Methodology Appendix: Designing Better Sugary Drink Taxes

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Abstract

This methodology appendix has five parts. First, we give an overview on the economic theory of corrective taxation. Second, we provide an overview of the relevant externalities and "internalities." Third, we derive mathematical formulas for the effects of sugar taxes vs. volumetric taxes on sugar-sweetened beverages. Fourth, we detail the empirical implementation of the formulas. Finally, we present results.

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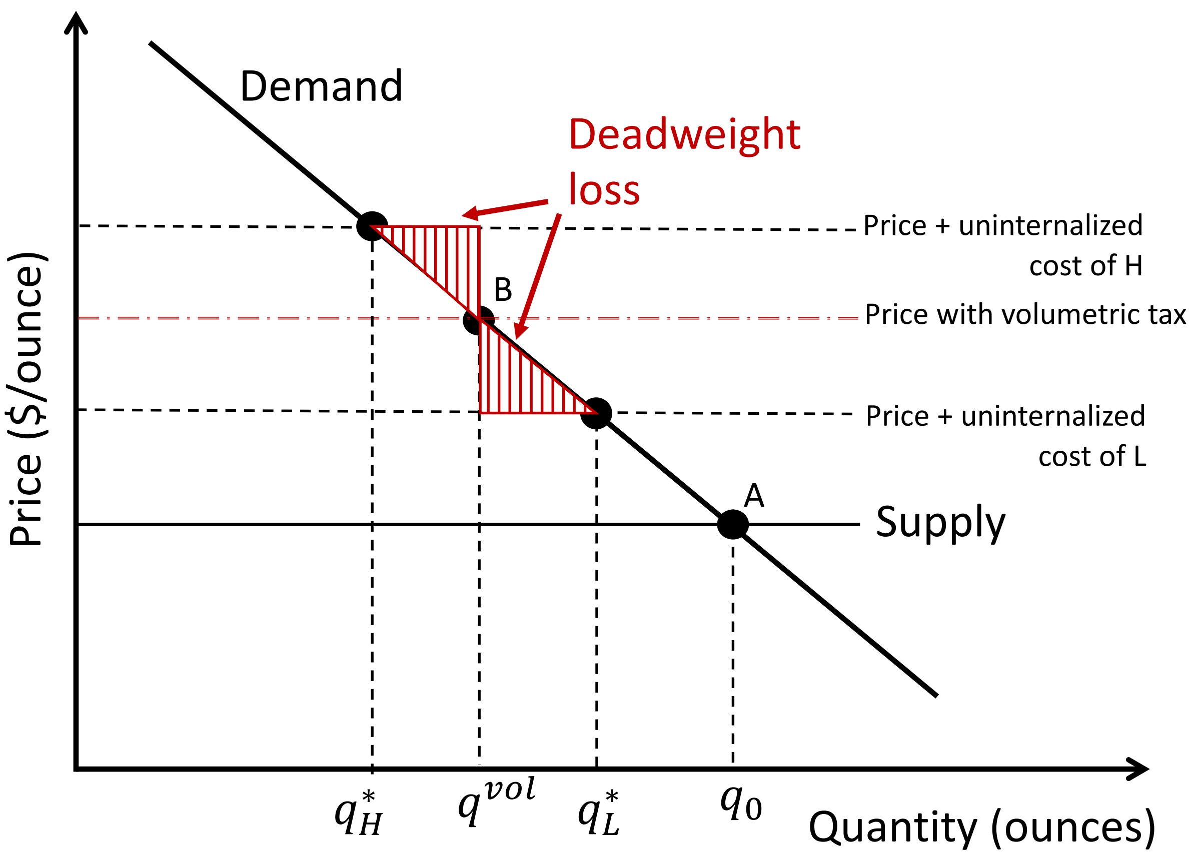
1 Overview: Economic Theory of Corrective Taxation

Appendix Figure 1 provides a quick primer on the economic theory of optimal corrective taxation. The downward-sloping line represents the demand curve for two different drinks, H and L, with high and low sugar content per unit volume, respectively. For this figure, we assume that the price of one drink does not affect purchases of the other drink; we relax this assumption in the derivations below. The horizontal line through point A is the marginal cost curve for each drink. We assume perfect competition, so the marginal cost curve is also the supply curve, which is perfectly elastic. This implies that any taxes on these drinks are passed through to consumers. Allcott, Lockwood, and Taubinsky (2019b) review the evidence on pass-through of sweetened beverage taxes, which shows that the majority of the taxes are indeed borne by consumers in the form of higher prices.

Without a tax, the market equilibrium will be at point A. There will be q_0 units of H sold, and q_0 units of L sold.

Figure 1: **Economic Theory of Corrective Taxation**



The two dotted horizontal lines represent the total social cost of consuming drinks H and L. Total social cost is the sum of marginal cost and the *uninternalized* harms from consumption. Uninternalized harms could be externalities—for example, the health care costs that are borne by a health insurance pool or by the government—or "internalities," if consumers don't consider the full cost that their consumption imposes on themselves. (Section 2 summarizes the sources of both internalities and externalities.) We assume that these uninternalized harms are linear in sugar content, so they are higher for drink H than for drink L.

Under the simplifying assumptions that the social planner does not consider distributional issues and redistributes tax revenues using lump sum transfers, social surplus is maximized when the taxes on H and L equal the uninternalized harms from each drink. Because uninternalized harms scale with sugar content, they are higher for H than for L, and the economically efficient "first best" tax on sugar would result in a higher per-ounce tax for H than for L. Under this optimal sugar tax, there would be q^*_H and q^*_L units sold, respectively, of H and L.

Instead of this first best sugar tax system, most sugary drink taxes impose a tax per unit volume that is uniform, i.e. does not vary across goods. Consider a volumetric tax that is "economically equivalent" in the sense that the rate equals the average of the two tax rates under the sugar tax. This economically equivalent uniform volumetric tax would change the market equilibrium to point B, reducing consumption of H and L to q^{vol} units each.

In the figure, both the economically efficient first best sugar tax and the economically equivalent volumetric tax lead to the same reduction in overall consumption of H plus L. However, because the sugar tax leads to a greater reduction in consumption of the high-sugar drink, the sugar tax reduces sugar consumption more than the volumetric tax. This generates a larger reduction in weight gain and other adverse health consequences.

