2019; Wang, Marsiliani and Renström 2020; Schmacker and Smed 2023; Gerster and Kramm 2024). Taxes on sin goods have also been found to lead to consumption responses through non-price mechanisms, such as media coverage and lobbying efforts (Taylor et al. 2019; Rees-Jones and Rozema 2023), as well as through oppositional behavioral responses (Ching and Goetz 2024). Further, excise taxes on sin goods have been shown to have important distributional consequences, including higher tax burdens among less educated and poorer individuals (Gruber and Kőszegi 2004; Colman and Remler 2008; Goldin and Homonoff 2013; Allcott, Lockwood and Taubinsky 2019a; Conlon, Rao and Wang 2022).

A related body of research considers regulation of externality-generating goods that feature multiple characteristics of interest. Ito and Sallee (2018) present an economic theory of attribute-based regulation, in which policies are targeted toward an externality-generating characteristic, but rely on a secondary characteristic to determine compliance. They find this can lead to benefits in the form of equalizing marginal compliance costs across firms, but costs incurred by distortionary incentives associated with the secondary characteristic.

Barzel (1976) introduced foundational theory demonstrating that excise taxes on specific attributes may induce consumers to substitute toward untaxed attributes. Compared with *ad valorem* taxes, excise taxes are expected to lead to a shift from quantity to quality.[3] This substitution effect is particularly relevant when considering how taxes might inadvertently encourage the consumption of untaxed, yet harmful, product characteristics. Several papers provide empirical evidence for tax-induced substitution effects between product characteristics, particularly in the case of cigarette excise taxes. Research finds that smokers respond to taxes by substituting toward cigarettes higher in tar and nicotine (Evans and Farrelly 1998) and attempting to extract more nicotine per cigarette (Adda and Cornaglia 2006).

Tax-avoidance behavior is another fundamental consideration in the design of excise taxes. There has been extensive work examining tobacco, alcohol, and other sin product markets documenting cross-border shopping impacts, substitution toward discount or generic brands, increased use of coupons, and pre-tax stockpiling, and in the case of tobacco, switching to purchasing cigarettes by the carton instead of by the pack to take advantage of bulk pricing (Hyland et al. 2005; Stehr 2005; Beatty, Larsen and Sommervoll 2009; Xu et al. 2013; Pesko, Licht and Kruger 2013; Chiou and Muehlegger 2014; White and Ross 2015; Gehrsitz, Saffer and Grossman 2021; Seiler, Tuchman and Yao 2021; Zhang et al. 2021).

There has been recent work specifically examining excise tax design for SSBs. A key question is which characteristic(s) should be taxed. While most specific excise taxes on SSBs are levied on volume, studies suggest that taxing the externality-generating characteristic—namely sugar—would be more efficient, as it directly targets the harmful constituent of SSBs and serves as a broader-based tax (Calcott 2022). Grummon et al. (2019) uses simulation methods to show that a tax on sugar in SSBs could increase health benefits and overall economic gains by as much as 30% compared to a volumetric tax. Allcott, Lockwood and Taubinsky (2019b) highlights that while volumetric taxes are easier to implement, they are poorly aligned with the health risks these taxes aim to reduce. Zhen, Brissette and

[3] Barzel (1976) considers a simple example comparing 12 one-month lightbulbs vs. one 12-month lightbulb, where an excise tax on lightbulbs will induce a shift toward fewer, higher-quality bulbs.

Ruff (2014) explores the impacts of taxing calories instead of ounces in SSBs, finding that a calorie-based tax is significantly more cost-effective. Similarly, Harding and Lovenheim (2017) finds through tax simulations that volumetric taxes are somewhat less effective and more distorting than sugar-based taxes.

Our research makes both conceptual and empirical contributions to the literature on excise tax design, particularly in the context of specific excise taxes on SSBs. To the best of our knowledge, we are the first to examine the disproportionate relative tax burden on larger- versus smaller-volume products, which arises from the interaction between a linear tax and a non-linear product price (as a function of volume). We are also the first to document that a specific excise tax imposes an equivalent relative tax burden on each characteristic within a taxed product. In addition, we find that a volumetric tax results in relatively smaller reductions in sugar purchased vs. volume purchased from SSBs. We are the first to empirically test mechanisms driving this gap, finding evidence of consumer substitution toward beverages with higher sugar concentrations. This effect is particularly prevalent in larger-volume products, which face the highest relative tax burdens.

A second collection of research considers the economic and health impacts associated with implementation of SSB taxes in particular. There has been significant work documenting the impact of implementing SSB taxes on several economic outcomes, including SSB volume purchases (Taylor et al. 2019; Cawley, Frisvold and Jones 2020; White et al. 2023), prices and tax pass-through (Cawley and Frisvold 2017; Grogger 2017; Cawley et al. 2018; Rojas and Wang 2021; Bollinger and Sexton 2023), cross-border shopping effects (Cawley et al. 2019b; Cawley, Frisvold and Jones 2020; Seiler, Tuchman and Yao 2021; Kaplan et al. 2024), and substitution toward alternative products (Vall Castelló and Lopez Casasnovas 2020; Léger and Powell 2021; Dickson, Gehrsitz and Kemp 2023), including a recent review documenting the impacts on each of these respective outcomes (Cawley et al. 2019a). An even more recent meta-analysis finds a mean reduction in SSB sales of 15%, corresponding to an estimated price elasticity of demand of -1.59, and an average tax pass-through rate of

82% (Andreyeva et al. 2022). Much of this work has focused on examining impacts at the individual-jurisdiction level. However, recent work has undertaken a joint estimation across jurisdictions, primarily across cities within the US, finding that SSB taxes in general have led to a 33.1% average increase in prices of SSB products, resulting in a 33.0% decrease in volume purchases (Kaplan et al. 2024).

There have only been a few studies estimating the impact of SSB taxes on changes in grams of sugar purchased from SSBs. Dubois, Griffith and O'Connell (2020) leverages longitudinal microdata from the UK to study changes in sugar purchases of individuals subject to a volumetric SSB tax of similar magnitude to those implemented in the US. They find tax implementation led to an 18% reduction on average of purchases of sugar from SSBs. However, they show that the tax delivers heterogeneous effects across different individuals, finding that it is not well-targeted toward individuals from households with high total dietary sugar, but is effective in targeting young and low-income consumers. Aguilar, Gutierrez and Seira (2021) examines the nationwide SSB and caloric-dense food taxes in Mexico, finding statistically significant, but small, impacts on changes in volume, calories, and sugar purchased from sugary drinks. However, these decreases are offset by shifts in the composition of food and drink purchases, primarily away from sugar and toward fat. In the US, Bleich et al. (2021) examines SSB purchases in small independent stores in Philadelphia and Baltimore, finding the Philadelphia SSB tax led to a 22.6% and 34.1% decline in calories and total sugar, respectively.[4] Powell, Leider and Oddo (2021) uses scanner data from stores in Seattle, WA and Portland, OR to assess changes in grams of sugar sold in response to the Seattle SSB tax, finding net reductions between 18-19% in the two years post-tax.

Finally, there has been even less work establishing the impact of SSB taxes on important nutritional and health outcomes. Kiesel, Lang and Sexton (2023) provides an overview of the SSB tax impact literature to date, finding that while studies have found evidence

[4] Lozano-Rojas and Carlin (2022) find that the SSB tax in Philadelphia facilitated a 4.3% increase in purchases of sugar from sweetened foods, offsetting about 19% of the decline in sugar purchases from SSBs in response to the tax.

in favor of decreases in purchases of SSBs in response to tax implementation, evidence for changes in actual consumption and substitution to healthier product alternatives is less clear. There is also only limited evidence to date suggesting that SSB taxes lead to measurable improvements in important health outcomes; some research finds reductions in body mass index (BMI) (Jones-Smith et al. 2024; Gračner, Marquez-Padilla and Hernandez-Cortes 2022; Flynn 2023; Young et al. 2024; Liu et al. 2025), while other research is not able to detect any statistically significant effect (Lawman et al. 2020; Cawley, Daly and Thornton 2021; Gregory et al. 2025).

We contribute to the existing literature by producing the strongest set of causal evidence to date, both in terms of granularity and breadth of data as well as methodological rigor, assessing the impact of volumetric SSB taxes on purchases of sugar from SSBs. With access to a rich set of retail scanner data containing both volume and nutritional information at the product level, we are able to directly compare relative changes in volume and sugar purchases from SSBs in response to SSB taxes. Relative to existing studies, such an approach allows us to provide a clear understanding of the impacts of volumetric SSB taxes on purchases of sugar as the externality-generating nutrient of interest.

The rest of the paper proceeds as follows. First, we present a conceptual framework that provides economic intuition behind our primary findings. We then describe and provide summary statistics on the retail scanner data. We detail our empirical strategy to evaluate outcomes associated with volume and sugar prices and purchases from SSB products. We then present the results of our analyses, followed by a discussion and interpretation of possible mechanisms. The final section provides concluding remarks and suggests general takeaways for other product categories with similar structures and considerations.

2 Conceptual Framework

This section introduces a simple conceptual framework to explain several of the economic mechanisms underlying our findings. The first subsection explores the relationship between product size (in volume) and the relative tax burden. The second subsection establishes the equivalence of the relative tax burden across all individual characteristics of a product under a specific excise tax. The final subsection addresses impacts on the untaxed characteristic of interest, highlighting potential mechanisms that drive the differences in relative purchases of volume versus sugar from SSBs in response to a volumetric excise tax.

2.1 Relative Tax Burden and the Taxed Characteristic

We first show that the relative tax burden associated with a volumetric tax increases with product size.[5] Consider the price of product i, $p_i(v_i, s_i)$, to be a function of total volume v_i and total sugar s_i for a given product. Assume $p_i' > 0$ and $p_i'' < 0$ in both arguments, and that $p(0,0) = 0$. Suppose that each product faces a specific excise tax t on v_i. We can then write the price of product i in the presence of a tax as:

$$p_i^t(v_i, s_i) = p_i(v_i, s_i) + \alpha_i t v_i \tag{1}$$

where $\alpha_i \in [0, 1]$ represents the tax pass-through rate.[6] The relative tax burden on product i can be written:

$$\Gamma_i = \frac{\mathcal{T}_i}{p_i^t(v_i, s_i)} \tag{2}$$

where $\mathcal{T}_i$ is the absolute tax burden on product i (in dollars), and can be explicitly written as $\mathcal{T}_i = \alpha_i t v_i$. The change in the relative tax burden as product size increases can be seen in

[5]Since the absolute tax burden is defined as the total tax, in dollars, levied on an individual good, it is by definition increasing in product size.

[6]In practice, one can also obtain over-shifting of more than 100% pass-through if suppliers opportunistically use a tax to pass along additional price increases (e.g. Xu et al. 2014; Apollonio and Glantz 2020).

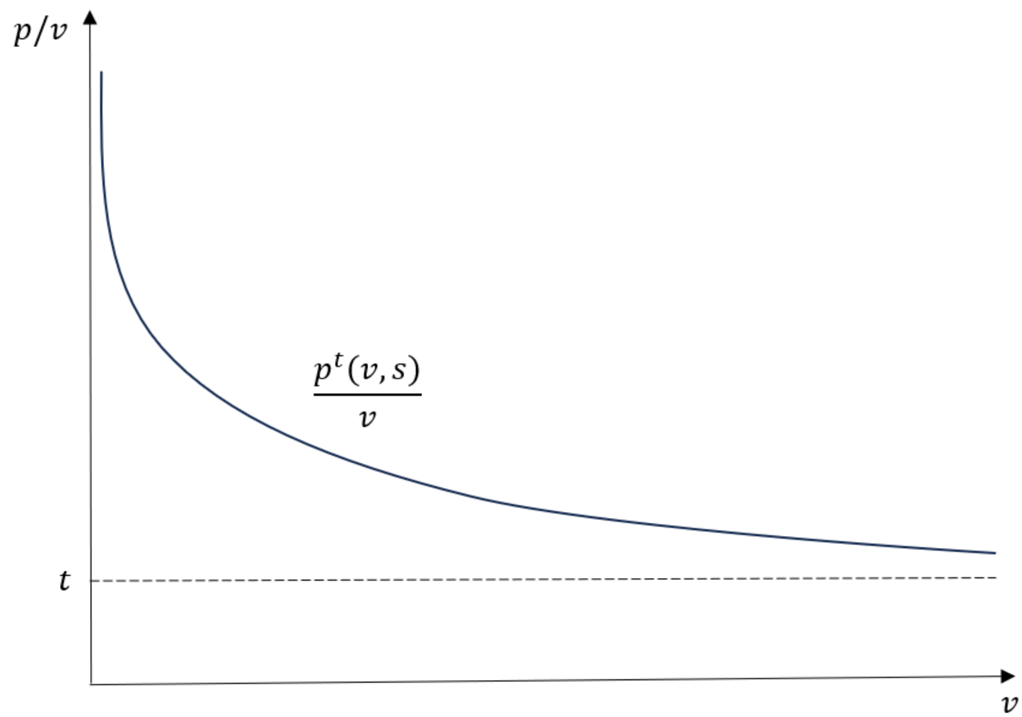
Equation 3:

$$\frac{\partial \Gamma_i}{\partial v_i} = \frac{\alpha_i t \left(p_i^t(v_i, s_i) - v_i \frac{\partial p_i^t(v_i, s_i)}{\partial v_i} \right)}{p_i^t(v_i, s_i)^2} > 0 \tag{3}$$

which is positive, because $p_i^t(v_i, s_i) - v_i \frac{\partial p_i^t(v_i, s_i)}{\partial v_i} > 0$.[7]

Figure 1 provides a visual representation of this finding. One can see that the relative tax burden is increasing in volume, assuming tax pass-through rates are the same across product sizes. Two primary features explain this: (i) a non-linear, concave relationship between product size and product price and (ii) the absolute tax burden increasing linearly in product size.[8]

Figure 1: Relative Tax Burden Increases with Product Volume



[7]Because $p_i' > 0$ and $p_i'' < 0$ in both arguments and $p(0,0) = 0$, the average rate of change $\left(\frac{p_i^t(v_i, s_i) - p(0,0)}{v_i} \right)$ over the interval $[0, v_i]$ is greater than the instantaneous rate of change $\left(\frac{\partial p_i^t(v_i, s_i)}{\partial v_i} \right)$ for all $v_i > 0$.

[8]As is the case with tax pass-through rates, it is also possible that the *absolute* tax pass-through may differ by product size.

2.2 Equivalence of Relative Tax Burden Across Taxed and Untaxed Characteristics

We show here that an excise tax on a specific characteristic generates an equivalent *relative* tax burden on all characteristics within the product. Specifically, when examining a volumetric excise tax, the relative tax burden per gram of sugar in an SSB product is equivalent to the relative tax burden per ounce of volume of an SSB product.

Consider a specific excise tax t on characteristic v_i. Rewriting Equation 2:

$$\Gamma_{i,vol} = \frac{\mathcal{T}_i}{p_i^t(v_i, s_i)} = \frac{\alpha_i t v_i}{p_i^t(v_i, s_i)} = \alpha_i \frac{t}{\frac{p_i^t(v_i,s_i)}{v_i}}$$

To show that the relative tax burden on characteristic v_i is equivalent to the relative tax burden on a different, untaxed characteristic s_i, we manipulate the previous expression as follows:

$$\Gamma_{i,vol} = \alpha_i \frac{t}{\frac{p_i^t(v_i,s_i)}{v_i}} = \frac{\frac{\mathcal{T}_i}{v_i}}{\frac{p_i^t(v_i,s_i)}{v_i}} = \frac{\frac{\mathcal{T}_i}{v_i}}{\frac{p_i^t(v_i,s_i)}{v_i}} \frac{\frac{v_i}{s_i}}{\frac{v_i}{s_i}} = \frac{\frac{\mathcal{T}_i}{s_i}}{\frac{p_i^t(v_i,s_i)}{s_i}} = \Gamma_{i,sug}$$

which can be simplified to:

$$\Gamma_{i,vol} = \frac{\frac{\mathcal{T}_i}{v_i}}{\frac{p_i^t(v_i,s_i)}{v_i}} \equiv \frac{\frac{\mathcal{T}_i}{s_i}}{\frac{p_i^t(v_i,s_i)}{s_i}} = \Gamma_{i,sug} \tag{4}$$

Under a specific excise tax on characteristic v_i, the relative tax burden on v_i is equivalent to relative tax burden on a separate, untaxed characteristic s_i for a given product. Notably, this equivalence is not affected by important sources of heterogeneity, including the sugar concentration of a product and tax pass-through rate for the product. However, the equivalence does not hold *across* products (i.e., when aggregating or averaging outcomes across multiple products) due to differences in composition of characteristics, as well as different possible pricing and tax pass-through structures.

2.3 Outcomes for Taxed versus Untaxed Characteristics

Understanding the impact of a volumetric tax on changes in purchases of sugar from SSBs compared with purchases of volume is critical for assessing the effectiveness of a volumetric tax policy instrument in reducing sugar consumption. We explore two primary channels through which volumetric taxes may lead to differential relative changes in volume vs. sugar purchases from SSBs.

The first channel considers the relationship between the sugar concentration of SSB varieties (sugar per ounce) and product size. Section 2.1 shows that the relative tax burden of a volumetric tax increases with product size. If sugar concentration varies across product sizes, a volumetric tax could result in different relative changes in sugar versus volume purchases from SSBs. Specifically, if larger products (by volume) tend to have lower (higher) sugar concentrations than smaller products, a volumetric tax may lead to smaller (larger) relative reductions in sugar purchases compared to volume purchases. Appendix D provides a numeric example that illustrates this possible channel in further detail.

