Sugar Taxes and Changes in Total Calorie Consumption: A Simple Framework

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Abstract

This paper demonstrates the potential importance, when considering total calorie intake, of allowing for the substitution effects of imposing a selective tax on a commodity having a high sugar content, when non-taxed commodities exist and also have relatively high calorie content. A framework is presented which allows the elasticity of calorie consumption with respect to a price change to be derived. This brings out the role of relative budget shares, relative calorie content of goods and relative prices to be clearly seen, along with own- and cross-price elasticities. Their absolute values for each commodity group are not required. It is demonstrated that the focus of attention needs to be much wider than a simple concentration on the own-price elasticity of demand for the commodity group for which a sumptuary tax is envisaged.

JEL Classification: I10; H2; H31

Keywords: Sugar-sweetened beverage; calorie intake; demand elasticity

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1 Introduction

It is widely recognised that high sugar consumption is linked to obesity, type-2 diabetes and cardiovascular disease. In view of the large proportion of sugar consumption attributed to non-alcoholic drinks, especially among young people, this has led to pressure for the imposition of a high sumptuary tax rate on sugar-sweetened beverages (SSBs), commonly referred to as a 'sugar tax'. For example, in New Zealand, Ni Mhurchu *et al.* (2014, p. 96) suggested that, 'a 20% tax on carbonated drinks could be a simple, effective component of a multifaceted strategy to tackle New Zealand's high burden of diet-related disease'. Indeed, such a 'sugar tax' has received most policy emphasis, although increased obesity can be attributed to a wide range of causes; see, for example, Cutler *et al.* (2003).

Arguments for a sugar tax obviously rely on, among other things, establishing a consequent significant reduction in consumption. This is complicated by a range of problems. For example, surveys usually measure expenditure at the household rather than indivdual level. The health status of those responding to a price increase is not generally known, and higher responses may come from healthy consumers rather than the target population group. Surveys typically measure expenditure rather than consumption, which may be spread over a period of time longer than the survey period. Combined with this last point is the fact that the price actually paid per unit is to a large extent endogenous, in view of the price variations in the market. Furthermore, even within the group of SSBs, there is considerable heterogeneity, and a failure to allow adequately for quality variations can lead to a substantial bias in the estimation of elasticities, as shown by Gibson and Kim (2013). Substitution towards lower-priced SSBs that are higher in calorie content may mean that a tax on SSBs could have harmful rather than beneficial effects.

In addition, emphasis is often placed only on the own-price elasticity of demand for SSBs.[1] Substitution towards other non-taxed goods that are high in calories can also take place, reducing or even eliminating any direct reduction in the consumption of SSBs.[2] However, greater recognition is being given to this feature, which arises from the relative price change produced by the tax. Fletcher *et al.* (2010) found that the US tax on soft drinks was 'completely offset' by substitution towards other high-calorie drinks, so that 'the revenue generation and health benefits of soft drink taxes appear to be weaker than expected' (2010, p. 973). The US taxes are relatively low, and they mention the possibility that there may be nonlinear or threshold effects for higher tax rates. However, Fletcher *et al.* (2014) later reported that they found no evidence of such effects.

Using data for Mexico, Aguilar *et al.* (2016) found full (and sometimes more than 100 per cent) shifting for a tax on sweetened drinks but 66 per cent shifting for a tax on other high calorie foods.[3] As a result of substitution combined with differential price changes, they found that 'total calories consumed from all products captured in our dataset did not change' (2016, p. 3). This led to the conclusion that, 'the taxes introduced are unlikely to have the desired effect of reducing obesity' (2016, p. 14). The change in relative prices arose because 'suppliers of products with more calories per unit passed less of the tax on to consumers', so that, 'the *relative* price of calories per unit actually *decreased*' (2016, p. 16).

Other evidence has been somewhat mixed. Smith *et al.* (2010) found a small degree of substitution in the US, using elasticities evaluated at mean values, thereby reducing but not eliminating the effects of a tax on SSBs. Lin *et al.* (2010), again using US data, observed substitution, but the cross-price elasticities were