Relative to the economically efficient sugar tax, the volumetric tax creates a "deadweight loss"—a loss of economic efficiency generated because the price of H is too low, so there are consumers who buy it but optimally would not, and the price of L is too high, so there are some consumers who don't buy it but optimally would. This deadweight loss is the area of the two shaded triangles in Appendix Figure 1.

2 Externalities and Internalities from SSB Consumption

2.1 Externalities

We quote from the discussion in Allcott, Lockwood, and Taubinsky (2019a), who estimate the externality to be \$0.85 per ounce:

> Using epidemiological simulation models, Wang et al. (2012) estimate that one ounce of soda consumption increases health care costs by an average of approximately one cent per ounce. Yong, Bertko, and Kronick (2011) estimate that for people with employer-provided insurance, about 15 percent of health costs are borne by the individual, while 85 percent are covered by insurance. Similarly, Cawley and Meyerhoefer (2012) estimate that 88 percent of the total medical costs of obesity are borne by third parties, and obesity is one of the primary diseases thought to be caused by SSB consumption. Accordingly, we approximate the health system externality at $e \approx 0.85$ cents per ounce.

As Allcott, Lockwood, and Taubinsky (2019b) write, "Strictly speaking, these are moral hazard costs or "fiscal externalities" (in the case of public insurance) which arise due to preexisting information frictions in a second-best world. We will call all such externalized costs "externalities," however, to emphasize that they are borne by people other than the sugar-sweetened beverage consumer." One might theoretically argue that instead of taxing SSBs, policymakers should redesign health insurance systems to charge different prices to different consumers based on their SSB consumption or resulting health conditions, but this issue is outside the scope of our analysis.

2.2 Internalities

Allcott, Lockwood, and Taubinsky (2019a) consider two types of internalities: imperfect information and self-control problems. Allcott, Lockwood, and Taubinsky (2019a) use a survey of Nielsen Homescan panelists to measure nutrition knowledge and perceived overconsumption of sugar-sweetened beverages, finding that soda consumption is higher among consumers who are less informed about nutrition and who profess less self-control, even after controlling for demographic variables and survey-based measures of health preferences and tastes for different drinks. Using assumptions detailed in the paper, Allcott, Lockwood, and Taubinsky (2019a) estimate that the average American household would consume 31 to 37 percent fewer sugar-sweetened beverages if they had perfect self-control and had the nutrition knowledge of dietitians and nutritionists. Translated into dollar terms, the estimated average marginal internality from sugar-sweetened beverage consumption is 0.91 to 2.14 cents per ounce.

In theory, it would be optimal to set heterogeneous SSB taxes that vary with each consumer's internalities and externalities, but it is not clear how such non-uniform taxes could be implemented, so we do not consider them here.

3 Formulas for the Effects of Sugar Taxes vs. Volumetric Taxes

Extending the logic from the above illustration, we can derive formulas for the sugar consumption decrease and economic efficiency gains from implementing a sugar tax instead of a volumetric tax. These derivations are based on the model and assumptions of Jacobsen et al. (2018).

Let the N different sugar-sweetened beverages (SSBs) be indexed by i or j, with q_j denoting the quantity of j purchased (measured in ounces) and p_j denoting the price per ounce. Let s_j denote the sugar content of j (measured in grams of sugar per ounce), and let $\bar{s}$ denote the unweighted average sugar content across all SSBs. We assume that the marginal uninternalized harms h_j from consuming j (combining externalities and internalities, in units of dollars per ounce) are proportional to s_j; that is, $h_j = Ks_j$, for some constant K.

Policymakers have two types of taxes, a volumetric tax t^{vol} (in cents per ounce, which increases the price per ounce p_j by the same amount for all SSBs) and a sugar tax t_j^{sug} (also in cents per ounce, which increases each SSB's price by a different amount, proportional to s_j). The economically efficient "first best" sugar tax equals the uninternalized harm: $t_j^{sug,*} = h_j$ dollars per ounce. We assume full pass-through, so tax changes and price changes have the same effect.

Let Q denote the total volume of SSBs consumed (in ounces per person per day), with $\frac{dQ}{dt^{vol}}$ denoting the impact of a volumetric tax on total demand for SSBs. We define

$$\alpha_j := \frac{\sum_{i \neq j} \frac{dq_i}{dp_j}}{-\frac{dq_j}{dp_j}}$$

as the average substitutability between SSB j and the other SSBs. In words, if an increase in p_j reduces demand for SSB j by X ounces, it also increases demand for other SSBs by a total of $\alpha_j X$ ounces as consumers substitute to those other SSBs. We define

$$\bar{\alpha} := \frac{1}{N} \sum_j \alpha_j$$

as the average cross-SSB substitution.

We adopt Jacobsen et al.'s assumptions that demand is locally linear and quasilinear in some untaxed numeraire good, that s_j is uncorrelated with $\frac{dq_j}{dp_j}$, and that cross-price effects between pairs of goods are uncorrelated with the product of those goods' sugar contents. We further assume that α_j is not correlated with $\frac{dq_j}{dp_j}$.[1] As we shall see, these assumptions allow us to simplify from a problem involving a large number of demand response parameters ($\frac{dq_j}{dp_i}$ for all pairs of SSBs i and j) to formulas involving only two demand parameters: the elasticity of total SSB demand with respect to a volumetric tax, which we use to get $\frac{dQ}{dt^{vol}}$, and the average cross-SSB substitution parameter $\bar{\alpha}$.

The following identity will prove useful in our derivations:

$$\begin{aligned} \frac{dQ}{dt^{vol}} &= \sum_i \sum_j \frac{dq_i}{dp_j} \\ &= \sum_i \left(\frac{dq_i}{dp_i} - \alpha_i \frac{dq_i}{dp_i} \right) \\ &= \sum_i (1 - \alpha_i) \frac{dq_i}{dp_i} \\ &= (1 - \bar{\alpha}) \sum_i \frac{dq_i}{dp_i}. \end{aligned} \tag{1}$$

Equation (1) says that the total impact on demand of a volumetric tax is the sum of the own-price effects on demand multiplied by one minus the average cross-SSB substitution.