The second channel considers the potential for tax-induced substitution by consumers toward products with higher sugar concentrations. In particular, consumers seeking to lessen the absolute tax burden faced on each gram of sugar may choose products with higher sugar concentrations. This behavior may explain part or all of any observed, tax-induced gap in relative changes in sugar and volume purchases from SSBs, to the extent that there is a *smaller* relative reduction in sugar purchases compared with volume purchases.

3 Data

Our primary dataset is the retail scanner dataset from NielsenIQ©.[9] It includes observations at the product-week-store level from 90+ retail chains across the US and covers most products sold in retail stores. The products are coded at the 12-digit UPC level. Store locations are identified at the 3-digit ZIP code level, with 873 total 3-digit ZIP codes covering nearly all of the US. Our study period takes place from January 1, 2012 through February 28, 2020.[10]

For each observation, we have information about the number of units sold and average shelf price per unit.[11] In order to identify all tax-eligible SSB products, we match NielsenIQ beverage product UPCs with UPC-level nutritional and product attribute information from Label Insight,[12] which provides a rich set of nutritional information about UPCs, as well as hand-coded sources.[13] Important product-level attributes from these data include product size (in ounces), total servings, and total sugar per serving. Our final sample contains 4,029 SSB UPCs that are tax-eligible and contain nutritional information on product size, total sugar content, and serving size.[14]

Table 1 provides descriptive information about the geographic jurisdictions and SSB excise tax landscape across the US. The five treated 3-digit ZIP codes in our study are Philadelphia, PA (191), Boulder, CO (803), Oakland, CA (946), San Francisco, CA (941), and Seattle, WA (803).[15] The five treated ZIP codes comprise three distinct treatment

[9] Data Disclaimer: All estimates and analyses in this presentation are by the authors and not by NielsenIQ. Researchers' own analyses calculated (or derived) based in part on data from Nielsen Consumer LLC and marketing databases provided through the NielsenIQ Datasets at the Kilts Center for Marketing Data Center at The University of Chicago Booth School of Business. The conclusions drawn from the NielsenIQ data are those of the researchers and do not reflect the views of NielsenIQ. NielsenIQ is not responsible for, had no role in, and was not involved in analyzing and preparing the results reported herein.

[10] The NielsenIQ retail scanner data are updated annually; we omit March 2020 and beyond due to possible confounding effects associated with the COVID-19 pandemic.

[11] The price is an average, because a given UPC may be offered at multiple shelf prices within a given store-week.

[12] Nielsen Consumer LLC. Label insight. NielsenIQ. https://nielseniq.com/global/en/landing-page/label-insight/

[13] See White et al. (2023) and Kaplan et al. (2024) for further detail on the hand-coding procedure.

[14] Even though the SSB tax in Philadelphia covers both sugar-sweetened and artificially-sweetened beverages, we examine SSBs only.

[15] We omit Berkeley, CA and Albany, CA (947) because they are part of the same 3-digit ZIP code, but adopted a tax at different times. Stores in each jurisdiction could not be separately identified in the NielsenIQ

Table 1: Descriptive Information About 3-Digit ZIP Codes

	191 (Phil.)	803 (Boul.)	946 (Oak.)	941 (SF)	981 (Sea.)	Borders	Donors
No. 3-digit ZIPs	1	1	1	1	1	13	855
No. stores	205	25	41	102	110	1,495	54,095
Date tax implemented	Jan. 2017	Jul. 2017	Jul. 2017	Jan. 2018	Jan. 2018	—	—
No. months pre-tax	60	66	66	72	72	—	—
No. months post-tax	38	32	32	26	26	—	—
Tax per ounce, in ¢	1.50	2.00	1.00	1.00	1.75	—	—

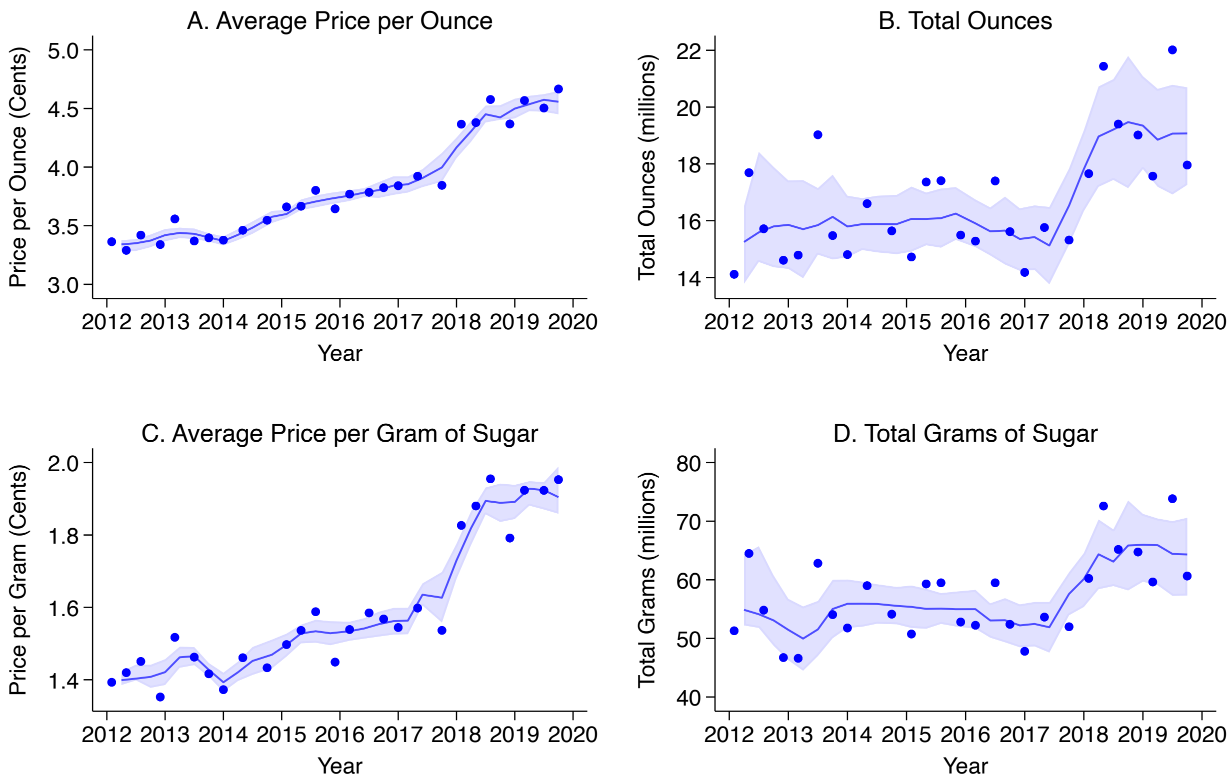
Note: The unweighted (weighted) composite tax is \$0.0145 (\$0.0144) per ounce. Border 3-digit ZIP codes comprise all immediately adjacent 3-digit ZIP codes to each of the five treated ZIP codes and include 800, 804, 805, 945, 948, 080, 081, 940, 949, 980, 982, 983, 984. Donor ZIP codes consist of all untreated, non-bordering 3-digit ZIP codes.

cohorts: January 1, 2017 (Philadelphia), July 1, 2017 (Boulder and Oakland), and January 1, 2018 (San Francisco and Seattle). Taxes range from 1¢ to 2¢ per ounce. There are a total of 13 immediately adjacent (bordering) 3-digit ZIP codes, which leaves 855 untreated, non-bordering ZIP codes in the sample. Additional information about the coverage of total SSB sales in the five treated geographies found within the NielsenIQ retail scanner data is provided in Table A.1 in Appendix Section B.

The analysis uses data aggregated to the 3-digit ZIP code-by-month level. The study examines four primary outcome variables associated with purchases of SSBs: total ounces, total sugar, average price per ounce, and average price per gram of sugar. We also examine a fifth outcome—average sugar per ounce—in evaluating possible substitution toward products with higher sugar concentrations. Figure 2 displays time trends for each of these four outcome variables, derived from kernel-based local quadratic regressions with robust bias-corrected confidence intervals (Calonico, Cattaneo and Farrell 2018). One can see that all outcomes trend upward, although steeper increases are exhibited in the average price per ounce (Panel A) and average price per gram (Panel C). There appears to be an observable jump in both price measures at the beginning of 2018, the first time period when all five SSB taxes are in place. Further details on the data aggregation procedure and additional,

retail scanner data. We also omit the two areas in the US with *ad valorem* taxes (Washington, DC and the Navajo Nation in the Southwestern US).

Figure 2: Time Trends of Four Primary Outcome Variables in Aggregated Data



Note: The vertical axis in each panel represents the average monthly value across 3-digit ZIP codes for each respective outcome measure. A binned scatterplot is overlaid with a local quadratic regression with mean squared error-optimal bandwidth and 30 evaluation points, constructed using an Epaneschnikov kernel. The shaded area denotes the 95% CI, calculated from a heteroskedasticity-robust nearest neighbor variance estimator with 3 neighbors.

sample-wide summary statistics for the four primary outcomes can be found in Appendix Section B.1.

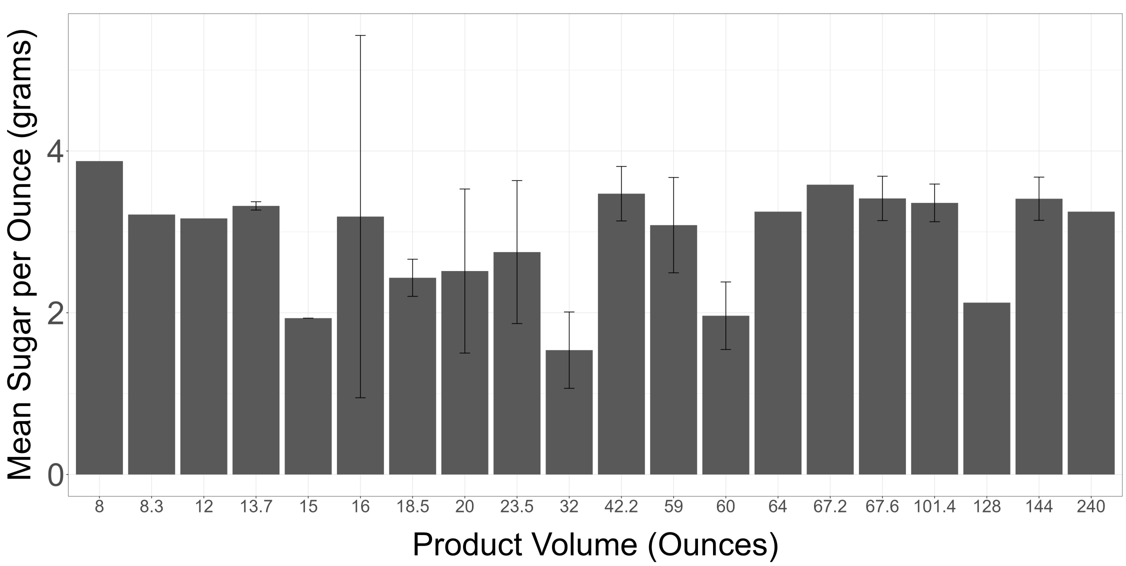
Table 2 displays summary statistics by product size quartile. The smallest product size quartile includes products ranging from 0 to 12.6 ounces, while the largest includes products from 52.0 to 1,152.0 ounces. Of note is the stark decline in average price per ounce by product size; the smallest product size quartile features an average price per ounce of 23.2¢, while average price per ounce in the largest quartile is nearly an order of magnitude lower at 2.8¢ per ounce. Because the volumetric tax ranges between 1¢ and 2¢ per ounce, these stark differences suggest that the relative tax burden is likely to be significantly higher on larger products. This hypothesis is confirmed in the analyses in Section 5.

Table 2: Summary Statistics by Product Size Quartile

Quartile	Product Size (oz)	No. UPCs	Mean (¢/oz)	SD (¢/oz)	Min (¢/oz)	Max (¢/oz)	Avg. grams sugar/oz
1	0 – 12.6	1,210	23.2	39.9	0.08	6815.9	3.16
2	12.7 – 19.9	1,154	14.0	5.9	0.05	234.9	4.24
3	20.0 – 51.9	1,281	6.6	4.6	0.02	1795.5	2.51
4	52.0 – 1,152.0	1,239	2.8	1.9	0.0009	74.6	3.21

The final column of Table 2 shows the average sugar concentration by product size quartile, which is relatively uniform. Figure 3 provides further detail about the distribution of sugar concentration by product size. The horizontal axis indicates the most common product sizes observed in the data, and includes all products with more than 50 million total units sold over all geographies during the study period. The bars represent the average sugar concentration (and accompanying standard deviation) of products by size. The distribution of average sugar concentration is quite uniform across product sizes.

Figure 3: Average Sugar Concentration for Most Commonly Sold Product Sizes



Note: Figure includes product sizes with > 50,000,000 total units sold across all ZIP-codes and time periods in the data.

This has important implications for understanding the underlying mechanism(s) driving any observed, tax-induced differences between relative changes in sugar versus volume purchases from SSBs. If average sugar concentrations were steeply increasing or decreasing in product size, this could at least partially explain any observed tax-induced disparity between relative volume and sugar purchases from SSBs. Temporal trends in average sugar concentration of purchased SSB products, as well as the distribution of sugar concentrations among the most commonly sold product sizes, can be found in Figures A.6 and A.7, respectively, in Appendix Section B.

4 Empirical Strategy

We employ the recently developed synthetic difference-in-differences (SDID) approach (Arkhangelsky et al. 2021) under a staggered adoption setting to assess several outcomes associated with implementation of volumetric excise taxes in the US. Using the data described in Section 3, we construct five separate outcome variables to analyze: total ounces, total grams of sugar, average price per ounce, average price per gram of sugar, and average sugar per ounce. We construct a balanced panel for each outcome variable at the 3-digit ZIP code-by-month level.[16] Further detail on the aggregation procedure for constructing each outcome variable is provided in Appendix Section B.1.

The SDID estimation we employ takes the following weighted two-way fixed effects structure in Arkhangelsky et al. (2021). For each treatment cohort (adoption date) $a \in A$:

$$(\hat{\tau}_a^{sdid}, \hat{\mu}_a, \hat{\alpha}_a, \hat{\beta}_a) = \arg\min_{\tau,\mu,\alpha,\beta} \left\{ \sum_{i=1}^{N} \sum_{t=1}^{T} (Y_{it} - \mu - \alpha_i - \beta_t - W_{it}\tau)^2 \hat{\omega}_{a,i}^{sdid} \hat{\lambda}_{a,t}^{sdid} \right\} \tag{5}$$

where Y_{it} denotes the outcome for 3-digit ZIP code i during month-of-sample t, and α_i and β_t indicate 3-digit ZIP code and month-of-sample fixed effects, respectively. W_{it} is a binary variable $= 1$ for treated ZIP code-by-month observations and $= 0$ otherwise. Unit-specific weights $\hat{\omega}_{a,i}^{sdid}$ are generated to match pre-treatment trends between control and treated 3-digit ZIP codes, and time-specific weights $\hat{\lambda}_{a,t}^{sdid}$ are generated to balance post- and pre-treatment

[16] The SDID approach requires a balanced panel with a reasonably small number of treated units.

outcomes for control 3-digit ZIP codes.[17] τ is the estimated average treatment effect on the treated (ATT) for treatment cohort a.

The approach offers several major benefits compared with difference-in-differences (DID) and synthetic control (SC) methods used individually. Similar to a DID approach, a perfect pre-treatment match with the constructed synthetic control is not necessary for identification; achieving parallel trends is sufficient. Similar to an SC estimation approach, unit-specific weights are assigned in constructing the synthetic control group such that parallel trends is more easily achieved than in a conventional DID estimation setting, although SDID adds time-specific weights to provide an improved counterfactual trend. Finally, the SDID approach has been shown to produce less biased and more precise estimates than both DID and SC methods under similar empirical settings.

We apply a recently developed extension to the conventional SDID approach in order to produce estimates for each period in event time, both for each individual treatment cohort (Clarke et al. 2023) and composite estimates across treatment cohorts (Ciccia 2024). Following Ciccia (2024), define $N = N_{tr} + N_{co}$, where N_{tr} and N_{co} are the number of treated and control units, respectively. We order the units such that the first $N_{co} = N - N_{tr}$ units make up the control group, and let I^a be the subset of treated units in cohort a among $\{N_{co}+1, ..., N\}$ total treated units. Define T^a_{tr} as the number of time periods post-treatment for treatment cohort a.