1 The way in which anticipated 'direct' demand reductions resulting from an SSB tax are calculated may also lead to an overstatement. Typically an elasticity is used to obtain the proportional change in demand, $\dot{q}$, following a proportional change in price of $\dot{p}$, using a 'point' elasticity, η, combined with an (implicit) linearisation of the demand function, such that $\dot{q} = \dot{p}\eta$. However, suppose the elasticity (rather than the slope) is thought to be constant, so that the demand curve is log-linear. In this case the appropriate formula is $\dot{q} = (1 + \dot{p})^{\eta} - 1$. The difference is likely to be negligible for very small price changes, but proponents of an SSB tax usually argue for at least a 20 per cent *ad valorem* rate. For example, with $\dot{p} = 0.2$, an elasticity of $\eta = -1.1$ gives $\dot{p}\eta = -0.22$ and $\dot{q} = (1 + \dot{p})^{\eta} - 1 = -0.1817$. If initial demand is 2 million units, the former overstates the demand reduction by 76,555 units. A 'higher' elasticity of -1.2 produces percentage reductions in demand of 24 and 19.65 for the two approaches, with the linearisation approximation overstating the reduction in demand by almost 87,000 units.

2 In a wide-ranging review of food taxes, Jeram (2016, p. 28-30) stressed problems arising from quality change within the taxed group and substitution towards other (untaxed) high calorie goods.

3 Colchero *et al.* (2015) also found full or over-shifting of the SSB tax for Mexico.

nevertheless quite small. Briggs *et al.* (2013) found evidence in the UK for substitution but reported small cross-price elasticities. In a different, but related, context Nhoaham *et al.* (2009, p. 1330) found that in New Zealand fruit and vegetables were gross complements with milk, cheese and fats, so that a subsidy for fruit and vegetables may not achieve its objective.[4]

Given a comprehensive set of own-price and cross-price elasticities for well-defined commodity groups, along with initial prices and quantities demanded, it is not difficult to work out the overall effect on the demand for each good as a result of a specified change in relative prices resulting from an indirect tax change (with suitable assumptions regarding the extent to which any tax is passed on to consumers in the form of higher unit prices). With information on the calorie content per unit of each good, the effect on total calorie consumption could then be evaluated. However, such extensive information is rarely available. It is therefore useful to construct a simple framework for examining the effect on total calorie consumption of a selective tax, rather than simply the consumption of SSBs. Furthermore, the overall effect on calorie consumption needs to consider the relative importance of the taxed group in total calorie consumption. A concentration on the proportional reduction in consumption of the taxed group only may overstate the effectiveness in achieving the ultimate objective.

The aim of the present paper is therefore to construct such a framework. The basic relationships are set out in Section 2, using a simple model in which there are just three types of good, two of which have a high calorie content. It is shown that the effectiveness of a sugar tax can be examined using just one own-price elasticity and one cross-price elasticity, and three fundamental ratios. These ratios are of relative budget shares, relative prices and relative calorie values of the groups with high calorie content. A convenient expression is obtained for the elasticity of total calorie consumption with respect to a change in the price of one of the goods. In the absence of empirical estimates, illustrative examples are given in Section 3. These examples illustrate the value of the framework in making it easy to consider the sensitivity of results to crucial variables. However, the analysis takes the relevant demand elasticities as given, so that it does not begin by specifying a form of utility function. Hence, no attempt is made to consider the wider question

4 Ni Mhurchu *et al.* (2013) found cross elasticities were mixed for New Zealand, with some groups being complements, but they used very broad categories. Nghiem *et al.* (2011) examine demand elasticities for foods in Australia and New Zealand but the categories used are not helpful in the context of SSBs.

of how to evaluate the costs (including excess burdens) and benefits (including any externalities) of such a tax policy. Brief conclusions are in Section 4.

2 A Simple Model

This section examines the elasticity of calorie consumption with respect to a change in the price (arising from a tax change) of a commodity with high sugar content, in a situation where a substitute exists which also has high calorie content but remains untaxed. Given the relationship between weight change and calorie intake, a link can then be made from the tax (and price) change to weight change.[5]

2.1 Total Calorie Consumption

For simplicity, suppose consumption can be divided into three goods. Goods 1 and 2 are high in calories per unit, while good 3 has no calories. Consumption of good i is denoted q_i. Define the coefficient, γ_i, as the calorie content per unit of consumption of good i. Hence the calories attributed to good i, defined as c_i, are:

$$c_i = \gamma_i q_i \tag{1}$$

Total calories arising from consumption are denoted by C. Since, by definition, $\gamma_3 = 0$, this is given by:

$$C = \sum_{i=1}^{2} \gamma_i q_i \tag{2}$$

Consider a change in the price of good 1. This can arise from an *ad valorem* tax at the rate, τ, on good 1 only. On the strong assumption that the tax is fully shifted