[1] Formally, we assume $Cov\left[\frac{dq_j}{dp_j}, s_j\right] = 0$, $Cov\left[\frac{dq_j}{dp_j}, s_j^2\right] = 0$, and $Cov\left[\frac{dq_j}{dp_j}, \alpha_j\right] = 0$ across all products j, and $Cov\left[\frac{dq_i}{dp_j}, s_j\right] = Cov\left[\frac{dq_i}{dp_j}, s_i s_j\right] = 0$ across all pairs of products i and $j \neq i$.

3.1 A Definition of Economically Equivalent Taxes

A very large volumetric tax will obviously have much larger effects than a very small sugar tax. Thus, in order to compare the two taxes, we would like to hold the size of the tax constant in some appropriate sense. We define "economically equivalent" taxes as those that apply the same tax rate to the SSB with average sugar content. Formally, economically equivalent sugar and volumetric taxes satisfy

$$t_j^{sug} = \frac{s_j}{\bar{s}} t^{vol}. \tag{2}$$

This economically equivalent sugar tax is the same as a sugar tax of $t^{vol}/\bar{s}$ cents per gram of sugar. For example, if the volumetric tax is one cent per ounce, the economically equivalent sugar tax would be $1/\bar{s}$ cents per gram of sugar. Under this economically equivalent sugar tax, SSBs with average sugar content $\bar{s}$ would thus still be taxed at one cent per ounce, while SSBs whose sugar content is above average would be taxed at a higher rate.

Under this definition, economically equivalent taxes have several properties. First, they have the same average tax rate, when averaged across all SSBs: $\frac{1}{N}\sum_j t_j^{sug} = \frac{1}{N}\sum_j \frac{s_j}{\bar{s}} t^{vol} = t^{vol}$. Second, they have the same average tax rate, when averaged across all ounces consumed at baseline, if products' baseline quantity sold is uncorrelated with their sugar content:

$$\begin{aligned}
\frac{\sum_j q_j t_j^{sug}}{\sum_j q_j} &= \frac{\sum_j q_j (s_j/\bar{s}) t^{vol}}{\sum_j q_j} \\
&= \frac{\sum_j q_j \cdot \sum_j (s_j/\bar{s}) t^{vol}}{\sum_j q_j} \\
&= t^{vol}
\end{aligned}$$

Finally, under our assumptions in footnote 1, they reduce total SSB consumption by the same amount. To see this, notice that the SSB consumption reduction from a volumetric tax is

$$\Delta Q^{vol} = \sum_i \sum_j \frac{dq_i}{dp_j} t^{vol} = \frac{dQ}{dt^{vol}} \cdot t^{vol}, \tag{3}$$

while the reduction due to an economically equivalent sugar tax is

$$\begin{aligned}
\Delta Q^{sug} &= \sum_i \sum_j \frac{dq_i}{dp_j} t_j^{sug} \\
&= \sum_i \sum_j \frac{dq_i}{dp_j} \left(\frac{s_j}{\bar{s}} t^{vol} \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\sum_i \frac{dq_i}{dp_i} s_i + \sum_i \sum_{j \neq i} \frac{dq_i}{dp_j} s_j \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\sum_i \sum_j \frac{dq_i}{dp_j} \right) \bar{s} \qquad (4) \\
&= t^{vol} \cdot \frac{dQ}{dt^{vol}} = \Delta Q^{vol},
\end{aligned}$$

where Equation (4) follows by the definition of $\bar{s}$ and the zero covariance assumptions in footnote 1.

3.2 Effects on Sugar and Calorie Consumption

Although the two taxes have the same effect on total quantity of SSBs consumed, the sugar tax has a larger effect on sugar consumption. The reduction in sugar consumption from a volumetric tax is

$$\begin{aligned}
\Delta sugar^{vol} &= \sum_i \sum_j t^{vol} \frac{dq_i}{dp_j} s_i \\
&= t^{vol} \bar{s} \cdot \frac{dQ}{dt^{vol}}. \qquad (5)
\end{aligned}$$

The reduction in sugar consumption from an economically equivalent sugar tax is

$$
\begin{aligned}
\Delta sugar^{sug} &= \sum_i \sum_j t_j^{sug} \frac{dq_i}{dp_j} s_i \\
&= \sum_i \sum_j \frac{s_j}{\bar{s}} t^{vol} \frac{dq_i}{dp_j} s_i \\
&= \frac{t^{vol}}{\bar{s}} \sum_i \sum_j s_j \frac{dq_i}{dp_j} s_i \\
&= \frac{t^{vol}}{\bar{s}} \left(\sum_i s_i^2 \frac{dq_i}{dp_i} + \sum_i \sum_{j \neq i} s_i s_j \frac{dq_i}{dp_j} \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\sum_i \frac{dq_i}{dp_i} \cdot \left(\bar{s}^2 + Var\left[s_j\right]\right) + \left(\frac{1}{N(N-1)} \sum_i \sum_{j \neq i} s_i s_j \right) \sum_i \sum_{j \neq i} \frac{dq_i}{dp_j} \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\sum_i \frac{dq_i}{dp_i} \cdot \left(\bar{s}^2 + Var\left[s_j\right]\right) + \left(\frac{\left(\sum_i s_i\right)^2 - \sum_i s_i^2}{N(N-1)} \right) \sum_i \sum_{j \neq i} \frac{dq_i}{dp_j} \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\sum_i \frac{dq_i}{dp_i} \cdot \left(\bar{s}^2 + Var\left[s_j\right]\right) + \left(\frac{N}{N-1} \bar{s}^2 - \frac{\sum_i s_i^2}{N(N-1)} \right) \sum_i \sum_{j \neq i} \frac{dq_i}{dp_j} \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\sum_i \frac{dq_i}{dp_i} \cdot \left(\bar{s}^2 + Var\left[s_j\right]\right) + \left(\bar{s}^2 + \frac{1}{N-1} \left(\bar{s}^2 - \frac{\sum_i s_i^2}{N} \right) \right) \sum_i \sum_{j \neq i} \frac{dq_i}{dp_j} \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\sum_i \frac{dq_i}{dp_i} \cdot \left(\bar{s}^2 + Var\left[s_j\right]\right) + \left(\bar{s}^2 - \frac{Var[s_j]}{N-1} \right) \sum_i \sum_{j \neq i} \frac{dq_i}{dp_j} \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\bar{s}^2 \sum_i \sum_j \frac{dq_i}{dp_j} + Var\left[s_j\right] \left(\sum_i \frac{dq_i}{dp_i} - \frac{\sum_i \sum_{j \neq i} \frac{dq_i}{dp_j}}{N-1} \right) \right) \\
&= \frac{t^{vol}}{\bar{s}} \left(\bar{s}^2 \frac{dQ}{dt^{vol}} + Var\left[s_j\right] \left(\sum_i \frac{dq_i}{dp_i} + \frac{\sum_i \alpha_i \frac{dq_i}{dp_i}}{N-1} \right) \right) \\
&= t^{vol} \bar{s} \left(\frac{dQ}{dt^{vol}} + Var\left[\frac{s_j}{\bar{s}}\right] \left(1 + \frac{\bar{\alpha}}{N-1} \right) \sum_i \frac{dq_i}{dp_i} \right) \\
&= t^{vol} \bar{s} \cdot \frac{dQ}{dt^{vol}} \left(1 + Var\left[\frac{s_j}{\bar{s}}\right] \frac{\left(1 + \frac{\bar{\alpha}}{N-1}\right) \sum_i \frac{dq_i}{dp_i}}{(1-\bar{\alpha}) \sum_i \frac{dq_i}{dp_i}} \right) \\
&= \Delta sugar^{vol} \left(1 + \frac{1 + \frac{\bar{\alpha}}{N-1}}{1 - \bar{\alpha}} \cdot Var\left[\frac{s_j}{\bar{s}}\right] \right) \\
&\approx \Delta sugar^{vol} \left(1 + \frac{1}{1 - \bar{\alpha}} \cdot Var\left[\frac{s_j}{\bar{s}}\right] \right),
\end{aligned} \tag{6}
$$