Ciccia (2024) shows that Equation 5 can be disaggregated into T^a_{tr} individual event time estimates, thus producing a treatment effect for each period $\ell \in [0, T^a_{tr}]$ beginning with and following treatment for each treatment cohort a. For each $a \in A$, event-study estimates for each ℓ are generated as follows:

$$\hat{\tau}^{sdid}_{a,\ell} = \frac{1}{N^a_{tr}} \sum_{i \in I^a} Y_{i,a^*+\ell} - \sum_{i=1}^{N_{co}} \omega_i Y_{i,a^*+\ell} - \sum_{t=1}^{a^*-1} \left(\frac{1}{N^a_{tr}} \sum_{i \in I^a} \lambda_t Y_{i,t} - \sum_{i=1}^{N_{co}} \omega_i \lambda_t Y_{i,t} \right) \tag{6}$$

[17]Both unit- and time-specific weights are generated using an optimization algorithm that can be found in Section I of Arkhangelsky et al. (2021), which also includes a full summary of the entire SDID algorithm.

where a^* is defined such that it takes on the numeric value of the adoption time period t corresponding to cohort a. To produce composite estimates for each event time ℓ across all treated cohorts in A, we can take the subset of treated cohorts $A_\ell \in A$ such that $a^* + \ell \leq T$. In other words, A_ℓ is the subset of treated cohorts for which we are able to estimate an event time-specific estimate in period ℓ, given the timing of their adoption relative to the end of the observed sample period. Define N_{tr}^{ℓ} as the number of treated units across cohorts for which we are able to estimate an event time-specific estimate in period ℓ. We can then aggregate treatment effects across cohorts for event time ℓ as follows:

$$\hat{\tau}_{\ell}^{sdid} = \sum_{a \in A_\ell} \frac{N_{tr}^{a}}{N_{tr}^{\ell}} \hat{\tau}_{a,\ell}^{sdid} \tag{7}$$

We then calculate a *balanced* ATT estimate across all event times ℓ in which *all* treated cohorts are present:

$$\widehat{ATT}_{bal} = \frac{1}{\min(T_{tr}^{a})} \sum_{\ell=0}^{\min(T_{tr}^{a})} \hat{\tau}_{\ell}^{sdid} \tag{8}$$

where $\min(T_{tr}^{a})$ represents the minimum value of T_{tr}^{a} across all treatment cohorts. As a result, the balanced ATT estimate is only constructed from event time-specific estimates for which treated units across all treatment cohorts are present. This is done both for transparency and interpretation purposes, so that composite estimates can be interpreted knowing that all treated units contribute equally to its composition. In our specific application, while we observe (and estimate ATT impacts for) the three separate treatment cohorts, our composite effects are estimated such that each taxed jurisdiction is given equal weight.

4.1 Inference

To conduct inference, we implement a unit-level clustered bootstrapping (cb) procedure.[18] For each bootstrapped sample $b \in B$, we estimate $\hat{\tau}_\ell^{sdid}$ for all ℓ. This enables us to generate the variance estimator $\hat{V}_\ell^{cb}$ for each ℓ across bootstrapped samples:

$$\hat{V}_\ell^{cb} = \frac{1}{B}\sum_{b=1}^{B}\left(\widehat{\tau}_\ell^{b} - \frac{1}{B}\sum_{b=1}^{B}\widehat{\tau}_\ell^{b}\right)^2 \tag{9}$$

An identical approach can be used to estimate $\hat{V}_t^{cb}$ for all t, where $T_{pre} \leq t < \ell = 0$; T_{pre} is defined as the minimum event time period in the analysis and t indexes event time periods prior to treatment. We can also use an analogous approach to estimate $\hat{V}_{ATT}^{cb}$ (aggregating across all ℓ event time periods). Each of our analyses sets $B = 500$.

5 Results

This section presents three sets of results. We first show the heterogeneous impact of volumetric taxes on the absolute and relative tax burden of SSB products across product sizes. The second set of results empirically validates the equivalence in relative tax burden of a volumetric tax on volume and sugar within a specific SSB product. We also show that this equivalence is unlikely to hold across a bundle of products by examining all SSBs among the four most commonly sold product sizes. Finally, we present results of the overall impacts of volumetric taxes on changes in prices and purchases of sugar and volume from SSB products. Section 6 provides further insight on these results, including a discussion and justification of plausible mechanisms driving differences in tax-induced relative changes in purchases of sugar vs. volume from SSBs.

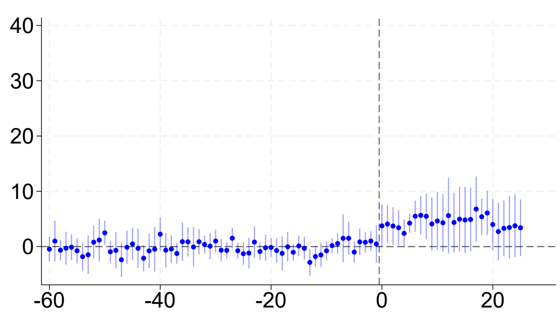
[18] Unit-level clustered bootstrapping ensures the balanced panel structure of the data is maintained.

5.1 Average Price per Ounce by Product Size

The first set of results presents estimates of the impact of volumetric SSB taxes on average price per ounce by product size quartile. Figure 4 separates UPCs into four quartiles based on product size.[19] There are two primary takeaways from this figure. First, we do not find evidence of a clear relationship between product size and the per-ounce absolute tax pass through associated with a volumetric tax. Specifically, the ATT for the volumetric tax corresponds to an absolute price increase ranging between 0.72¢ and 1.25¢ per ounce. On the other hand, we do find strong evidence of increases in the *relative* tax burden by product size. In particular, the ATT for the smallest products is an average price increase of 4.4%, compared to the impact on average prices for the largest products of 24.6%. This is driven primarily by non-linear pricing in SSB products, accompanied by a constant specific excise tax per ounce structure; larger products have a much lower average price per ounce than smaller products, as seen in Table 2.

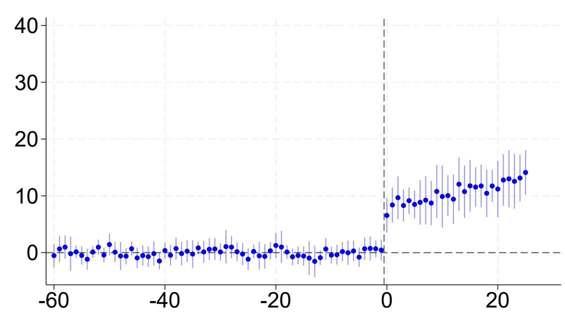
Figure 4: Composite Impact of Volumetric SSB Taxes on Average Price per Ounce by Product Size Quartile

Quartile 1



ATT: 0.77¢ (0.40¢); 4.4% (2.3%)

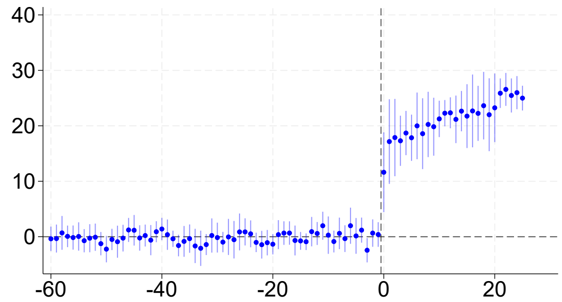
Quartile 2



ATT: 1.25¢ (0.24¢); 10.6% (2.0%)

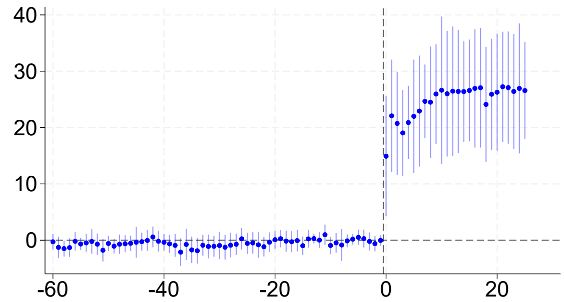
[19] The product size cutoffs for each quartile can be found in Table 2.

Quartile 3



ATT: 1.16¢ (0.13¢); 21.3% (2.4%)

Quartile 4



ATT: 0.72¢ (0.14¢); 24.6% (5.0%)

Note: The vertical axis in each panel represents the ATT, expressed as a percent change in average price per ounce compared to the pre-treatment baseline average price per ounce across all treated units. The horizontal axis represents months from tax implementation in event time. Below each panel is the estimated ATT and its SE in parentheses, both as an absolute change (in black) and percent change (in blue). Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

5.2 Equivalence of Relative Tax Burden on Sugar vs. Volume

The second set of results empirically validates the equivalence in relative tax burden for grams of sugar and ounces within an individual SSB product derived in Section 2.2. Table 3 shows the impacts of a volumetric tax on average price per ounce (Panel a) and average price per gram of sugar (Panel b) for the the top-selling UPC (by total units sold) within each of the four most common product size categories across all geographies during our study period. The UPCs are a 12 oz. can of Coca-Cola, a 32 oz. bottle of Gatorade Fruit Punch, a 67.6 oz. (2 liter) bottle of Coca-Cola, and a 12-pack of 12 oz. cans of Coca-Cola (144 oz. total). Each column presents an SDID ATT estimate for each UPC.

Panel (a) of Table 3 shows that the absolute increase in average price per ounce of these four products is between 0.6¢ and 0.8¢. The relative price increases for each of these products exhibit more heterogeneity, due to variation in average price per ounce for each. Panel (b) presents results of each estimation with average price per gram of sugar as the dependent variable. As expected, the absolute changes in average price per gram of sugar differ, because unit ranges of sugar and ounces within a given product are quite different. However, one

Table 3: Tax Burden on SSB Price/Ounce and Price/Gram of Sugar by Common UPCs

	12 oz. Coca-Cola	32 oz. Gatorade	67.6oz Coca-Cola	12-Pack 12 oz. Coca-Cola
Panel (a). Tax burden on average price per ounce				
Treatment	0.0083***	0.0064***	0.0084***	0.0067***
	(0.0008)	(0.0008)	(0.0005)	(0.0004)
N	81928	81928	81928	81928
Dep. Var. Mean	0.085	0.033	0.023	0.028
% Change	9.783	19.126	37.105	23.755
Panel (b). Tax burden on average price per gram				
Treatment	0.0026***	0.0037***	0.0026***	0.0020***
	(0.0002)	(0.0005)	(0.0002)	(0.0001)
N	81928	81928	81928	81928
Dep. Var. Mean	0.026	0.019	0.007	0.009
% Change	9.783	19.126	37.105	23.754

Note: The number of observations may differ slightly by specification due to 3-digit zip codes not containing sales information for all time periods for a given product or product size. Standard errors indicated in parentheses.
* p<0.10 ** p<0.05 *** p<0.01

can see from comparing the last row in each panel that the relative price increase for the average price per gram of sugar is identical to that for the average price per ounce.

Table 4 presents a similar set of estimates for *all* UPCs within the product sizes represented in Table 3. Specifically, we estimate the changes in average price per ounce (Panel a) and average price per gram (Panel b) for all 12 oz., 32 oz., 67.6 oz., and 144 oz. SSB products. While the percent changes in average price per ounce and average price per gram of sugar are similar within product size, they are no longer identical. Whereas the equivalence of relative tax burden between ounces of volume and grams of sugar holds within product, it may not hold across multiple products, even among products with the same size.

5.3 Overall Impacts on Prices and Purchases of Sugar and Volume

The final set of results presents the average impacts of implementing a volumetric tax on prices and purchases of both grams of sugar and ounces of volume across all UPCs.

Table 4: Tax Burden on SSB Price/Ounce and Price/Gram of Sugar by Common Product Sizes

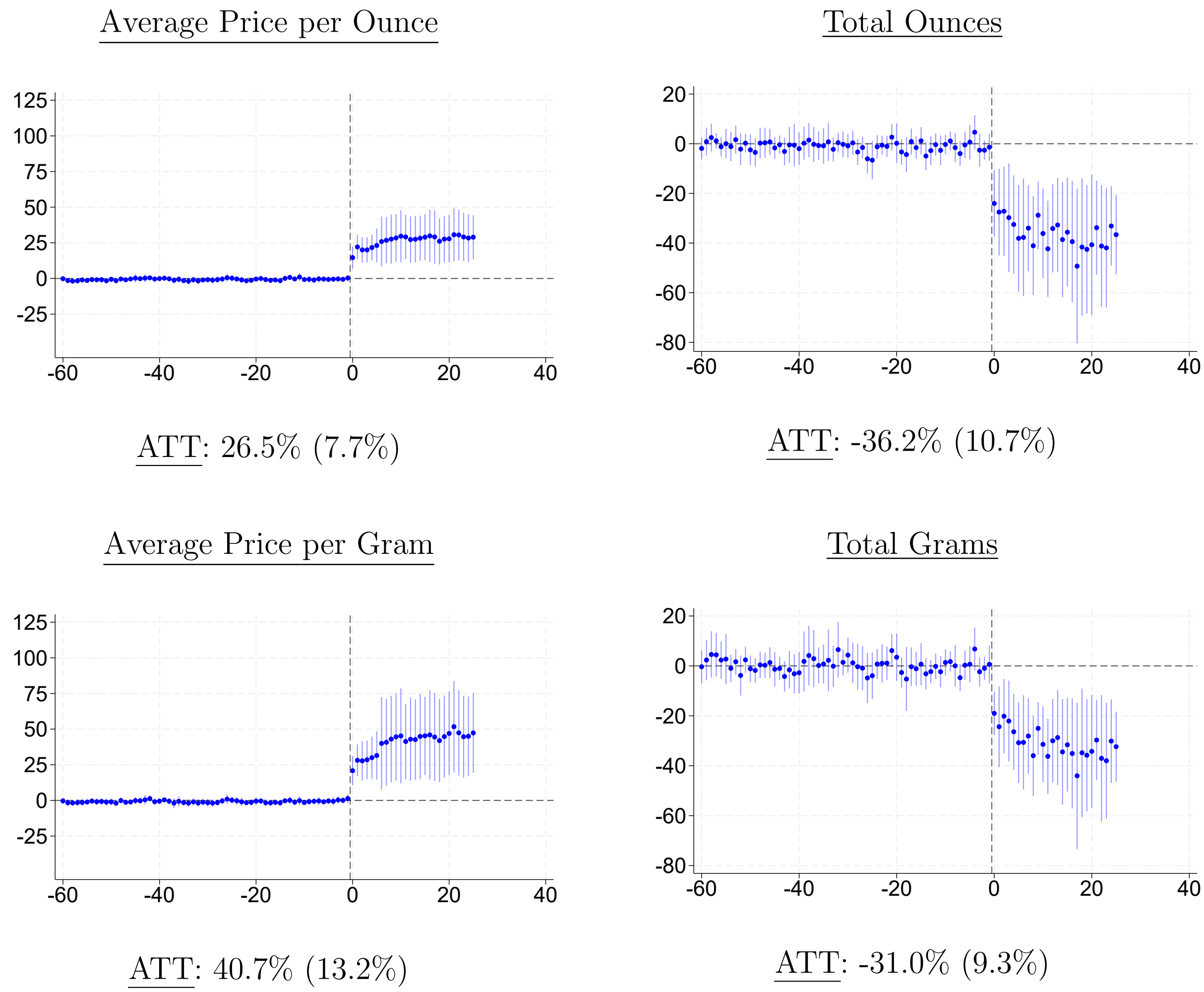
	12 oz.	32 oz.	67.6 oz.	144 oz.
Panel (a). Tax burden on average price per ounce				
Treatment	0.0107***	0.0076***	0.0084***	0.0069***
	(0.0009)	(0.0011)	(0.0005)	(0.0004)
N	84280	83006	84280	84280
Dep. Var. Mean	0.072	0.035	0.021	0.027
% Change	14.779	21.524	40.490	25.157
Panel (b). Tax burden on average price per gram				
Treatment	0.0030***	0.0057***	0.0025***	0.0020***
	(0.0004)	(0.0017)	(0.0001)	(0.0002)
N	84280	83006	84280	84280
Dep. Var. Mean	0.032	0.027	0.006	0.009
% Change	9.578	20.873	39.940	22.309

Note: The number of observations may differ slightly by specification due to 3-digit zip codes not containing sales information for all time periods for a given product or product size. Standard errors indicated in parentheses.
* p<0.10 ** p<0.05 *** p<0.01

Figure 5 presents the ATT estimates, as a percent change, for the four primary outcomes of interest: average price per ounce, total ounces, average price per gram of sugar, and total sugar. There are several key takeaways from these findings. First, the tax causes average price per gram of sugar to experience larger relative increases than the average price per ounce; average price per gram of sugar increases by an estimated 40.7% while the average price per ounce increases an estimated 26.5%. Conversely, sales of total ounces of SSBs fell more drastically (-36.2%) than total grams of sugar sold from SSBs (-31.0%) in response to volumetric SSB taxes. Estimated changes in prices and quantities deliver a price elasticity of demand for volume from SSBs of -1.37, and a price elasticity of demand for sugar from SSBs of -0.76. This suggests that consumers may be more sensitive to changes in the price of ounces from SSBs than changes in the price of sugar from SSBs.

Figure 6 presents the ATT estimates, as a percent change, for the four primary outcomes of interest among all 13 3-digit ZIP codes immediately bordering one of the five treated 3-digit

Figure 5: Composite Impact of Volumetric SSB Taxes on Overall Prices and Quantities of Sales of Ounces and Sugar from SSBs

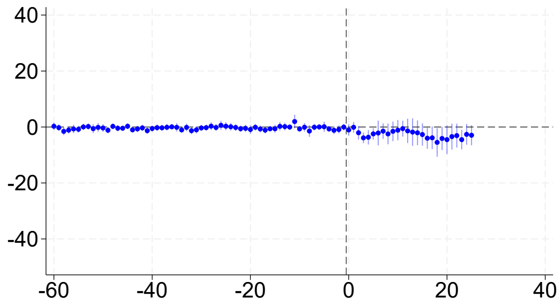


Note: The vertical axis in each panel represents the ATT, expressed as a percent change in each respective outcome variable compared to the pre-treatment baseline of that outcome across all treated units. The horizontal axis represents months from tax implementation in event time. Below each panel is the estimated ATT and its SE in parentheses. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

ZIP codes. We do not find evidence of cross-border impacts following tax implementation for any of the outcomes. Sales of total ounces and total grams of SSBs marginally decreased, rather than increased, during the post-tax period.

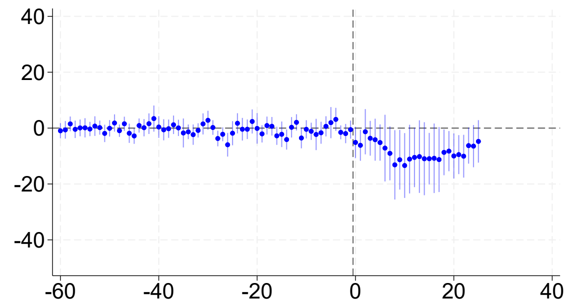
Figure 6: Composite Impact of Volumetric SSB Taxes on Overall Prices and Quantities of Cross-Border Sales of Ounces and Sugar from SSBs

Average Price per Ounce



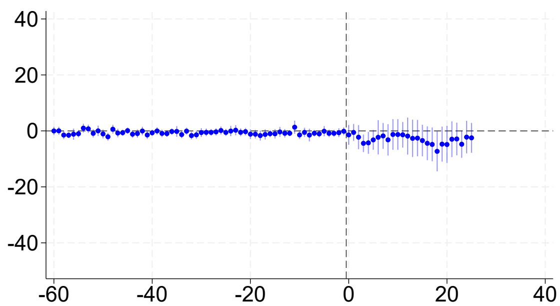
ATT: -2.7% (1.8%)

Total Ounces



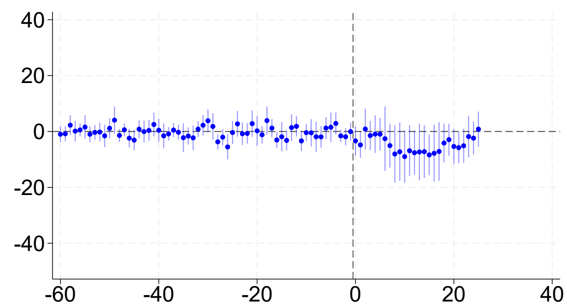
ATT: -8.4% (4.7%)

Average Price per Gram



ATT: -3.1% (2.7%)

Total Grams



ATT: -4.7% (3.9%)

Note: The vertical axis in each panel represents the ATT, expressed as a percent change in each respective outcome variable compared to the pre-treatment baseline of that outcome across all treated units. The horizontal axis represents months from tax implementation in event time. Below each panel is the estimated ATT and its SE in parentheses. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

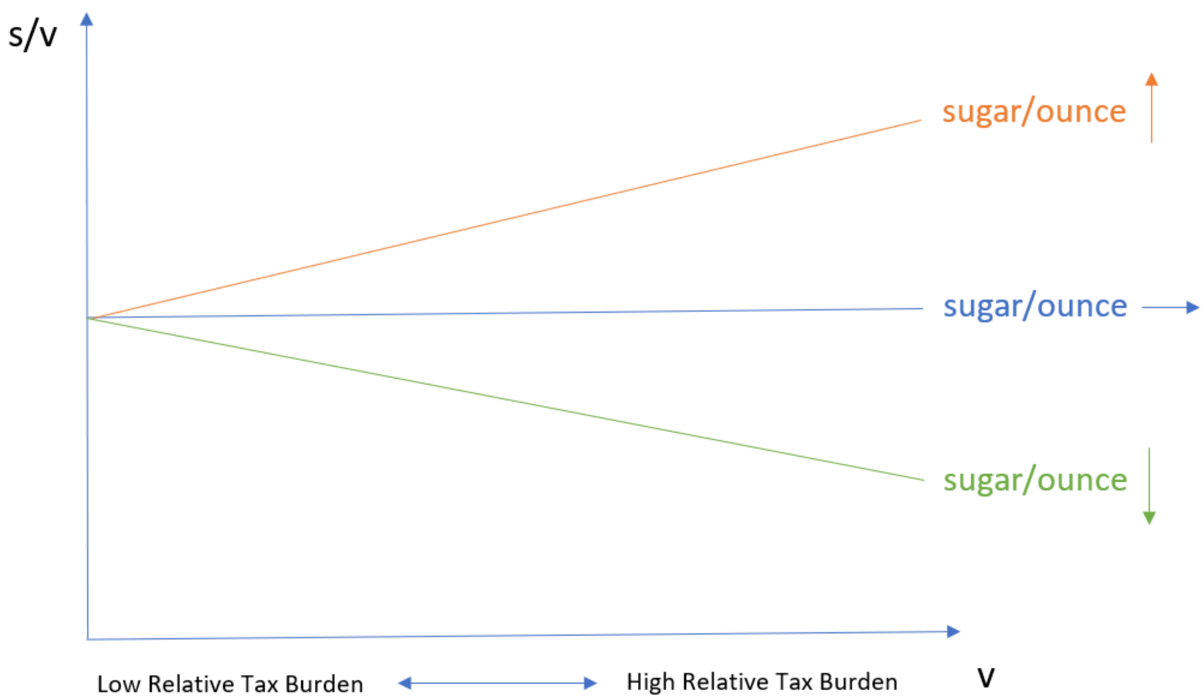
5.4 Mechanisms

Understanding the mechanisms driving the gap in relative changes in volume versus sugar purchases from SSBs in response to a volumetric tax is important for assessing the effectiveness of such taxes in targeting untaxed characteristics of interest. We explore two potential mechanisms that could explain this observed discrepancy.

5.4.1 Heterogeneity in Sugar Concentration by Product Size

The first mechanism is heterogeneity in sugar concentration by product size. Put simply, if larger products have lower sugar concentrations on average than smaller products, but experience a higher relative tax burden, then overall volume purchases from SSBs may fall by more than sugar purchases from SSBs.[20]

Figure 7: Heterogeneity in Sugar-per-Ounce by Product Size: Visual Intuition



Note: The horizontal axis represents product size (ounces) and the vertical axis represents sugar-per-ounce. The conceptual and empirical results establish that relative tax burden is increasing in product size. Three hypothetical scenarios are presented: sugar-per-ounce is increasing in product size (orange), decreasing in product size (green), and uniform across product size (blue).

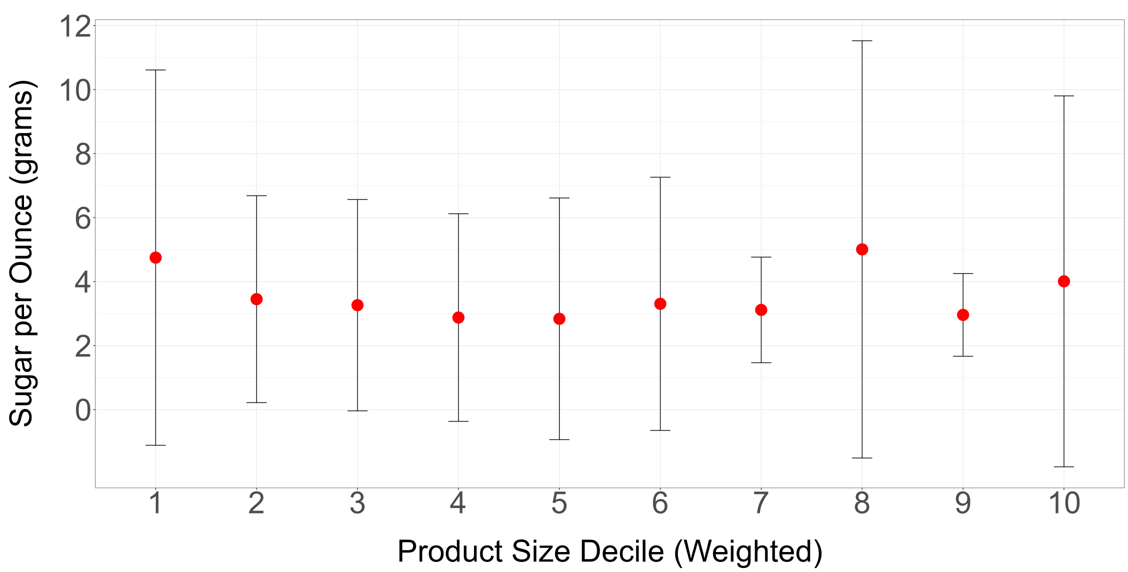
Figure 7 presents the intuition behind this possible mechanism. Building on the conceptual and empirical results that relative tax burden increases with product size, the effect of a volumetric tax on relative reductions in sugar versus volume depends on how sugar concentration varies with product size. If sugar concentration is increasing/decreasing/uniform

[20] If, for instance, we had instead observed larger reductions in sugar vs. volume purchases from SSBs in response to a volumetric tax, the same intuition would hold if larger products have higher average sugar concentrations than smaller products.

in product size, a volumetric tax is expected to result in larger/smaller/identical relative reductions in sugar compared to volume purchased from SSBs. A more detailed explanation is provided in the numeric example in Appendix D.[21]

Given that we observe a larger relative reduction in volume versus sugar, for this mechanism to be justified, one would expect larger products to have a lower average sugar concentration compared to smaller products. Figure 8 shows the distribution of average sugar concentration by product size decile, weighted by volume.[22] We see that the distribution of sugar concentration across product size is relatively uniform. This is intuitive, as larger SSB products often have the same formula as smaller products (e.g. 12 oz. can vs. 2 liter bottle of Coca-Cola). While this mechanism may not be responsible for the gap in relative changes in volume and sugar purchased from SSBs, it could be relevant in other geographic contexts with SSBs, or for different product categories subject to specific excise taxes.

Figure 8: Sugar-per-Ounce by Product Size Decile



Note: The red dots indicate the average sugar concentration estimate by decile. Error bars represent one standard deviation.

[21] Additional intuition for this mechanism can also be found in Grummon et al. (2019).

[22] Weighted product size deciles are constructed such that total ounces sold is held constant across deciles. In other words, each decile plotted in Figure 8 contains the same number of total ounces sold.

5.4.2 Substitution to Products with Higher Sugar Concentrations

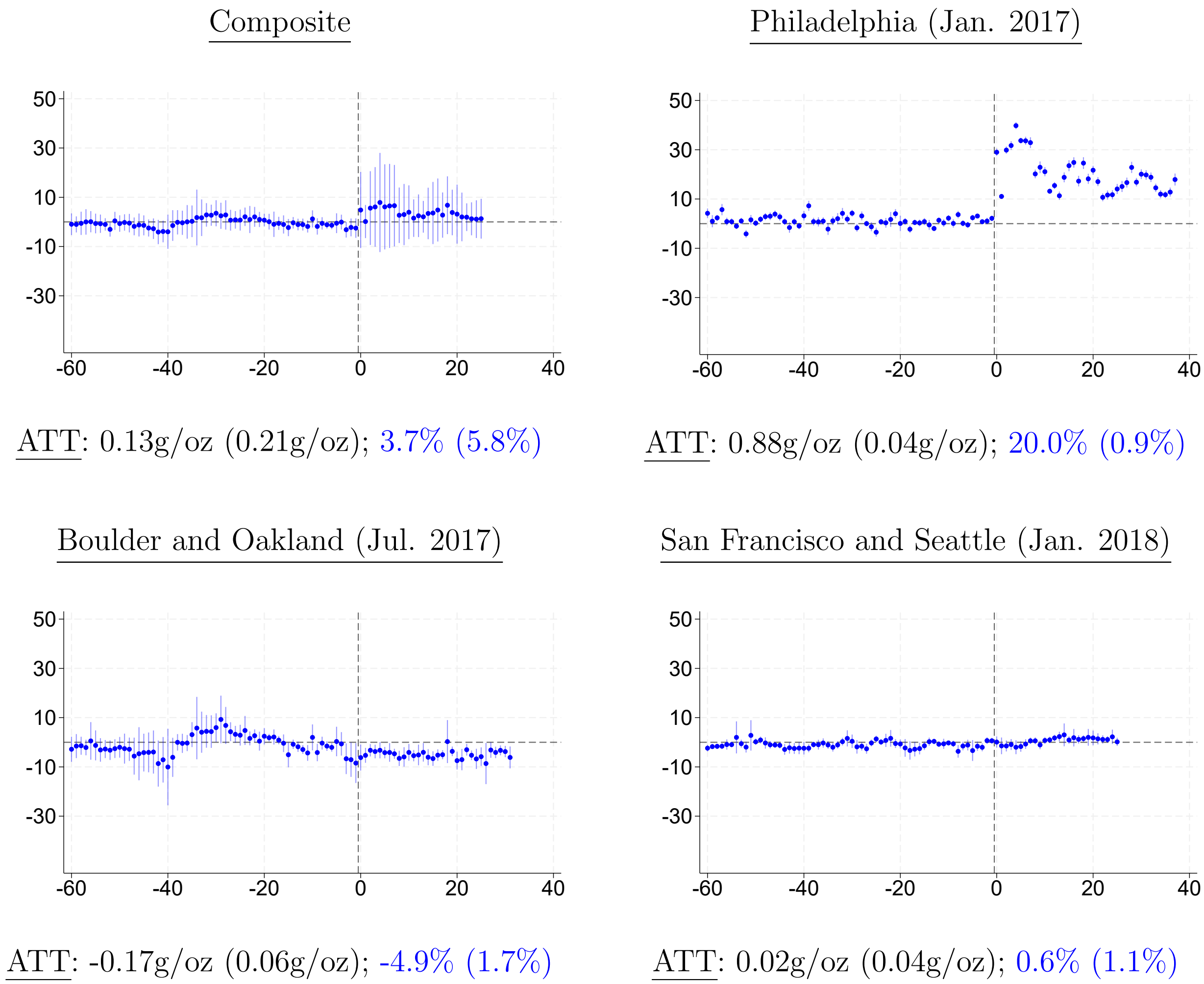
The second mechanism plausibly driving the gap in relative reductions in volume versus sugar purchases from SSBs in response to a volumetric excise tax is changes in the sugar concentration of purchased products pre- versus post-tax implementation. If consumers respond to the tax by substituting to products with higher sugar concentrations (to reduce the absolute tax paid per gram of sugar), this would explain the smaller relative reduction in sugar compared to volume purchases from SSBs.

To analyze the effect of a volumetric SSB tax on this characteristic, we calculate the sugar per ounce for each unique UPC and then take the weighted average sugar per ounce by 3-digit ZIP code-month within the sample.[23] Figure 9 presents the ATT estimates, in both absolute and relative terms, for the composite SDID estimation, as well as for the three individual treatment cohort-level estimations. The composite effect of implementation of a volumetric tax on the sugar concentration of purchased products is a 3.7% increase, but is not statistically different from zero. The sign and size of this effect suggests plausible evidence in favor of this "sugar-seeking" behavioral mechanism, considering the sign and size of the gap between the relative reductions in sugar (-31.0%) and volume (-36.2%) following tax implementation.

Perhaps more interesting, though, is the heterogeneity observed across treatment cohorts. Purchases of SSB products in both the Boulder and Oakland cohort as well as the San Francisco and Seattle cohort do not exhibit economically meaningful changes in average sugar concentrations post- vs. pre-tax (Appendix Figures A.13 and A.14). However, the sugar concentration of purchased SSB products in Philadelphia increases significantly following its tax; the absolute increase in average sugar-per-ounce is 0.88g/oz, corresponding to a 20.0% increase.

[23] We weight each product-week-store observation by total ounces sold from that observation. The sugar concentration for each product is independent from the construction of weights. Of course, the weights will be affected by heterogeneous changes in ounces purchased post- vs. pre-tax, but this further supports the mechanism by which relative changes in sugar purchases were lower than relative changes in volume purchases from SSBs.