where the final line represents a close approximation when the number of products N is large. (The calculations described below involve several thousand products.) Since SSBs vary in their sugar content, $Var\left[\frac{s_j}{\bar{s}}\right]$ is unambiguously positive. Since aggregate SSB demand slopes downward, $\bar{\alpha} < 1$ and thus $\frac{1}{1-\bar{\alpha}}$ is also positive. Therefore, the term multiplying $\Delta sugar^{vol}$ in Equation (6) is greater than one, showing that a sugar tax reduces sugar consumption more than a volumetric tax.

The effects of taxes on total calorie consumption are given by analogous equations, under the assumption that each SSB's calorie content is proportional to sugar content plus a deviation that satisfies the same zero correlation assumptions detailed in footnote 1.[2] Denoting product j's calorie content (in calories per ounce of drink) as c_j and average calorie content as $\bar{c}$, we have:

$$\Delta calories^{vol} = t^{vol}\bar{c} \cdot \frac{dQ}{dt^{vol}}. \tag{7}$$

$$\begin{aligned} \Delta calories^{sug} &= \Delta calories^{vol}\left(1 + \frac{1+\frac{\bar{\alpha}}{N-1}}{1-\bar{\alpha}} \cdot Var\left[\frac{c_j}{\bar{c}}\right]\right) \\ &\approx \Delta calories^{vol}\left(1 + \frac{1}{1-\bar{\alpha}} \cdot Var\left[\frac{c_j}{\bar{c}}\right]\right) \end{aligned} \tag{8}$$

3.3 Health Effects

The effect of a tax on health outcomes (weight, obesity, or diabetes) is

$$\Delta health = \Delta calories \times \zeta^h, \tag{9}$$

where $\Delta calories$ is from Equation (7) or (8), and ζ^h is the effect of SSB calorie intake on health outcome h, with $h \in \{weight, obesity, diabetes\}$.

3.4 Economic Efficiency Gains

Relative to an equilibrium without any SSB taxes, the economic efficiency gain (or deadweight loss reduction) from a volumetric tax is

$$\begin{aligned} \Delta efficiency^{vol} &= -\sum_i \sum_j s_i K \frac{dq_i}{dp_j} t^{vol} + \frac{1}{2}\sum_i \sum_j \frac{dq_i}{dp_j}(t^{vol})^2 \\ &= -\left(\bar{s}K - \frac{t^{vol}}{2}\right) t^{vol} \frac{dQ}{dt^{vol}}. \end{aligned} \tag{10}$$

[2]Formally, we assume $c_j = ks_j + \varepsilon_j$, where $Cov[\varepsilon_j, s_j] = 0$, $Cov\left[\frac{dq_j}{dp_j}, \varepsilon_j\right] = 0$, and $Cov\left[\frac{dq_j}{dp_j}, \varepsilon_j^2\right] = 0$ across all products j, and $Cov\left[\frac{dq_i}{dp_j}, \varepsilon_j\right] = Cov\left[\frac{dq_i}{dp_j}, \varepsilon_i\varepsilon_j\right] = 0$ across all pairs of products i and $j \neq i$. The proportionality assumption is natural because there are four calories per gram of sugar, and 93 percent of the calories in SSBs are from sugar.

The economic efficiency gain from an economically equivalent sugar tax t_j^{sug} is:

$$\begin{aligned}
\Delta efficiency^{sug} &= -\sum_i \sum_j s_i K \frac{dq_i}{dp_j} t_j^{sug} + \frac{1}{2} \sum_i \sum_j \frac{dq_i}{dp_j} t_i^{sug} t_j^{sug} \\
&= -\sum_i \sum_j s_i K \frac{dq_i}{dp_j} \frac{s_j}{\bar{s}} t^{vol} + \frac{1}{2} \sum_i \sum_j \frac{dq_i}{dp_j} \left(\frac{s_i}{\bar{s}} t^{vol}\right) \left(\frac{s_j}{\bar{s}} t^{vol}\right) \\
&= -\frac{t^{vol}}{\bar{s}^2} \sum_i \sum_j s_i s_j \left(\bar{s}K - \frac{t^{vol}}{2}\right) \frac{dq_i}{dp_j} \\
&= \frac{\sum_i \sum_j s_i s_j \frac{dq_i}{dp_j}}{\bar{s}^2 \frac{dQ}{dt^{vol}}} \Delta efficiency^{vol}.
\end{aligned}$$

From the derivation of Equation (6), we have that $\frac{\sum_i \sum_j s_i s_j \frac{dq_i}{dp_j}}{\bar{s}^2 \frac{dQ}{dt^{vol}}} = 1 + \frac{1+\frac{\bar{\alpha}}{N-1}}{1-\bar{\alpha}} \cdot Var\left[\frac{s_j}{\bar{s}}\right]$. For large N, this then gives

$$\Delta efficiency^{sug} \approx \Delta efficiency^{vol} \left(1 + \frac{1}{1-\bar{\alpha}} \cdot Var\left[\frac{s_j}{\bar{s}}\right]\right). \tag{11}$$

Equations (6) and (11) show that a sugar tax generates sugar intake reductions and economic efficiency gains that are larger than those from the volumetric tax by the same scaling factor: $1 + \frac{1}{1-\bar{\alpha}} \cdot Var\left[\frac{s_j}{\bar{s}}\right]$. This scaling factor demonstrates that the sugar tax generates larger relative gains when SSBs vary more in sugar content. Intuitively, if there is little variation in sugar content, volumetric taxes and sugar taxes impose similar tax rates on each SSB, and the gains from the latter are thus small. The sugar tax also generates larger relative gains when $\bar{\alpha}$ is larger. To see the intuition, consider the effect of an increase in cross-SSB substitution $\bar{\alpha}$, holding constant the slope of aggregate SSB demand $\frac{dQ}{dt^{vol}}$. The gains from a volumetric tax depend only on $\frac{dQ}{dt^{vol}}$, so these gains are unchanged. However, the gains from the sugar tax are determined by substitution away from individual high-sugar products, which is governed by the own-price effects $\frac{dq_j}{dp_j}$. As we see in Equation (1), $\frac{dq_j}{dp_j}$ must increase in absolute value when $\bar{\alpha}$ increases and $\frac{dQ}{dt^{vol}}$ is held constant. Thus, all else equal, the gains from a sugar tax are larger when there is more substitution between SSBs.

These results are a generalization of the formula for the deadweight loss from an imperfectly targeted tax in Jacobsen et al. (2018). There, deadweight loss is measured relative to the first best targeted tax, i.e., the special case where $t_i^{sug} = s_i K$ for all i, in which case the economically equivalent volumetric tax is second best optimal:[3]

$$t^{vol} = \bar{s}K. \tag{13}$$

3.5 Summary

Table (1) summarizes the equation numbers used to calculate our results.

Table 1: **Equation Numbers for Computing Effects of Sugar-Sweetened Beverage Taxes**

	(1) Volumetric tax	(2) Sugar content tax
Tax rate	1 cent/ounce	(2)
SSB consumption decrease (ounces/person-day)	(3)	(4)
SSB sugar consumption decrease (grams/person-day)	(5)	(6)
SSB calorie consumption decrease (calories/person-day)	(7)	(8)
Health effects (weight, obesity, diabetes)	(9)	(9)
Economic efficiency gain ($/person-year)	(10)	(11)

4 Empirical Implementation

For both consumption and health effects, we use parameters relevant for U.S. adults. We present Monte Carlo simulations to illustrate uncertainty in estimates of four parameters: price elasticity, caloric compensation, and the effects of SSB calorie intake on obesity and type 2 diabetes.

[3]Specifically, using Equation (11), the efficiency gains from replacing a volumetric tax with a sugar tax are

$$\begin{aligned}
\Delta efficiency^{sug} - \Delta efficiency^{vol} &= -\frac{\bar{s}^2 K^2}{2} \cdot \frac{dQ}{dt^{vol}} \left(\frac{\sum_i \sum_j s_i s_j \frac{dq_i}{dp_j}}{\bar{s}^2 \frac{dQ}{dt^{vol}}} - 1 \right) \\
&= -\frac{K^2}{2} \left(\sum_i \sum_j s_i s_j \frac{dq_i}{dp_j} - \bar{s}^2 \frac{dQ}{dt^{vol}} \right) \\
&= -\frac{K^2}{2} \left(\bar{s}^2 \sum_i \sum_j \frac{dq_i}{dp_j} - \bar{s} \sum_i \sum_j s_i \frac{dq_i}{dp_j} - \bar{s} \sum_i \sum_j s_j \frac{dq_i}{dp_j} + \sum_i \sum_j s_i s_j \frac{dq_i}{dp_j} \right) \\
&= -\frac{K^2}{2} \left(\sum_i \sum_j \left(\bar{s}^2 - \bar{s} s_i - \bar{s} s_j + s_i s_j \right) \frac{dq_i}{dp_j} \right) \\
&= -\frac{1}{2} \sum_i \sum_j \left(t^{vol} - s_i K \right) \left(t^{vol} - s_j K \right) \frac{dq_i}{dp_j}. \qquad (12)
\end{aligned}$$

Equation (12) is identical to Equation (6) from Jacobsen et al. (2018).

4.1 Data and Economic Assumptions

Using the formulas above, we estimate the effects of imposing a volumetric tax vs. a sugar tax on SSBs, using data from the United States. We observe the list of SSB products sold, as well as prices and purchases of each product, from Nielsen Homescan, a nationally representative dataset of all grocery purchases made by about 60,000 U.S. households.

We define "SSBs" based on what beverages are taxed by most existing SSB taxes in the U.S.: carbonated soft drinks, sweetened juice drinks, packaged coffee and tea, sports drinks, and energy drinks, but not milk-based drinks, diet drinks using zero- or low-calorie artificial sweeteners, or 100% fruit juice. This includes powdered drinks such as powdered Gatorade and sweetened instant coffee or tea, as well as concentrated drink mixes. Consistent with most existing SSB taxes, we consider the volume of powdered and concentrated drinks as consumed (i.e. after adding water). We observe sugar content in a dataset collected from each drink's Nutrition Facts Panel. We take all UPCs within the 22 Nielsen product module codes comprising SSBs, dropping UPCs with zero grams of sugar or less than 1/2 calorie per ounce.

We define SSB "products" (indexed by i and j in the model) uniquely by brand, size, and flavor—for example, a 16-ounce bottle of cherry-flavored Brand X. Each of our "products" may contain one or more UPCs. There are 2324 products in our dataset. This gives us the set of products $j \in \{1, ..., J\}$, each with sugar content s_j and calorie content c_j.