Figure 9: Impact of Volumetric SSB Taxes on Sugar Concentration of Purchased SSB Products

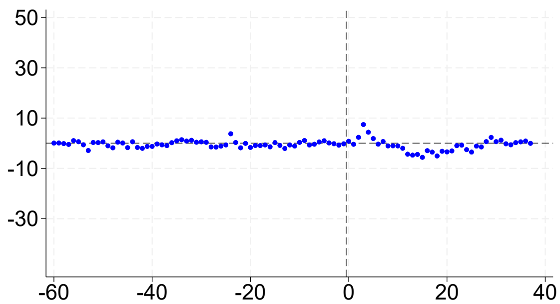


Note: The vertical axis in each panel represents the ATT, expressed as a percent change in the average sugar concentration of purchased products compared to the pre-treatment baseline average sugar concentration of purchased products across all treated units. The horizontal axis represents months from tax implementation in event time. Below each panel is the estimated ATT and its SE in parentheses. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

Figure 10 explores this phenomenon in Philadelphia more closely by estimating the impacts on average sugar concentration of purchased SSBs by product size quartile. Within Philadelphia, there is substantial heterogeneity by product size. In particular, the average sugar concentration of products purchased within the largest product size quartile increases 27.8% post-tax (1.34g/oz), whereas the increases are significantly lower for products

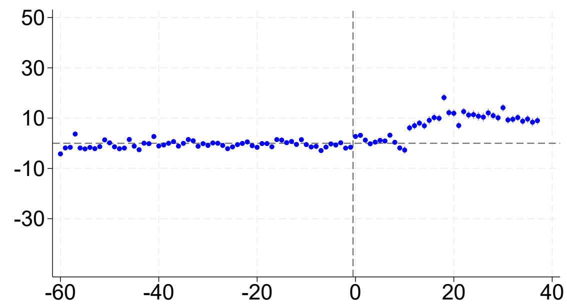
Figure 10: Impact of Volumetric SSB Taxes on Sugar Concentration of Purchased SSB Products in Philadelphia: By Product Size Quartile

Quartile 1



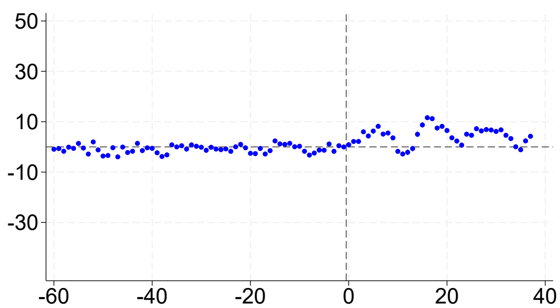
ATT: -0.03g/oz (0.01g/oz); -0.9% (0.4%)

Quartile 2



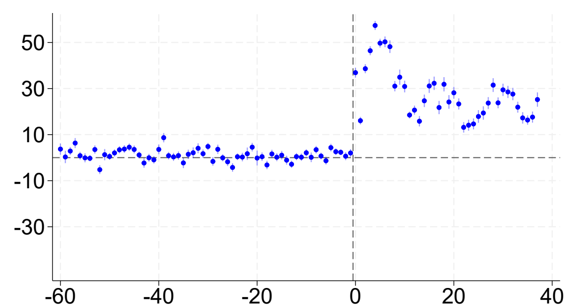
ATT: 0.25g/oz (0.02g/oz); 7.5% (0.7%)

Quartile 3



ATT: 0.10g/oz (0.01g/oz); 4.3% (0.5%)

Quartile 4



ATT: 1.34g/oz (0.06g); 27.8% (1.3%)

Note: The vertical axis in each panel represents the ATT, expressed as a percent change in the average sugar concentration of purchased products compared to the pre-treatment baseline average sugar concentration of purchased products across all treated units. The horizontal axis represents months from tax implementation in event time. Below each panel is the estimated ATT and its SE in parentheses. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

in quartiles 2 and 3, and quartile 1 exhibiting no change. Considering the relative tax burden increases in product size, this finding may be explained by greater substitution rates toward SSBs with higher sugar concentrations among products experiencing larger relative tax burdens.

6 Discussion

Our findings suggest that a volumetric tax leads to a significantly higher relative price change for larger products than smaller products. This is driven by the tax burden increasing linearly in product size, while average price per ounce falls as product size increases. Given a primary goal of SSB excise taxes is to curb excessive sugar consumption, it is desirable for a tax structure to facilitate greater price increases for larger products (in both relative and absolute terms), particularly if sugar concentrations are relatively uniform (or increasing) in product size. Beyond the fact that larger products simply contain more sugar (holding sugar concentration constant), offering greater possible absolute reductions in sugar intake, such a policy design may be even further desirable if the marginal externality cost of sugar is increasing in total sugar intake. In other words, the relative burden of a volumetric excise tax is largest for the products containing the most (overall) sugar, thereby reducing consumption the most from those SSBs producing the highest marginal externality costs associated with sugar intake.

Our final set of results examines the overall impacts of a volumetric tax on prices and purchases of volume and sugar from SSBs. We observe a higher relative increase in price per gram of sugar than price per ounce of SSBs, but smaller relative reductions in purchases of sugar from SSBs compared with volume purchases. Consumers appear to be have more price-elastic demand with respect to volume from SSBs compared with sugar from SSBs; we estimate a price elasticity of demand for volume from SSBs of -1.37 compared to a price elasticity for sugar from SSBs of -0.76. This result is consistent with SSBs being subject to possible issues of habit formation and internalities (Allcott, Lockwood and Taubinsky 2019a; Dubois, Griffith and O'Connell 2020), which would lead us to predict consumers trying to maintain consumption of the "addictive" ingredient, namely sugar.[24]

While it may seem intuitive that consumers are less responsive to changes in the price

[24] Adda and Cornaglia (2006) and Evans and Farrelly (1998) also find evidence of this behavior in response to cigarette excise taxes, where consumers try to maintain the same level of nicotine consumption.

of sugar—the key desirable characteristic of SSBs—it is less clear the mechanisms driving the greater reduction in volume purchases compared to sugar purchases from SSBs. Specifically, we find that volumetric SSB taxes lead to an estimated 36.2% reduction in volume purchases, but only a 31.0% reduction in sugar purchases. Put differently, the elasticity of sugar purchases relative to volume purchases is 0.86; for every 1% decrease in volume purchased from SSBs, sugar purchases fall by only 0.86%. Of course, it is worth noting that the discrepancy in relative reductions in volume and sugar purchases from SSBs is not substantial (5.2 percentage points), suggesting that volumetric taxes remain quite effective in altering sugar purchases from SSBs.[25]

We propose two possible mechanisms to explain the observed difference in tax-induced relative changes in volume and sugar purchased from SSBs. The first mechanism explores heterogeneity in average sugar concentration by product size. If larger products, which face a higher relative tax burden, contain lower sugar concentrations, one would expect the reduction in volume to be greater than the reduction in sugar purchased. Manufacturers' reformulation of SSBs to feature lower sugar concentrations would be one way this heterogeneity could arise (Dickson, Gehrsitz and Kemp 2023). However, average sugar concentration among products observed in the data remains relatively uniform across product sizes. This uniformity suggests this mechanism is unlikely to explain the gap in relative reductions of volume and sugar purchases.[26]

We find much stronger empirical evidence in support of the second mechanism, which examines consumer substitution toward products with higher sugar concentrations. Our results suggest that purchases of volume from SSBs fell relatively more than purchases of sugar from SSBs in response to volumetric taxes. The direction and magnitude of our findings can be explained by shifts in consumption to products with more sugar per ounce,

[25] A 5.2-percentage point difference corresponds to 16.8% of the effect size of relative reductions in sugar purchases (31.0%).

[26] One would expect greater reformulation efforts by manufacturers in response to SSB taxes directly tied to sugar content as opposed to volumetric taxes, i.e. through tiered taxes based on sugar concentration or specific taxes levied directly on quantity of sugar.

presumably in an effort by consumers to reduce the tax burden they face on each gram of sugar from SSBs.

Among the three treatment cohorts, Philadelphia exhibited the largest change in sugar concentration of purchased SSBs post-tax; Figure 9 suggests the average sugar concentration of purchased drinks in Philadelphia increased by 20.0%. This finding is further supported by the magnitudes of treatment cohort-specific differences in relative changes in volume versus sugar purchases from SSBs, seen in Figures A.9 and A.11. In particular, Philadelphia experienced a 13.4 percentage point difference in relative volume versus sugar purchase reductions (-45.4% for volume and -32% for sugar), representing the largest difference across all treatment cohorts.[27]

Figure 10 depicts changes in average sugar concentration of purchased SSBs by product size quartile in Philadelphia. Interestingly, we observe a strong relationship between product size and the magnitude of the increase in average sugar concentrations of purchased SSBs post-tax; the smallest quartile of products purchased experience a change in average sugar concentration of -0.9%, while the largest quartile exhibits a 27.8% increase in average sugar concentration of purchased SSBs. This is especially notable because the largest product size quartile faces the highest relative tax burden, suggesting that consumers in Philadelphia may not only be substituting to products with higher sugar concentrations overall, but differentially more among products facing a larger relative tax burden. This may be explained by consumers attempting to reduce the tax burden faced on each gram of sugar in response to a volumetric tax.

While there is no clear reason one would expect average sugar concentration of purchased SSB products to be significantly higher in Philadelphia compared to the other two treatment cohorts, we provide some possible explanations. First, Philadelphia is the only taxed jurisdiction in our sample that levied a volumetric excise tax both on SSBs and artificially-

[27]The Oakland-Boulder treatment cohort exhibited a 3.5 percentage point difference (-39.4% for volume and -35.9% for sugar) while the San Francisco-Seattle treatment cohort exhibited a 1.2 percentage point difference (-30.7% for volume and -29.5% for sugar).

sweetened beverages. Eliminating the price incentive to substitute toward diet drinks may induce consumers to shift their consumption within SSBs to varieties with higher concentrations of sugar. Second, across the three treatment cohorts, Philadelphia experienced the largest relative increase in average price per ounce (Figure A.8), providing a strong incentive to adjust behavior on the sugar concentration dimension.[28] Finally, Philadelphia has a markedly different demographic and socioeconomic makeup than the other four cities we study. In addition to being nearly twice as large (by population) as the next largest US city with an SSB tax (San Francisco), Philadelphia has a considerably higher poverty rate and different racial composition than each of the other taxed cities we study. Such factors may contribute to differences in consumer behavioral responses to implementation of a volumetric SSB tax.

6.1 Economic and Health Implications

While there is relatively little research empirically estimating the direct impacts of volumetric SSB taxes on health outcomes (e.g. BMI, obesity rates, etc.), several studies have used simulation approaches to translate reductions in consumption of SSBs to improvements in health while considering the cost-effectiveness of this intervention. Long et al. (2015) finds that a 20% reduction in consumption of SSBs leads to a reduction in average BMI of 0.16. Under relatively conservative demand elasticity estimates, Wilde et al. (2019) finds that a fully passed-through 1¢ per ounce tax imposed nationally would lead the average US adult to gain 0.02 quality-adjusted life years (QALYs). Lee et al. (2020) evaluates three different SSB tax structures (volumetric, tiered sugar content, and absolute sugar content), finding the tiered and absolute sugar content taxes generate cost-effective health gains approximately double that of a volumetric tax.[29]

However, none of these studies considers differences in purchases of volume versus sugar

[28] Relatedly, Philadelphia also experienced the highest ratio of relative price increase per ounce to relative price increase per gram of sugar (Figures A.8 and A.10).

[29] A significant driver of their findings is that taxes targeting sugar directly will lead to substantial industry reformulation of SSB products.

from SSBs under a volumetric tax. In fact, the results in Lee et al. (2020) may actually underestimate the gains from a tiered or absolute sugar content tax structure for this reason. Our findings suggest this difference may be relevant; we estimate tax-induced changes in sugar purchased from SSBs is approximately 15% lower than changes in volume purchased (-31.0% vs. -36.2%). Therefore, attributing proportional changes in volume directly to proportional changes in sugar may lead to an overestimate of the economic and health benefits associated with volumetric SSB taxes. At the same time, even when adjusting the incremental cost-effectiveness ratios (which measure the cost associated with an additional quality-adjusted life year, or QALY) estimated in Wilde et al. (2019) for different consumer groups by 15%, a volumetric SSB tax is still cost-effective in comparison to the willingness-to-pay threshold for an additional QALY recommended by the American College of Cardiology and American Heart Association.[30]

Another key consideration in evaluating the importance of the volumetric tax-induced gap in relative purchases of volume vs. sugar from SSBs is the respective magnitudes of estimated externality and internality costs associated with sugar intake. Most studies generally assume constant marginal externality and internality costs associated with consumption of sugar, although there is suggestive evidence that these costs may differ across individuals (Griffith et al. 2020). Specifically, Allcott, Lockwood and Taubinsky (2019b) suggest that the externality cost associated with each ounce of SSB consumption is approximately 0.85¢, and estimate internality costs to be between 0.91¢ - 2.14¢ per ounce.[31]

Using these estimates, as well as several other key parameters, we conduct a back-of-the-envelope analysis that measures the extent to which volumetric SSB taxes overestimate

[30]These organizations establish a willingness-to-pay range for each additional QALY between $50,000-$150,000. Wilde et al. (2019) estimate incremental cost-effectiveness ratios from a societal perspective between $21,955 - $46,133, which when inflated by 15% translate to $25,829 - $54,274. The findings are similar when considering estimates from other cost-effectiveness studies examining volumetric SSB taxes.

[31]Wang et al. (2012) suggest that "one ounce of soda consumption increases health care costs by an average of approximately one cent per ounce." Combining this with Yong, Bertko and Kronick (2011), who find that 85% of health costs for individuals with employer-provided insurance are borne by insurance providers, translates to an externality cost of 0.85¢. The range of internality costs is estimated using responses to survey questions of US households regarding nutritional knowledge and self-control. Additional detail can be found in Section III.D. of Allcott, Lockwood and Taubinsky (2019b).

averted externality and internality costs when assuming proportional changes in volume and sugar are identical. Under a baseline scenario with no uncertainty, we find that the overestimate in averted annual externality and internality costs associated with SSB consumption range from \$2.98 - \$11.33 per capita in response to a volumetric tax.

Figure 11: Distribution of Annual Overestimate of Averted Externality and Internality Costs

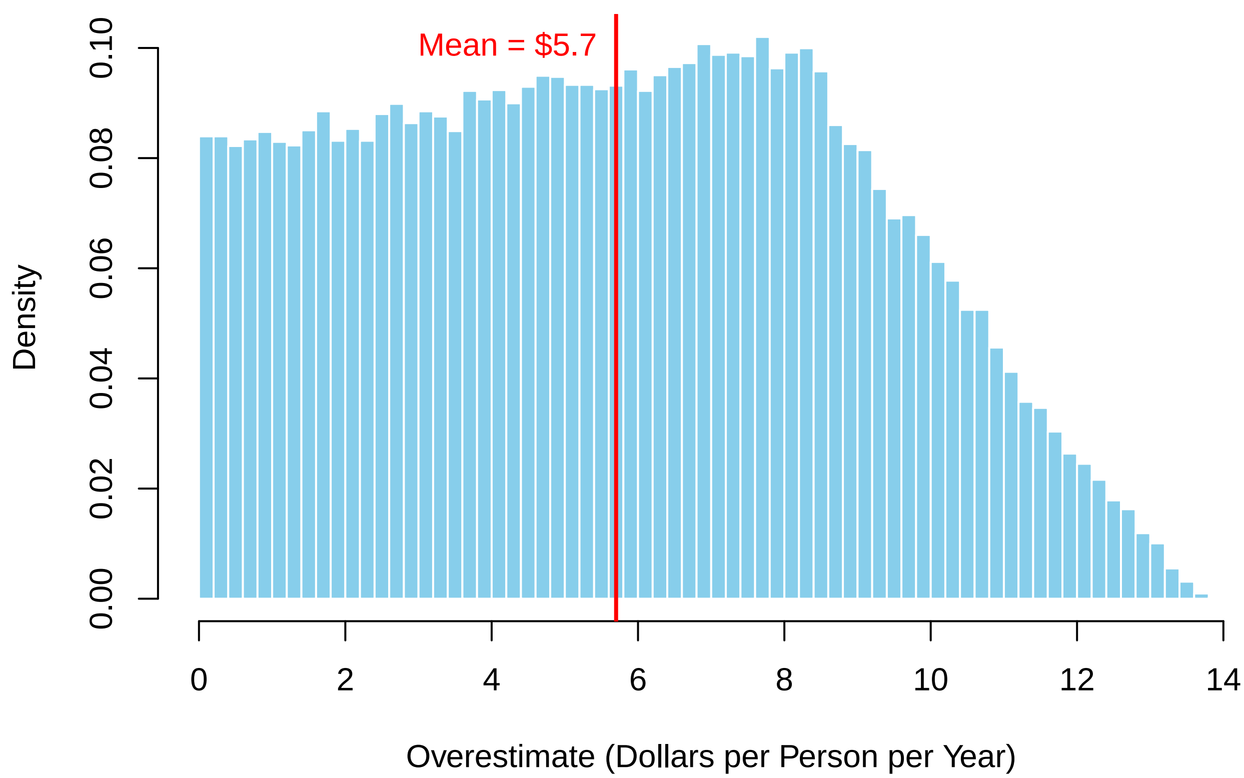


Figure 11 provides results from an accompanying Monte Carlo simulation. We estimate a mean (SD) annual overestimate of \$5.70 (\$3.29) per capita, assuming a precisely estimated effect size for the relative reduction in volume purchases of SSBs (36.2%) and a range of relative reductions in sugar purchases centered around 31.0%.[32] There is significant variation in the per-capita estimates, with a standard deviation of \$3.29, and 5th and 95th percentile values of \$0.60 and \$11.15, respectively. An overestimate of \$5.70 per capita, scaled across the entire US population of approximately 330 million people, suggests assigning identical

[32]The midpoint of this range is 15%, in line with the approximate percent difference in the estimates of relative volume and sugar purchase reductions from SSBs.

relative reductions in sugar purchased from SSBs to volume purchases resulting from a volumetric tax would overestimate averted total externality and internality costs by $1.88 billion annually. Additional detail regarding distributions of key parameters and a description of this analysis is found in Section E of the Appendix.

While these findings provide a simulated approximation of overestimated reductions in externality and internality costs associated with a volumetric SSB tax, there are several other important considerations to account for, such as changes in consumption of other possible externality- and internality-generating characteristics (e.g. caffeine) as well as the individual-level heterogeneity in both responsiveness to volumetric SSB taxes and externality and internality costs from sugar consumption.

7 Conclusion

This paper presents three key findings. First, volumetric taxes disproportionately increase the relative tax burden on larger-volume products: the smallest product size quartile saw a 4.4% price increase after tax implementation while the largest quartile experienced a 24.6% increase. Second, we document the equivalence of the relative, characteristic-specific tax burden across all characteristics within an SSB product, and provide empirical evidence validating this finding. Finally, we estimate a larger relative reduction in overall beverage volume compared to grams of sugar purchased from SSBs in response to a volumetric tax. We propose two potential mechanisms behind this difference: lower average sugar concentrations in larger versus smaller products, and consumer substitution toward higher sugar concentration products in response to the tax. We find plausible evidence supporting the second mechanism, showing that the sugar concentration of purchased products increased post-tax, particularly in Philadelphia and for the largest quartile of products. While this evidence suggests the second mechanism is relevant in our context, it does not rule out the importance of the first mechanism in different cities, countries, or product contexts.

The findings in this paper contribute significantly to the literature on specific excise taxes, especially in the context of SSBs. The evidence underscores the importance of considering product heterogeneity when designing excise taxes. Applying a uniform tax across different product sizes leads to uneven effects, which could influence tax avoidance behavior and targeted public health outcomes. This paper provides empirical support for tax structures directly targeting the externality-generating characteristic (e.g., sugar content). However, policymakers should also account for any additional transaction costs involved in implementing and enforcing such a tax design.

Beyond the findings of this study, there are several avenues for future research that could further enrich our understanding of specific excise taxes and their broader implications. One promising area is the continued study of sin taxes on other harmful products, such as tobacco, e-cigarettes, alcohol, and cannabis, where policymakers must consider multiple characteristics when designing specific taxes with certain targets in mind. It is important to further explore the relationship between specific excise taxes and product pricing across different characteristics. In addition, understanding the complexities and heterogeneity in consumer responses to taxes across different products, demographic groups, and in different geographies can inform the design of more targeted and equitable policies. This is key to ensuring accurate assessment of the health and economic benefits associated with such taxes. Further, research on behavioral responses to multi-characteristic taxes, where multiple aspects of a product are taxed simultaneously (e.g., taxes on air travel), could uncover complex interactions and guide the development of more sophisticated tax designs. Finally, it is important to further study the interplay between policy-induced supply-side responses and demand-side responses from consumers.

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Appendix

A Details of Scanner Data

The NielsenIQ retail scanner dataset was obtained through a subscription to the Kilts Marketing Center at the University of Chicago Booth School of Business. The dataset encompasses ten broad product categories: HEALTH AND BEAUTY CARE, DRY GROCERY, FROZEN FOODS, DAIRY, DELI, PACKAGED MEAT, FRESH PRODUCE, NON-FOOD GROCERY, ALCOHOLIC BEVERAGES, GENERAL MERCHANDIZE, and UNCLASSIFIED. For this study, we focus exclusively on products within the DRY GROCERY category. Within this category, we select specific subcategories of products that constitute the initial sample of UPCs: JUICE DRINKS – CANNED, BOTTLED; CARBONATED BEVERAGES; SOFT DRINKS – NON-CARBONATED; COFFEE; SUGAR/SWEETENERS; TEA; and JUICE DRINKS - FROZEN. Products in the MILK category are excluded, as milk products are generally exempt from taxation in most jurisdictions.

Given that the NielsenIQ data provides limited nutritional information for each product, we supplement it with 10-digit UPC data from Label Insight (LI) and hand-coded data from a previous study (White et al. 2023) to classify products as SSBs or non-SSBs. These two supplementary datasets offer information on total calories, total sugar, total sugar per serving, serving size, and the presence of artificial sweeteners, enabling the classification of each UPC. To merge the data, we reconcile the format differences: NielsenIQ UPCs are in EAN-13 format (excluding the check digit), while the LI and hand-coded data are at the 10-digit UPC level. Following Label Insight's documentation, we convert the NielsenIQ 12-digit UPCs into 10-digit UPCs by dropping the first two digits of the NielsenIQ UPCs and the first and last digits of the Label Insight UPCs. Any resulting duplicate UPCs are aggregated. The same classification procedure is applied to the hand-coded data.

Through this matching process, we successfully linked 18,147 10-digit UPCs, representing 84.0% of the total sales volume in the NielsenIQ beverage data during the study period. Among these matched UPCs, 5,500 are classified as SSBs, accounting for 39.7% of the sales volume within the matched data subset. Of these, 4,029 UPCs (73.3%) include the necessary nutritional information—product size (in ounces), total sugar per serving, and serving size (in ounces)—required for analysis. This subset of 4,029 UPCs represents 85.1% of the total volume sales of matched data classified as SSBs and forms the final set of products in the sample.

B Additional Descriptive Statistics

Table A.1: Total Coverage of SSB Ounces Sold in Matched NielsenIQ Retail Scanner Data

City (first complete fiscal year of SSB tax)	**Tax Revenue ($000's)**	**Tax (¢/Oz.)**	**Total SSB Sales (1000s of Oz.)**	**SSB Sales NielsenIQ UPCs (1000s of Oz.)**	**Coverage (%)**
Boulder (2018)	4,868	2	243,400	61,917	25.44
Oakland (Jul 2017–Jun 2018)	11,076	1	1,107,600	178,429	16.11
Philadelphia (Jul 2017–Jun 2018)	77,421	1.75	5,161,400	322,951	6.26
San Francisco (Jul 2018–Jun 2019)	16,098	1	1,609,800	290,918	18.07
Seattle (2018)	22,254	1.5	1,271,657	419,425	32.98
Composite	131,717	1.45	9,083,931	1,273,640	13.56

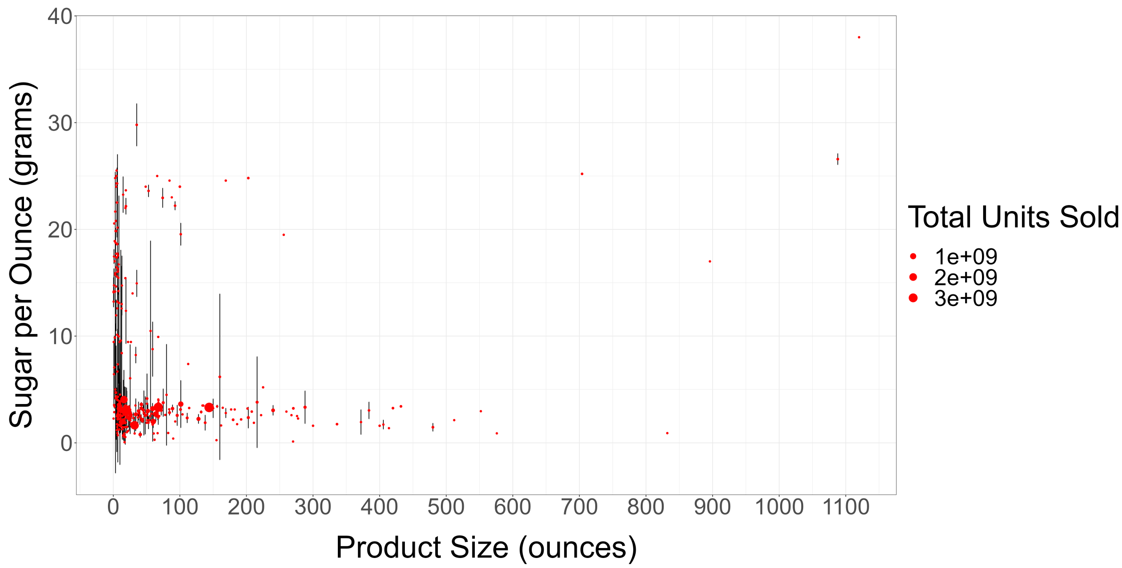
Note: Tax revenues taken from Krieger et al. (2021). Coverage estimates use the first fiscal year of each city's respective tax implementation. Lower coverage in Philadelphia is in part due to the exclusion of artificially sweetened beverages in our analysis. The tax amount for the Composite geographic category is the unweighted average of the tax amounts across the five taxed cities.
Source: Krieger J Magee K Hennings T Schoof J Madsen KA. How sugar-sweetened beverage tax revenues are being used in the United States. Preventive Medicine Reports. 2021 Sep 1;23:101388.

Table A.2: Percentage of Total Units, Ounces, and Sugar Sold by SSB Category

Beverage Type	**Units**	**Ounces**	**Sugar**
Club Soda/Tonic Water	0.0	0.0	0.0
Energy drink	0.6	0.2	0.1
Other	2.8	2.0	1.4
Coffee	3.9	1.3	1.1
Flavored water	4.1	1.9	0.8
Fruit drink	7.9	8.0	16.0
Tea	8.2	7.3	6.0
Sports drink	14.1	8.5	4.1
Soda	58.4	70.8	70.5

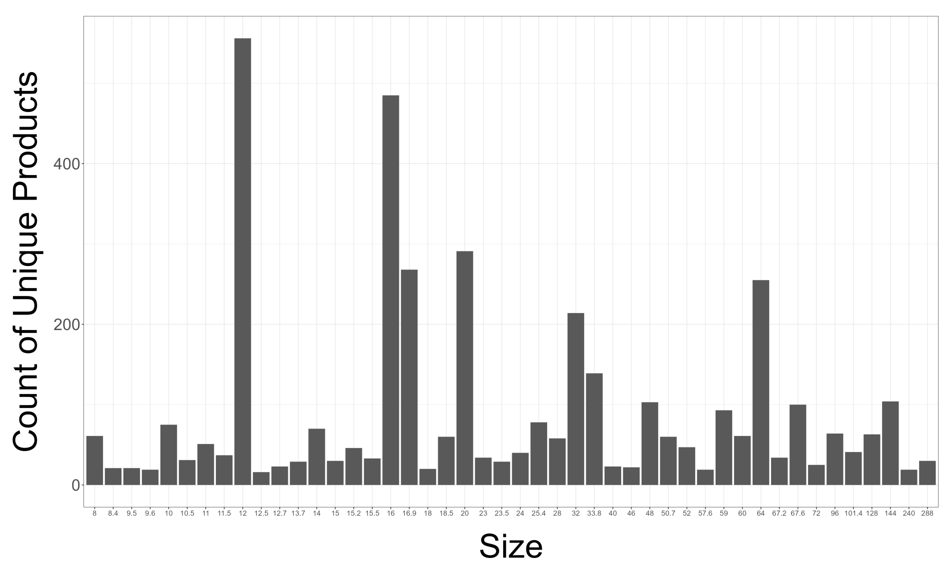
Note: Beverage categories for each UPC determined through manual classification.

Figure A.1: Sugar-per-Ounce by Product Size for All UPCs



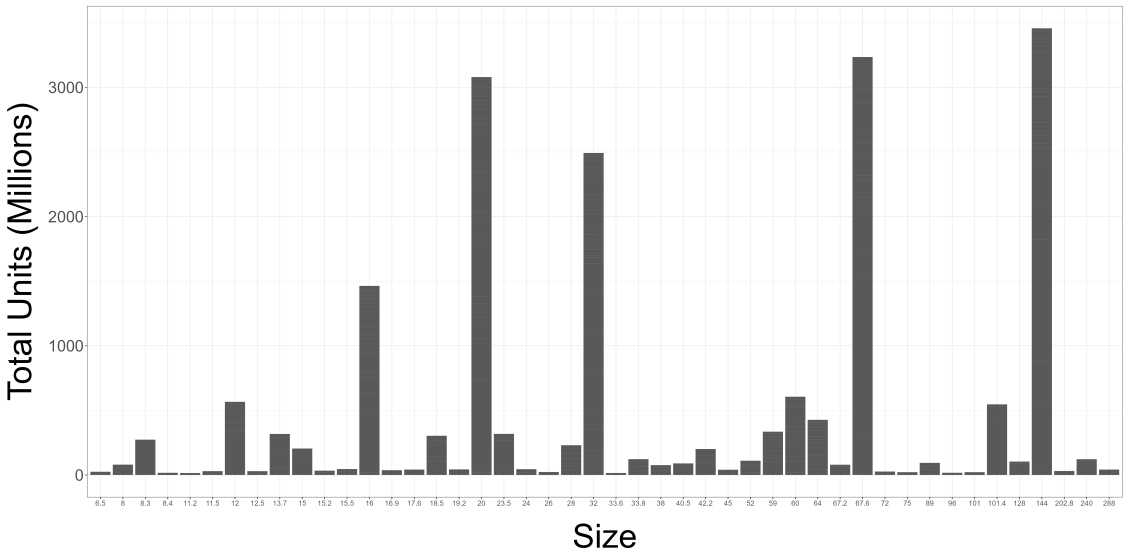
Note: Larger-sized dots indicate a greater number of total units sold of a given UPC throughout the entire study period across geographies.

Figure A.2: Number of Unique UPCs by Product Size



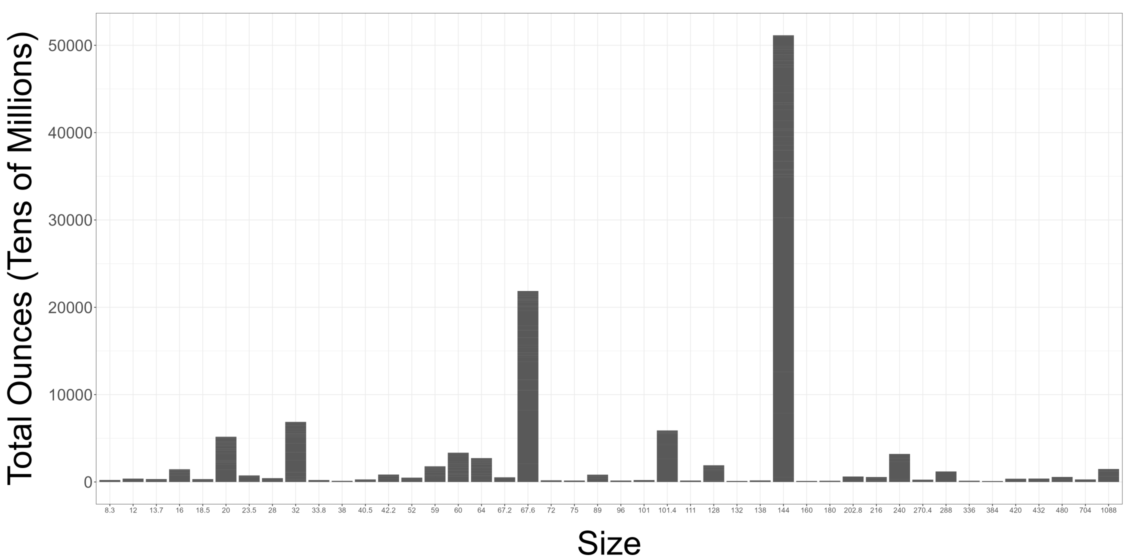
Note: Due to space constraints on the horizontal axis, we only display the number of unique products for product sizes with > 15 unique products.

Figure A.3: Total Units Sold by Product Size



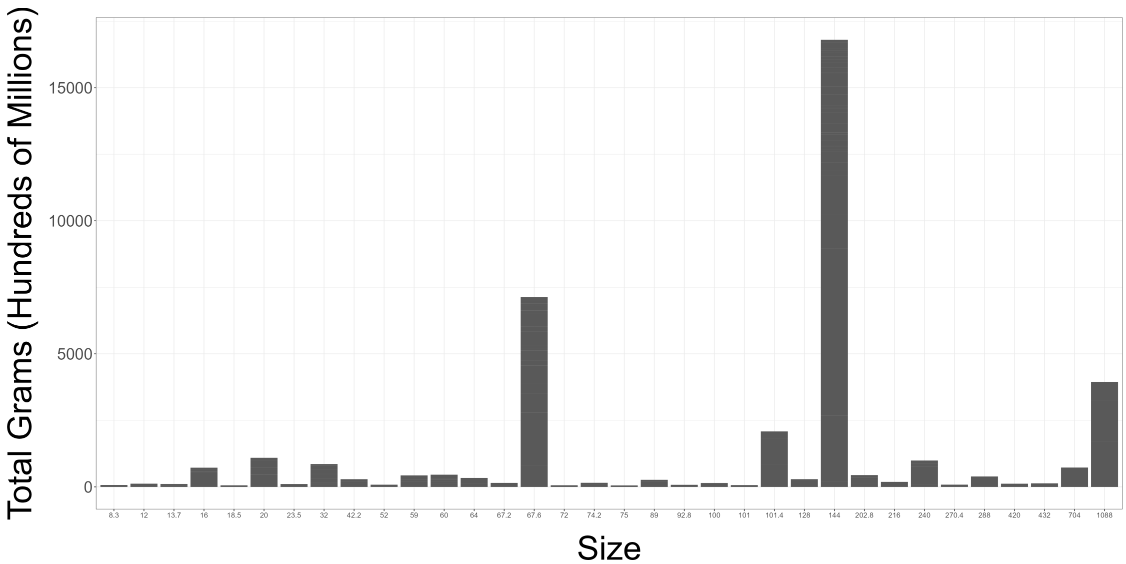
Note: Due to space constraints on the horizontal axis, we only display the number of total units sold for product sizes with > 15 million total units sold.