In our Monte Carlo simulations, we place 50% weight on the result from Allcott, Lockwood, and Taubinsky (2019a) that the price elasticity of demand for SSBs is $\frac{dQ/Q}{dP/P} \approx -1.37$. We place 5% weight on each of the ten price elasticity estimates reported in the systematic review by Powell et al. (2013). These estimates are comparable to recent estimates from six studies that measure the effects of SSB taxes on sugary drink purchasing and consumption, both in U.S. cities and in other countries; see Table 2. To translate from $\frac{dQ/Q}{dP/P}$ to $\frac{dQ}{dt^{vol}}$, we set a baseline $Q_0 = 154/11.57$ ounces per person-day on the basis of estimates from the 2013-2014 National Health and Nutrition Examination Survey (NHANES) that the average American adult consumes 154 calories of SSBs per day (Allcott, Lockwood, and Taubinsky, 2019b), and our calculation that the average SSB has $\bar{c} = 11.57$ calories per ounce. We set a baseline $P_0 = 4.5$ cents per ounce, which is approximately midway between the quantity-weighted average price of 2.8 cents per ounce in our Nielsen Homescan data for 2014-2016 and the Powell et al.'s (2014) consumption-weighted average price of 5.9 cents per ounce from a national sample of food outlets near public schools. We then set $dP = t^{vol} = 1$ cent per ounce and back out the demand slope dQ/dt^{vol} implied by a constant-elasticity functional form.[4]

We estimate $\bar{\alpha}$ using results presented in Tables 2.2, 2.3, and B.2 of Dubois, Griffith, and O'Connell (2019). Their Table B.2 reports the own-price elasticity and substitution elasticity for on-the-go purchases of 16 major SSB products. Using market share data reported in their Tables 2.2 and 2.3, we can then translate these elasticities into cross-SSB substitution parameters α_j. The

[4]Specifically, we assume $Q = \kappa P^{-1.4}$, so $Q' = Q_0 \cdot (\frac{P_0 + t^{vol}}{P_0})^{-1.4}$ and $\frac{dQ}{dt^{vol}} = \frac{Q' - Q_0}{t^{vol}}$.

average is $\bar{\alpha} \approx 0.46$.

To estimate K, we assume that one cent per ounce, the most common SSB tax rate in U.S. cities, is economically equivalent to the first-best sugar tax rate. This implies that $K = 1/\bar{s} \approx 0.37$ cents per gram of sugar.

Table 2: **Implied Elasticities from Previous Studies of City- and National-Level SSB Taxes**

Study	Context	Elasticity
Caro et al. (2018)	Chile, carbonated SSBs	-2.1
Caro et al. (2018)	Chile, non-carbonated SSBs	-1.3
Colchero et al. (2015; 2017)	Mexico	-0.8
Falbe et al. (2016)	Berkeley, CA	-2.6
Roberto et al. (2019)	Philadelphia, PA	-1.7
Silver et al. (2017)	Berkeley, CA	-1.2
Zhong et al. (2018)	Philadelphia, PA	-1.5

Notes: This table shows implied price elasticities for SSBs (% change in purchases or consumption per 1% change in price) from recent studies of SSB taxes implemented in U.S. cities and other countries.

4.2 Assumptions about Health Effects

4.2.1 Effects on Weight and Type 2 Diabetes

To estimate the health effects ($\Delta health$ from Equation (9)), we calibrate the health effect/calorie consumption parameters ζ^h using standard epidemiological modeling assumptions. We consider three health outcomes: steady-state average weight, steady-state obesity prevalence, and annual type 2 diabetes incidence. (Prevalence is the stock of cases in a population, while incidence is the flow of new cases over a given period.)

To estimate the effect of SSB calorie consumption on weight ζ^{weight}, we first account for the possibility that people who reduce their SSB intake replace calories from SSBs with calories from other sources. Three studies have measured caloric compensation after supplementation with SSBs vs. non-caloric (or very low-calorie) artificially sweetened beverages, finding that a one calorie change in SSB intake yields a 0.63 (Tordoff and Alleva, 1990), 0.67 (Reid et al., 2007), or 0.92 (Van Wymelbeke et al., 2003) calorie change in total energy intake (TEI). That is, individuals compensate 8%, 33%, or 37% of SSB calorie intake. We translate reductions in SSB calorie intake into TEI reductions by multiplying the average daily SSB calorie intake reduction by 0.92, 0.67, or 0.63, respectively. In our Monte Carlo simulations, we place equal weight on these three estimates.

To translate from TEI to steady-state weight, we apply a validated model of weight change developed by the National Institutes of Health (NIH) (Hall et al., 2011). The model quantifies how a change in total energy intake (such as from a reduction in SSB intake) affects body weight over time. A commonly used heuristic derived from the NIH weight change model is that an adult who permanently reduces her calorie intake by 100 kilojoules (23.9 calories) per day can expect to lose about 1 kilogram of body weight in steady state (Hall et al., 2011; Wang et al., 2012; Long et al., 2015; Basu, Seligman, and Bhattacharya, 2013). Half of this weight loss occurs in the first year after reducing energy intake, and the remainder occurs within three to five years. We apply this heuristic to arrive at average weight loss per American adult in steady state, presented in units of pounds/person. Thus, $\zeta^{weight} = (1 - compensation\ factor) \cdot \frac{1\ kg}{23.9\ calories/day}$.

We place equal weight on three estimates of the effect of SSB calorie consumption on obesity prevalence $\zeta^{obesity}$. First, we rescale results from Basu et al.'s (2014) microsimulation, which found that a 24.2 calorie/day reduction in SSB intake would yield a 2.4% reduction in adult obesity prevalence after 10 years. Thus, $\zeta^{obesity} = \frac{2.4\%\ prevalence}{24.2\ calories/day}$. Second, we consider Long et al.'s (2015) estimate that a 20% reduction in SSB intake (from a baseline of about 162.25 calories/day, see Bleich et al. (2018)) would yield a 0.99% reduction in obesity prevalence after ten years. Third, we apply Wang et al.'s (2012) estimate that a 15% reduction in SSB intake (from a baseline of 203 calories/day) would yield a 1.5% reduction in obesity prevalence after ten years.