Figure A.4: Total Ounces Sold by Product Size



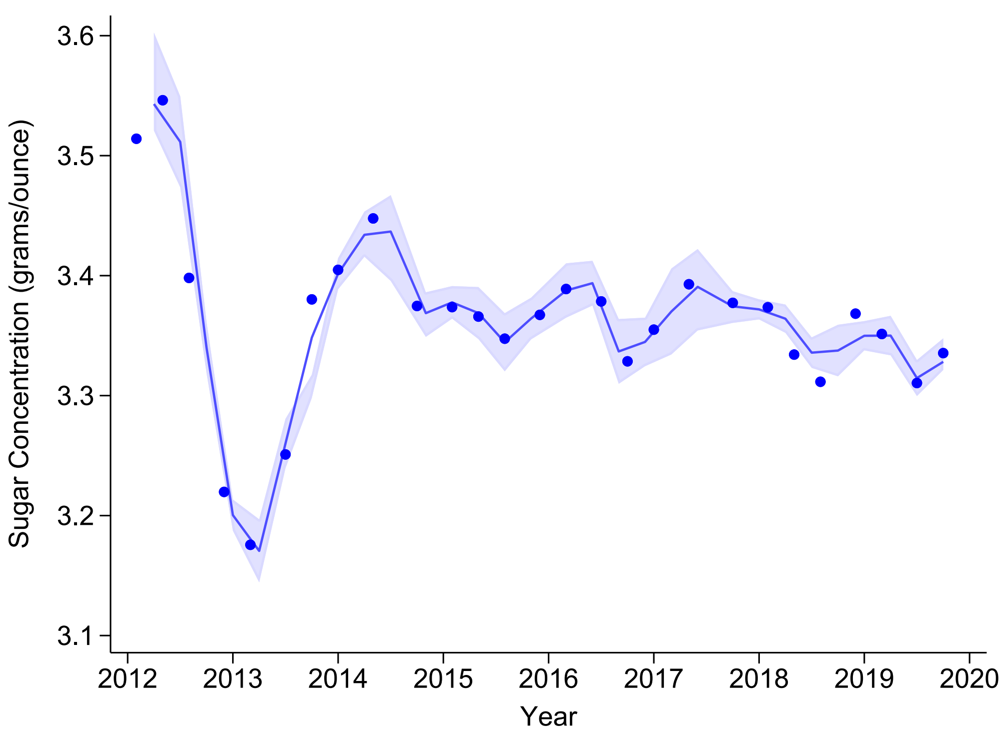
Note: Due to space constraints on the horizontal axis, we only display the number of total ounces sold for product sizes with > 1 billion total ounces sold.

Figure A.5: Total Sugar Sold by Product Size



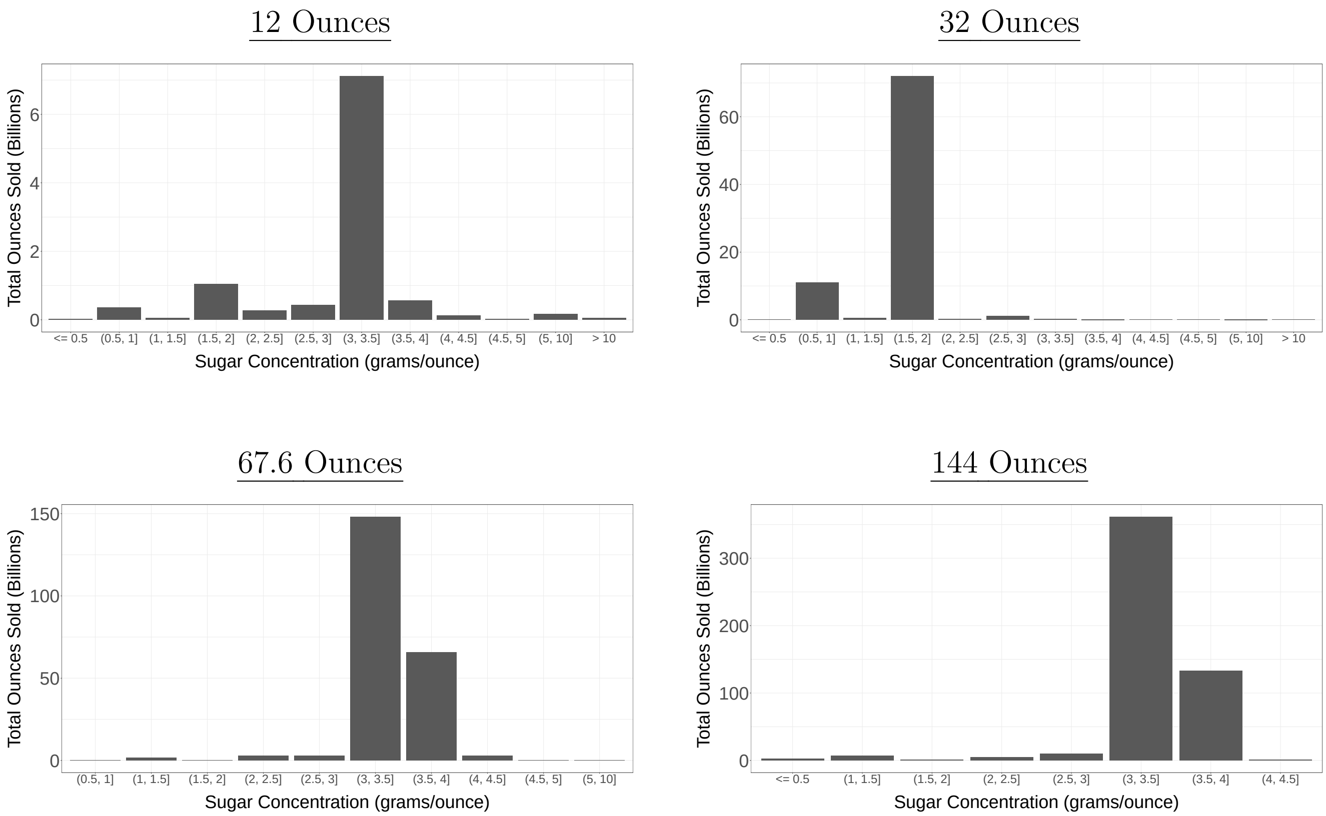
Note: Due to space constraints on the horizontal axis, we only display the number of total grams of sugar sold for product sizes with > 5 billion total grams of sugar sold.

Figure A.6: Time Trend of Sugar Concentration of Purchased SSB Products



Note: The vertical axis represents the average monthly sugar concentration (weighted by ounces sold) of purchased SSB products across 3-digit zip codes.

Figure A.7: Distribution of Sugar-per-Ounce Concentration for Four Most Common Product Sizes by Total Ounces Sold



Note: The y-axis in each panel represents the count of total ounces sold (in billions) by sugar/ounce concentration. The x-axis presents binned sugar concentration; the bin spacing is 0.5 units between 0 and 5 grams/ounce, followed by bins of 5-10 and > 10 grams/ounce.

B.1 Data Aggregation

We construct five separate outcome variables to analyze using the SDID estimation approach: total ounces, total grams of sugar, average price/ounce, average price/gram of sugar, and average sugar/ounce. Total ounces and total sugar are constructed by summing ounces and sugar purchases at the observation-level (UPC-week-store) to the 3-digit ZIP code-by-month level. Average price/ounce and average price/gram of sugar are first calculated at the observation-level, and then an average is taken at the 3-digit ZIP code-by-month level (weighted by total ounces sold).[33] Sugar/ounce is calculated as a time-invariant, UPC-specific characteristic assigned at the

[33] Average price/ounce is calculated at the observation level as follows: total units sold $*$ average price per unit $\div$ total ounces sold. Average price/gram of sugar is calculated identically, except divided by total grams of sugar sold.

observation level, and then an average is taken at the 3-digit ZIP code-by-month level (weighted by total ounces sold).

Table A.3: Summary Statistics by Outcome Variable in Aggregated Data

Outcome Variable	**N**	**Mean**	**St. Dev.**	**Min**	**Max**
Total Ounces (thousands of ounces)	85,554	16,687	21,905	11,792	233,125
Average Price per Ounce (¢/ounce)	85,554	3.8	0.9	1.9	11.0
Total Sugar (thousands of grams)	85,554	56,947	76,488	36,251	847,682
Average Price per Gram of Sugar (¢/gram)	85,554	1.6	0.5	0.7	6.1
Average Sugar/Ounce Concentration (grams/ounce)	85,554	3.36	0.59	2.34	16.85

Note: Average Sugar/Ounce Concentration refers to the average sugar-per-ounce concentration of purchased UPCs. We compute the sugar-per-ounce for each unique UPC, which is UPC-specific and not varying over time, and then take the weighted average sugar-per-ounce by 3-digit ZIP code-month of sample (weighted by total ounces sold of each UPC during each ZIP code-month of sample observation).

C Additional Results

Table A.4: Tax Impacts on SSB Sales of Ounces and Sugar by Common UPCs

Panel (a): Tax Impacts on Total Ounces

	Dependent Variable: Total Ounces			
	12 oz. Coca-Cola	**32 oz. FP Gatorade**	**2L Coca-Cola**	**12-Pack 12 oz. Coca-Cola**
Treatment	-93321.21***	-105172.50***	-360590.90**	-516813.50***
	(33063.16)	(14198.17)	(140443.60)	(198274.10)
N	81928	81928	81928	81928
Dep. Var. Mean	3.47e+05	2.80e+05	1.10e+06	1.74e+06
% Change	-26.896	-37.598	-32.744	-29.663

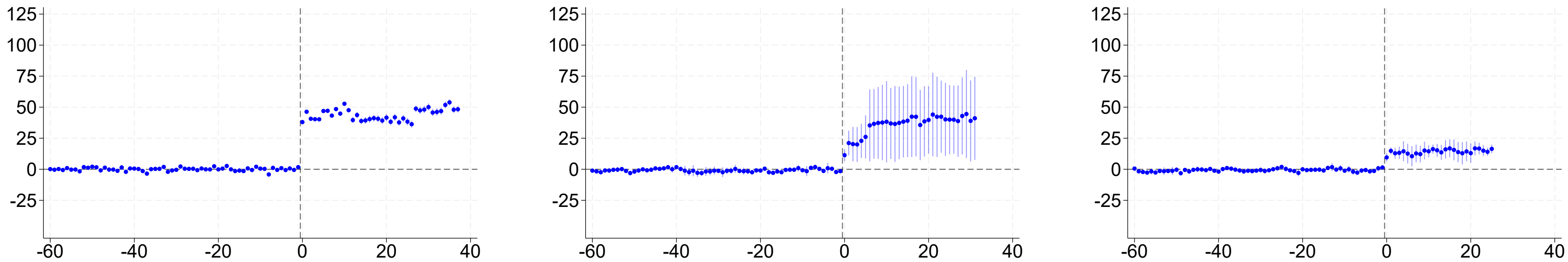
Panel (b): Tax Impacts on Total Sugar

	Dependent Variable: Total Sugar			
	12 oz. Coca-Cola	**32 oz. FP Gatorade**	**2L Coca-Cola**	**12-Pack 12 oz. Coca-Cola**
Treatment	-303293.90***	-184051.90***	-1.172e+06**	-1.680e+06***
	(107455.30)	(24846.80)	(456411.70)	(644390.90)
N	81928	81928	81928	81928
Dep. Var. Mean	1.13e+06	4.90e+05	3.58e+06	5.66e+06
% Change	-26.896	-37.598	-32.744	-29.663

Standard errors in parentheses.
* p<0.10 ** p<0.05 *** p<0.01

Figure A.8: Treatment Cohort-Specific Impacts of a Volumetric SSB Tax on Average Price/Ounce

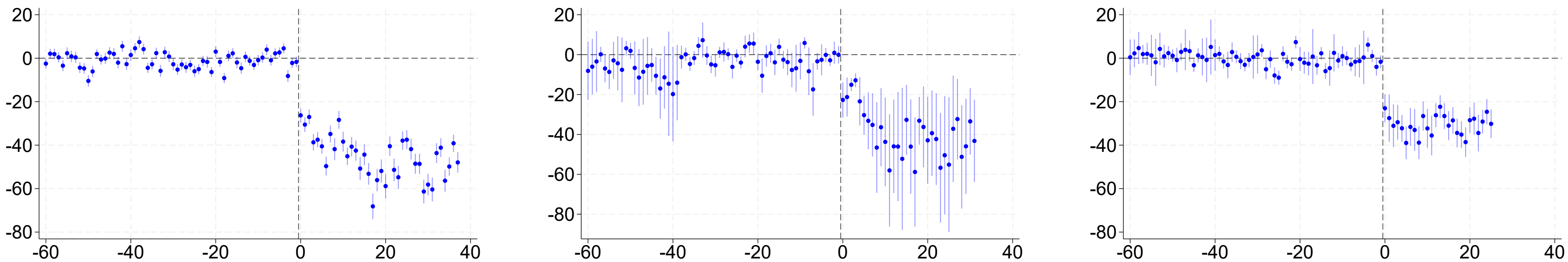
Philadelphia | Boulder and Oakland | San Francisco and Seattle



Note: The y-axis in each panel represents the percent change in average price/ounce compared to the pre-treatment baseline mean of average price/ounce for the treatment cohort indicated. The x-axis represents months from tax implementation in event time. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

Figure A.9: Treatment Cohort-Specific Impacts of a Volumetric SSB Tax on Total Ounces Sold

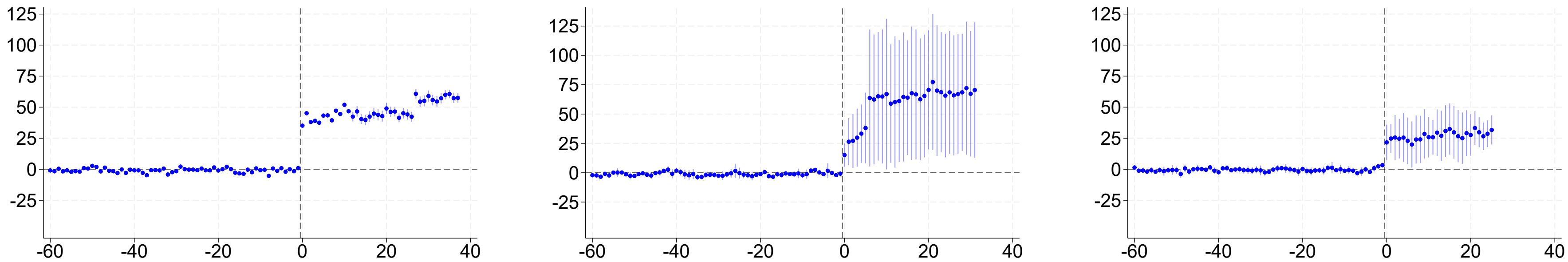
Philadelphia | Boulder and Oakland | San Francisco and Seattle



Note: The y-axis in each panel represents the percent change in total ounces sold compared to the pre-treatment baseline mean of total ounces sold for the treatment cohort indicated. The x-axis represents months from tax implementation in event time. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

Figure A.10: Treatment Cohort-Specific Impacts of a Volumetric SSB Tax on Average Price/Gram of Sugar

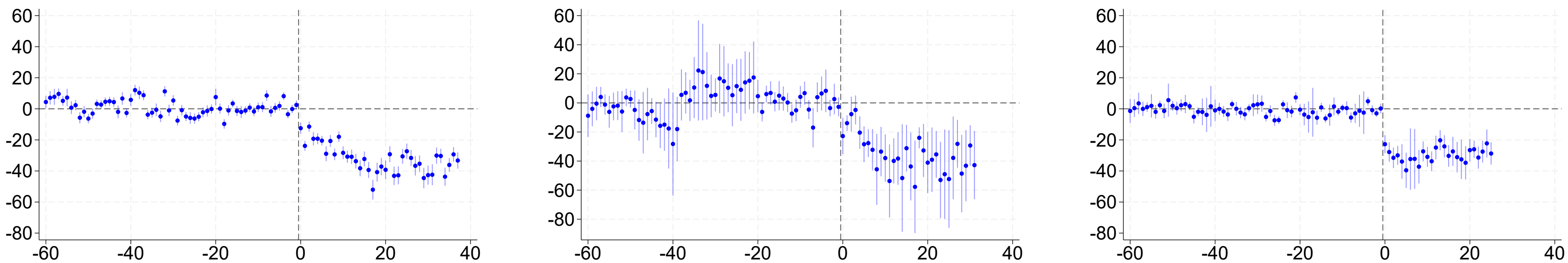
Philadelphia | Boulder and Oakland | San Francisco and Seattle



Note: The y-axis in each panel represents the percent change in average price/gram of sugar compared to the pre-treatment baseline mean of average price/gram of sugar for the treatment cohort indicated. The x-axis represents months from tax implementation in event time. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

Figure A.11: Treatment Cohort-Specific Impacts of a Volumetric SSB Tax on Total Grams of Sugar Sold

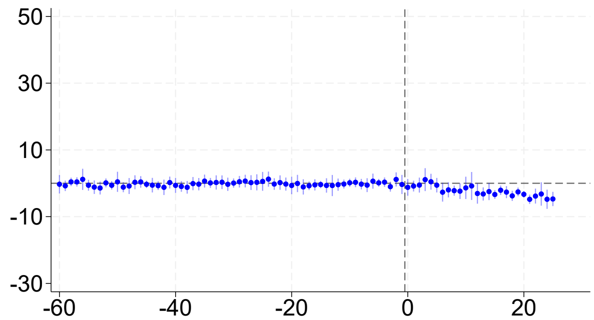
Philadelphia | Boulder and Oakland | San Francisco and Seattle



Note: The y-axis in each panel represents the percent change in total grams of sugar sold compared to the pre-treatment baseline mean of total grams of sugar sold for the treatment cohort indicated. The x-axis represents months from tax implementation in event time. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

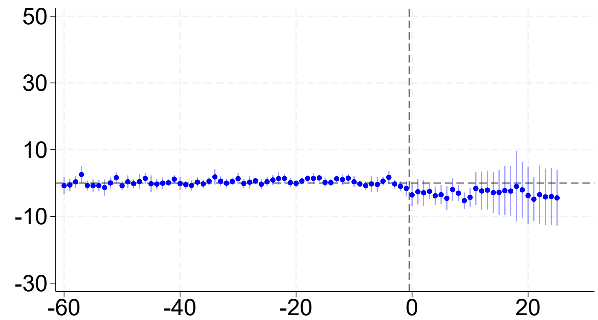
Figure A.12: Impact of VB SSB Taxes on Sugar Concentration of Purchased SSB Products (Composite): By Product Size Quartile

Quartile 1



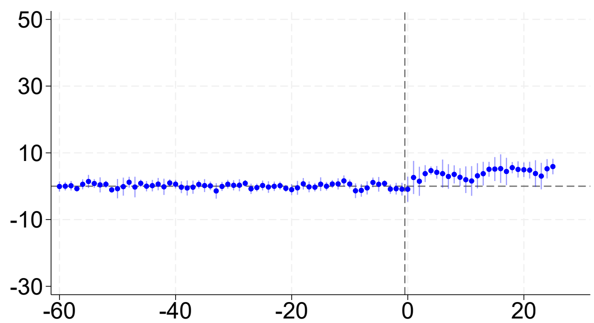
ATT: -0.07g/oz (0.04g/oz); -2.3% (1.2%)

Quartile 2



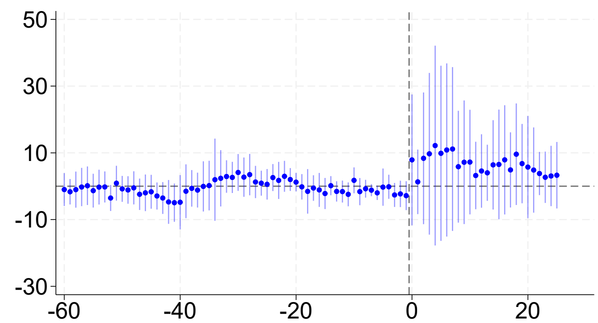
ATT: -0.10g/oz (0.09g/oz); -3.2% (2.9%)

Quartile 3



ATT: 0.08g/oz (0.04g/oz); 3.7% (1.7%)

Quartile 4

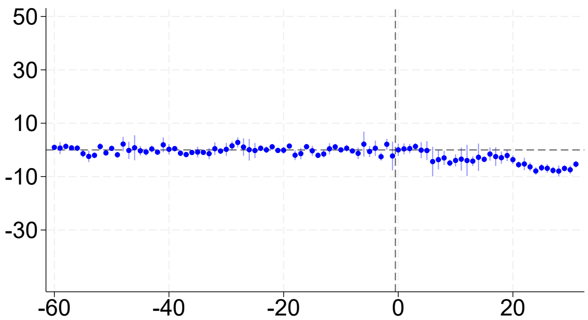


ATT: 0.25g/oz (0.32g); 6.5% (8.0%)

Note: The y-axis in each panel represents the percent change in the average sugar/ounce concentration of purchased products compared to the pre-treatment baseline average sugar/ounce concentration of purchased products across all treated units. The x-axis represents months from tax implementation in event time. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

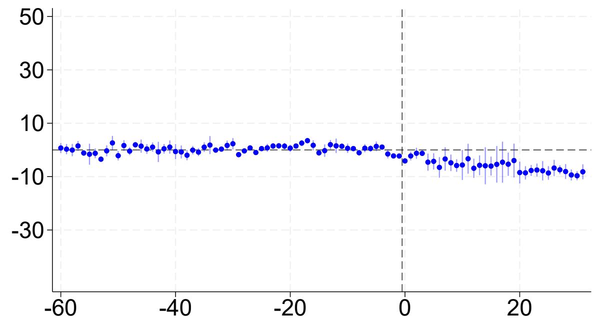
Figure A.13: Impact of VB SSB Taxes on Sugar Concentration of Purchased SSB Products in Boulder & Oakland: By Product Size Quartile

Quartile 1



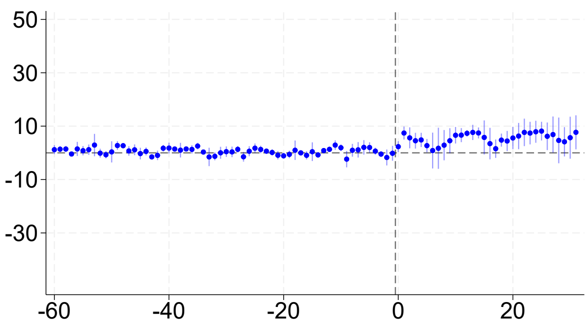
ATT: -0.12g/oz (0.04g/oz); -3.8% (1.2%)

Quartile 2



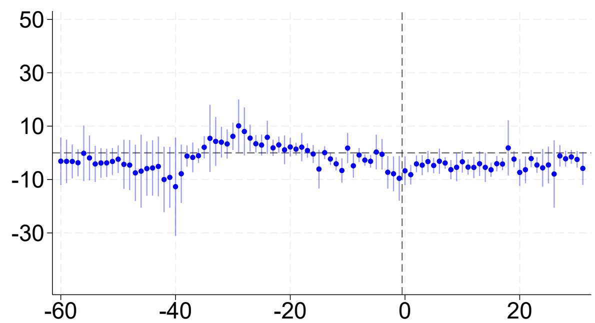
ATT: -0.18g/oz (0.04g/oz); -5.9% (1.8%)

Quartile 3



ATT: 0.12g/oz (0.05g/oz); 5.4% (2.3%)

Quartile 4

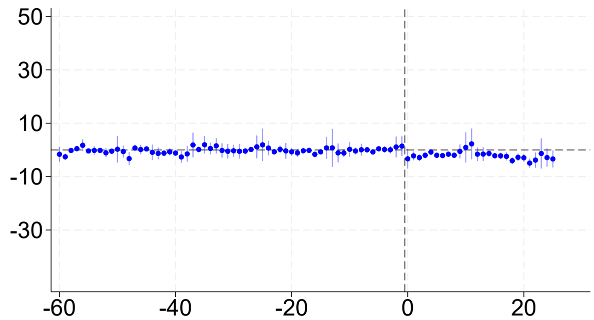


ATT: -0.17g/oz (0.09g/oz); -4.6% (2.2%)

Note: The y-axis in each panel represents the percent change in the average sugar/ounce concentration of purchased products compared to the pre-treatment baseline average sugar/ounce concentration of purchased products in Boulder and Oakland. The x-axis represents months from tax implementation in event time. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

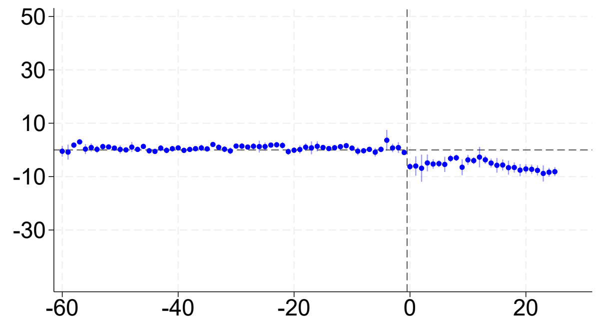
Figure A.14: Impact of VB SSB Taxes on Sugar Concentration of Purchased SSB Products in San Francisco & Seattle: By Product Size Quartile

Quartile 1



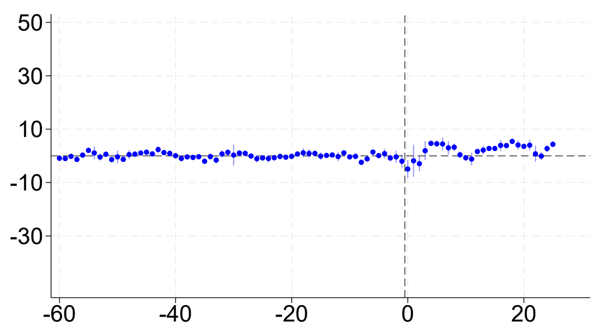
ATT: -0.07g/oz (0.04g/oz); -2.1% (1.1%)

Quartile 2



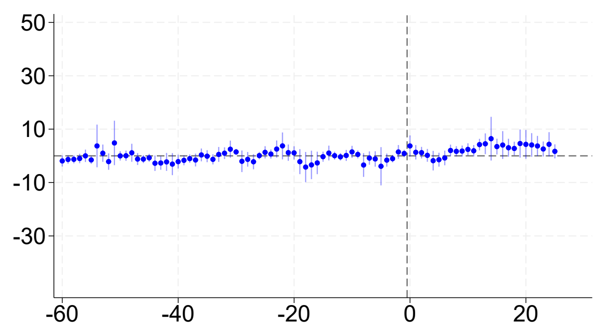
ATT: -0.18g/oz (0.04g/oz); -5.8% (1.1%)

Quartile 3



ATT: 0.05g/oz (0.02g/oz); 2.0% (0.9%)

Quartile 4



ATT: 0.09g/oz (0.06g/oz); 2.5% (1.7%)

Note: The y-axis in each panel represents the percent change in the average sugar/ounce concentration of purchased products compared to the pre-treatment baseline average sugar/ounce concentration of purchased products in San Francisco and Seattle. The x-axis represents months from tax implementation in event time. Each plotted point represents a coefficient estimate with its corresponding 95% confidence interval. Confidence intervals overlapping zero in the pre-period suggest parallel trends between the treatment and synthetic control groups pre-tax implementation.

D Sugar per Ounce by Product Size: Numeric Example

Consider the following setup. There are three scenarios, each of which features two representative and divisible products (small and large). The three scenarios are defined as follows: (i) sugar per ounce is uniform, (ii) sugar per ounce is decreasing, and (iii) sugar per ounce increasing in product size. Assume a unit price elasticity of demand and a $0.01/ounce tax with 100% pass-through.[34] Hold (i) total volume and (ii) price per ounce constant across scenarios *within product size*. Finally, hold total sugar constant across scenarios.

Tables A.5, A.6, and A.7 present results from the uniform, decreasing, and increasing sugar-per-ounce scenarios, respectively. The main takeaway is that the relative change in purchases of sugar from SSBs compared to volume in response to a volumetric tax depends on the distribution of sugar-per-ounce by product size.

Table A.5: Uniform Sugar per Ounce by Product Size

	Product 1 (Small) *12 individual 12 oz. cans of Coca-Cola*	**Product 2 (Large)** *12-pack 12 oz. cans of Coca-Cola*
Nutrition	39g sugar/can (3.25 g/oz)	39g sugar/can (3.25 g/oz)
Tax Amount	$1.44	$1.44
Price	$12 (8.3¢/oz)	$5 (3.5¢/oz)
% Change Price	12%	28.8%
% Change Volume	-12%	-28.8%
	Overall Unit and % Changes	
Unit Change Volume	-58.75 oz	
Unit Change Sugar	-190.94 g	
% Change Volume	-20.4%	
% Change Sugar	-20.4%	

[34] These assumptions can be relaxed; they are simply made for tractability in the example.

Table A.6: Decreasing Sugar per Ounce by Product Size

	Product 1 (Small)	**Product 2 (Large)**
	12 individual 12 oz. cans of Mountain Dew	*12-pack 12 oz. cans of Starbucks Doubleshot*
Nutrition	55g sugar/can (4.58 g/oz)	23g sugar/can (1.92 g/oz)
Tax Amount	$1.44	$1.44
Price	$12 (8.3¢/oz)	$5 (3.5¢/oz)
% Change Price	12%	28.8%
% Change Volume	-12%	-28.8%

	Overall Unit and % Changes
Unit Change Volume	-58.75 oz
Unit Change Sugar	-158.69 g
% Change Volume	-20.4%
% Change Sugar	-16.9%

Table A.7: Increasing Sugar per Ounce by Product Size

	Product 1 (Small)	**Product 2 (Large)**
	12 individual 12 oz. cans of Starbucks Doubleshot	*12-pack 12 oz. cans of Mountain Dew*
Nutrition	23g sugar/can (1.92 g/oz)	55g sugar/can (4.58 g/oz)
Tax Amount	$1.44	$1.44
Price	$12 (8.3¢/oz)	$5 (3.5¢/oz)
% Change Price	12%	28.8%
% Change Volume	-12%	-28.8%

	Overall Unit and % Changes
Unit Change Volume	-58.75 oz
Unit Change Sugar	-223.2 g
% Change Volume	-20.4%
% Change Sugar	-23.8%

E Simulation Analysis of Overestimated Benefits from Volumetric SSB Taxes

This section provides a detailed description and additional results from the simulation analysis evaluating the range of overestimated economic benefits associated with volumetric SSB taxes when considering the wedge between relative reductions in volume vs. sugar resulting from volumetric SSB taxes.

E.1 Baseline Deterministic Calculations

We outline the core steps for translating volume and sugar reductions into an estimate of the "wedge" in daily per-capita sugar reduction induced by a volumetric SSB tax. We generate this difference by comparing a scenario where tax-induced relative SSB volume reductions are *identical* to relative SSB sugar reductions, compared with our empirical estimates suggesting these relative reductions may differ. Under a deterministic framework using an initial set of key parameters, we compute an estimate of the difference in externality + internality costs:

1. **Baseline Volume.** Using estimates from the 2013-14 National Health and Nutrition Examination Survey (NHANES), as cited in Allcott, Lockwood and Taubinsky (2019b), we assume individuals consume:

$$\frac{154 \text{ kcal/day}}{11.57 \text{ kcal/oz}} \approx 13.32 \text{ ounces of SSBs per day.}$$

2. **Range of Sugar-per-Ounce.** Grummon et al. (2019) sugar concentration vary from 2.76 grams/ounce (taken from Grummon et al. 2019) to 4.12 grams of sugar per ounce, which is the average sugar concentration of products from our analysis sample. Hence the range of average baseline daily sugar consumption per capita from SSBs is:

$$\text{Sugar}_{\text{baseline}} = 13.32 \times (2.76 \text{ to } 4.12) \approx 36.7 \text{ g/day to } 54.9 \text{ g/day.}$$

3. **Volume vs. Sugar Reduction.** Our estimates suggest a volumetric SSB tax causes volume reductions of 36.2%, but reductions in sugar from SSBs of only 31.0%, corresponding to a wedge of 5.2 percentage points (≈15%). The baseline, naive calculation would assume proportional reductions in sugar are identical to volume (36.2%). Thus:

$$\text{Naive sugar reduction} = 0.362 \ \times \ \text{Sugar}_{\text{baseline}}$$

$$\text{Actual sugar reduction} = 0.310 \ \times \ \text{Sugar}_{\text{baseline}}$$

4. **Daily Sugar Wedge.** The wedge in daily sugar reduction between these two assumptions is:

$$\text{Wedge} = \big(0.362 - 0.310\big) \times \text{Sugar}_{\text{baseline}} = 0.052 \times \text{Sugar}_{\text{baseline}}.$$

With $\text{Sugar}_{\text{baseline}}$ in the 36.7–54.9 g/day range, the wedge is approximately 1.90 g/day - 2.85 g/day.

5. **Converting Cents per Ounce to Cents per Gram.** According to Allcott, Lockwood and Taubinsky (2019b), externality costs are approximately 0.85 cents/oz, and internality costs range from 0.91 - 2.14 cents/oz. Since sugar concenetrations range from 2.76–4.12 g/oz, the cost per gram of sugar is:

$$\text{Cost per gram} = \frac{\text{Cost per ounce}}{\text{Grams of sugar per ounce}}.$$

For instance, externality cost per gram could range from approximately $\frac{0.85}{4.12} \approx 0.21$ cents/g to $\frac{0.85}{2.76} \approx 0.31$ cents/g. Similarly, internality cost per gram might range from about 0.22 cents/g up to 0.78 cents/g, depending on the specific combination.

6. **Annual Overestimate of Averted Externality and Internality Costs from a Volumetric SSB Tax** The wedge in daily sugar reduction (1.90–2.85 g/day) implies 694–1040 g/year. Multiplying by a total cost (externality + internality) of 0.43–1.09 cents/g

translates to \$2.98 to \$11.33 per person per year in overestimated costs averted:

$$\underbrace{(\text{Wedge in g/day}) \times 365}_{\text{grams per year}} \times \underbrace{(\text{Cost in cents/g})/100}_{\text{convert cents to \$}} \approx \text{\$2.98–\$11.33 per person per year.}$$

Scaling this across the entire United States, which has approximately 330 million people, suggests an overestimate of averted annual externality and internality costs associated with a volumetric SSB tax between \$983.4 million - \$3.74 billion.

E.2 Monte Carlo Analysis

We conducted a Monte Carlo simulation to assess the extent to which averted externality and internality costs associated with a volumetric SSB tax may be overestimated. Along with deterministic values of key parameters stated in section E.1, the simulation varies the average sugar concentration of SSBs, estimated externality and internality costs (separately), and the ratio of the relative reduction in sugar purchases from SSBs to the relative reduction in volume purchases (i.e. the wedge in proportional reductions in sugar vs. volume from SSBs). Table A.8 summarizes the parameters varied in the analysis, along with the distributions, means, standard deviations (for normal distributions), and ranges (for uniform distributions).

Table A.8: Monte Carlo Parameter Distributions

Parameter	**Distribution**	**Range**
Sugar per ounce (g/oz)	Uniform	2.76–4.12
Externality cost (cents/oz)	Uniform	0.80–0.90
Internality cost (cents/oz)	Uniform	0.91–2.14
Sugar–Volume Proportional Wedge w	Uniform	0.00–0.30

Notes: The volume reduction rate is fixed at $V = 36.2\%$ using our empirical estimate. The wedge parameter w is drawn uniformly between 0 and 0.30, where $w = 0$ implies no difference between relative sugar and volume reductions, and $w = 0.30$ implies a 30% lower relative reduction in sugar purchased from SSBs compared with volume. The upper bound of this range is motivated by evidence from Grummon et al. (2019), which suggests that taxing sugar directly may increase an SSB tax's health benefits and overall economic gains by approximately 30%.