Excess SSB consumption has also been consistently linked to increased risk of developing type 2 diabetes (Imamura et al., 2015), both via its effects on obesity and by disrupting metabolic processes. We place equal weight on two estimates of the effect of SSB calorie consumption on type 2 diabetes incidence $\zeta^{diabetes}$. First, we rescale results from Basu et al. (2014) that a 24.2 calorie/day reduction in SSB intake would yield a reduction in type 2 diabetes incidence of 8.5 cases per 100,000 adults per year. This represents a 1.3% reduction from the Centers for Disease Control and Prevention's most recent estimates of type 2 diabetes annual incidence of 670 cases per 100,000 adults Centers for Disease Control (2017). Thus, $\zeta^{diabetes} = \frac{1.3\%\ incidence}{24.2\ calories/day}$. Second, we consider Wang et al.'s (2012) estimate that a 15% reduction in SSB intake would yield a 2.6% reduction in type 2 diabetes incidence.

4.2.2 Global Health Benefits

We rescale the U.S. estimates to provide an estimate of worldwide health benefits from sugar taxes instead of volumetric taxes. There are seven cities and 18 countries with volumetric SSB taxes, not counting those with tiered tax systems that more closely approximate sugar taxes (Global Food Research Program (GFRP), 2019).[5] We gather estimates of each country's per capita SSB consumption from Popkin and Hawkes (2016). We calculate the change in per capita SSB consumption from SSB taxes under the assumptions that these jurisdictions would implement a 1 cent per ounce tax and that adults in city or country c would experience the same percent reduction in SSB calorie intake as adults in the U.S.:

$$\Delta calories_c = \Delta calories_{US} \times \frac{Q_c}{Q_{US}}, \tag{14}$$

[5] Of the 18 countries with volumetric taxes, we exclude 10 small countries without published data on SSB consumption or purchases—for example, Brunei, French Polynesia, and Vanuatu. This causes us to slightly underestimate worldwide health benefits of a sugar content tax. We also exclude 13 countries with ad valorem SSB taxes, such as Colombia, India, and Saudi Arabia, as our model does not focus on ad valorem taxes. As these taxes are also poorly targeted, this causes us to significantly underestimate worldwide health benefits.

where Q is per capita average SSB consumption. We then use ζ^{weight} to translate this to per-capita steady-state weight loss. We calculate total weight loss in country or city c by multiplying by adult (ages 15 years and older) population size gathered from the Central Intelligence Agency World Factbook (2018) or the American Community Survey (2017).

4.3 Monte Carlo Simulations

In order to quantify the uncertainty in our predictions, we run 1,000 Monte Carlo simulations over different parameter assumptions. We account for uncertainty in estimates of four parameters: price elasticity, caloric compensation factor, and the effects of SSB calorie intake on obesity and type 2 diabetes. Table 3 provides details. For all four parameters, we weight estimates from different sources with equal probability. For price elasticity, we additionally allow for sampling variation in the parameter estimate from Allcott, Lockwood, and Taubinsky (2019a). For parameters other than price elasticity, the original sources typically do not report standard errors in a usable format.

Table 3: **Overview of Monte Carlo Simulations**

Parameter	Share of simulations: estimate	Source
Price elasticity $\frac{dQ/Q}{dP/P}$	50%: -1.37 (SE=0.087)	Allcott, Lockwood, and Taubinsky (2019a)
	5% each: -1.86, -.41, -.609, -.712, -.87, -1.264, -.54, -2.26, -1.12, -1.3	Powell et al. (2013)
Compensation factor	33%: 0.67	Reid et al. (2007)
(to calculate ζ^{weight})	33%: 0.63	Tordoff and Alleva (1990)
	33%: 0.92	Van Wymelbeke et al. (2003)
Calories to obesity $\zeta^{obesity}$	33%: $\frac{2.4\%\ prevalence}{24.2\ calories/day}$	Basu et al. (2014)
	33%: $\frac{0.99\%\ prevalence}{32.45\ calories/day}$	Long et al. (2015)
	33%: $\frac{1.5\%\ prevalence}{30.45\ calories/day}$	Wang et al. (2012)
Calories to diabetes $\zeta^{diabetes}$	50%: $\frac{1.3\%\ incidence}{24.2\ calories/day}$	Basu et al. (2014)
	50%: $\frac{2.6\%\ incidence}{30.45\ calories/day}$	Wang et al. (2012)

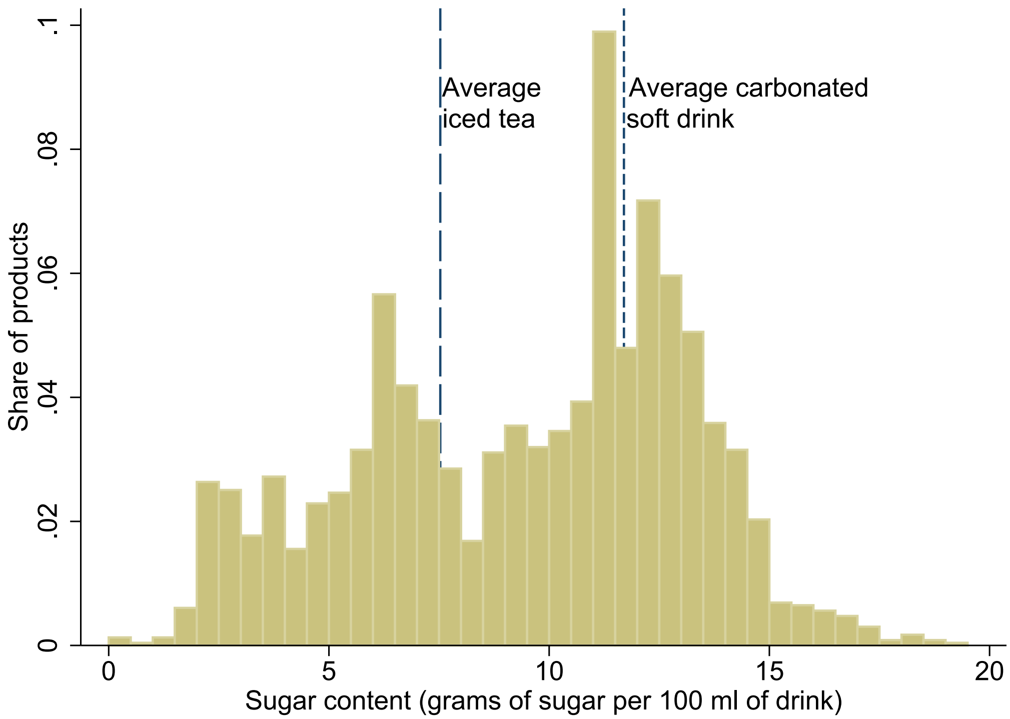
5 Results

Figure 2 presents the histogram of sugar content by product, across all SSB products available in the Nielsen Homescan data over 2014-2016. These are the data used to calculate $Var\left[\frac{s_j}{\bar{s}}\right]$. Table 4 presents Monte Carlos estimates of the range of effects of the volumetric tax and the relative gains from the sugar tax, using the equation numbers specified in Table 1 and the parameters weightings described in Table 3. Table 5 presents the weight loss effects of volumetric taxes and sugar taxes in countries and U.S. cities that currently impose volumetric taxes and have data available on SSB consumption, using the mean of the Monte Carlo estimates.

Under our assumptions, the sugar tax generates about 29% larger reductions in sugar and calorie consumption and deadweight loss compared to the volumetric tax. This can be seen from Equations (6), (8), and (11), which all show that the sugar tax effect equals the volumetric tax effect times $\left(1+\frac{1}{1-\bar{\alpha}}\cdot Var\left[\frac{c_j}{\bar{c}}\right]\right) \approx \left(1+\frac{1}{1-0.46}\cdot 0.16\right) \approx 0.29$.

As detailed in footnote 1, these calculations require the assumption that cross-price effects between pairs of goods are uncorrelated with the product of those goods' sugar contents. Another approach that allows this assumption to be relaxed is to calibrate the effects using a demand system with more flexible substitution patterns. To do this, we use the Dubois, Griffith, and O'Connell (2019) estimates. Dubois, Griffith, and O'Connell (2019) estimate a random coefficient logit model of SSB demand with utility function given by their Equation (3.1). We simulate a population of consumers with their estimated joint distribution of α, β, and γ parameters and back out the ξ parameter for each SSB product in our dataset using the Berry, Levinsohn, and Pakes (1995) contraction mapping. In this model, a one cent per ounce SSB tax reduces sugar consumption by 13.8% relative to baseline, and the economically equivalent sugar tax reduces sugar consumption by 16.1%. Thus, the sugar tax reduces consumption by 17.1% more than the volumetric tax. This is somewhat less than the 29% percent reduction in our model, although within the range of the sensitivity analyses that we present in our Monte Carlo simulations.

Figure 2: **Variation in Sugar Content Across Sugar-Sweetened Beverages**



Notes: This is a histogram of sugar content by SSB product, for all SSB products available in the Nielsen Homescan data over 2014-2016. “SSBs” comprise products taxed in city-level SSB taxes in the U.S.: carbonated soft drinks, sweetened juice drinks, packaged coffee and tea, sports drinks, and energy drinks, but not milk-based drinks, “diet” drinks using zero- or low-calorie artificial sweeteners, or 100% fruit juice. “Products” are defined by brand, size, and flavor, e.g. a 16-ounce bottle of cherry-flavored Brand X.

Table 4: **Monte Carlo Simulations of Effects of Volumetric or Sugar Taxes on Sugar-Sweetened Beverages**

(a) **Volumetric Tax Relative to No Tax**

	10th pctile	Mean	90th pctile
SSB consumption decrease (ounces/person-day)	1.4	2.9	3.8
SSB sugar consumption decrease (grams/person-day)	3.7	7.8	10.2
SSB calorie consumption decrease (calories/person-day)	15.9	33.4	43.9
Steady-state weight loss (pounds/person)	1.0	2.3	3.3
Steady-state obesity prevalence decrease (% change)	0.8	2.0	3.7
Type 2 diabetes incidence decrease (% change)	1.0	2.3	3.3
Economic efficiency gain ($/person-year)	2.5	5.3	6.9
Global steady-state weight loss (millions of pounds)	146.7	323.6	462.9

(b) **Sugar Tax Relative to Volumetric Tax**

	10th pctile	Mean	90th pctile
SSB consumption decrease (ounces/person-day)	0.0	0.0	0.0
SSB sugar consumption decrease (grams/person-day)	1.1	2.3	3.0
SSB calorie consumption decrease (calories/person-day)	4.8	10.0	13.1
Steady-state weight loss (pounds/person)	0.3	0.7	1.0
Steady-state obesity prevalence decrease (% change)	0.2	0.6	1.1
Type 2 diabetes incidence decrease (% change)	0.3	0.7	1.0
Economic efficiency gain ($/person-year)	0.7	1.6	2.0
Global steady-state weight loss (millions of pounds)	43.9	96.8	138.5

Notes: This table presents Monte Carlo simulations of the effects of a volumetric tax (Panel a) and the relative benefits from a sugar tax (Panel b) on sugar-sweetened beverages, as calculated using the equation numbers specified in Table 1 and the parameter variations described in Table 3. The first seven rows in each panel reflect calculations for adults in the United States, while the final row is a global calculation for all adults in cities and countries that currently have volumetric SSB taxes.

Table 5: **Effects of Taxes on Weight Loss for Countries and Cities with Volumetric Taxes**

Jurisdiction	(1) Per capita SSB consumption (calories/day)	(2) Adult population size (1000s)	(3) Volumetric tax weight loss (1000s lbs)	(4) Sugar tax weight loss (1000s lbs)	(5) Gain from sugar tax (column 4 - column 3) (1000s lbs)
Mexico	158	92,441	215,795	280,374	64,579
Norway	75	4,405	4,882	6,343	1,461
Finland	72	4,627	4,922	6,395	1,473
Belgium	88	9,580	12,456	16,184	3,728
Hungary	65	8,385	8,053	10,463	2,410
Malaysia	30	23,068	10,225	13,285	3,060
Morocco	25	25,574	9,446	12,273	2,827
Philippines	48	70,874	50,263	65,305	15,042
Berkeley	154	109	249	324	75
Oakland	154	346	788	1,024	236
San Francisco	154	765	1,742	2,264	521
Boulder	154	94	215	280	64
Philadelphia	154	1,277	2,907	3,777	870
Seattle	154	596	1,358	1,764	406
Albany	154	15	35	46	11
Total		242,156	420,101	323,338	96,763

Notes: This table presents the weight loss effects of volumetric taxes and sugar taxes on sugar-sweetened beverages in countries and U.S. cities that currently impose volumetric taxes and have data available on SSB consumption. Per capita SSB consumption estimates are from Popkin and Hawkes (2016). Weight loss is calculated using the assumptions described in Section 4.2.2.

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