[5] A general framework was also presented by Schroeter *et al.* (2008), who examined a food demand model involving maximisation of a utility function. The 'arguments' of the function include different food types (differing by calorie content) along with body weight. The latter is affected by exercise as well as total calorie intake. Utility is maximised subject to the budget constraint, involving food costs along with the cost of exercise (though a time constraint was not included). However, their focus was actually on the relationship between body weight, W, exercise and food consumption, which was used to provide an elasticity decomposition of weight change with respect to the price of the high-calorie food. Writing the general function, $W = W(x_1, x_2, ...)$, straightforward total differentiation of W gives $\frac{dW}{dp_1} = \sum_i \frac{\partial W}{\partial x_i}\frac{\partial x_i}{\partial p_1}$. In general, let $\eta_{a,b}$ denote the elasticity of a with respect to a change in b. Then it is easily seen that: $\eta_{W,p_1} = \frac{p_1}{W}\frac{dW}{dp_1} = \sum_i \left(\frac{x_i}{W}\frac{\partial W}{\partial x_i}\right)\left(\frac{p_1}{x_i}\frac{\partial x_i}{\partial p_1}\right) = \sum_i \eta_{W,x_i}\eta_{x_i,p_1}$. Here η_{W,p_1} is a total elasticity, while all others are partials (although Schroeter use partial derivatives throughout). The authors examined evidence relating to the various elasticities.

to consumers, this leads to a proportional change in the price of the good given by $dp_1/p_1 = \tau$.

The resulting change in total calorie consumption is given by:

$$\frac{dC}{dp_1} = \sum_{i=1}^{2} \gamma_i \frac{dq_i}{dp_1} \tag{3}$$

This can be written as:

$$\frac{dC}{dp_1} = \frac{1}{p_1} \sum_{i=1}^{2} (\gamma_i q_i) \frac{p_1}{q_i} \frac{dq_i}{dp_1} \tag{4}$$

Define the price elasticity of good i with respect to a change in the price of good j as $e_{i,j}$, so that:

$$e_{i,j} = \frac{p_j}{q_i} \frac{dq_i}{dp_j} \tag{5}$$

and define the elasticity of total calorie consumption with respect to the price of good 1, η_{C,p_1}, using:

$$\eta_{C,p_1} = \frac{p_1}{C} \frac{dC}{dp_1} \tag{6}$$

Using (5) and (2), and multiplying (4) by p_1/C, (6) becomes:

$$\eta_{C,p_1} = \sum_{i=1}^{2} \left(\frac{\gamma_i q_i}{\sum_{i=1}^{2} \gamma_i q_i} \right) e_{i,1} \tag{7}$$

Let s_i denote the share of good i in total calorie consumption. Then, by definition:

$$s_i = \frac{\gamma_i q_i}{\sum_{i=1}^{2} \gamma_i q_i} \tag{8}$$

Substituting (8) into (7) gives:

$$\eta_{C,p_1} = \sum_{i=1}^{2} s_i e_{i,1} \tag{9}$$

This result shows that the total elasticity, η_{C,p_1}, is a calorie-share-weighted sum of the own-price elasticity $e_{1,1}$ and the cross-price elasticity, $e_{2,1}$. The latter measures the proportional change in the demand for good 2 resulting from a unit proportional change in the price of good 1. In the simple case where both γ_2 and γ_3 are zero, then $\eta_{C,p_1} = e_{1,1}$, since $\gamma_1 = 1$: this elasticity is usually the only focus of attention when considering the effectiveness of a sugar tax. Where a substitute good exists that is also high in calories ($\gamma_2 > 0$) then, even if the cross-price elasticity, $e_{2,1}$, is zero, the proportional reduction in total calorie consumption is $\eta_{C,p_1} = s_1 e_{1,1}$ and is clearly less than $e_{1,1}$.

Equation (9) shows that the total effect of a tax on good 1 can be obtained with knowledge only of the initial calorie shares and the two elasticities, $e_{1,1}$ and $e_{2,1}$. If, as is likely, goods 1 and 2 are gross substitutes, the consumption of good 2 increases when the price of good 1 increases, so that $e_{2,1} > 0$. The own-price elasticity, $e_{1,1}$, is of course negative.

2.2 Calorie Shares

Consider the determination of the s_i values. Let w_i denote the budget share of good i, so that:

$$w_i = \frac{p_i q_i}{\sum_{i=1}^{3} p_i q_i} \tag{10}$$

and if total expenditure is defined as $y_i = \sum_{i=1}^{3} p_i q_i$, the budget shares are simply:

$$w_i = \frac{p_i q_i}{y} \tag{11}$$

Hence the quantity, q_i, can be written as $q_i = w_i y / p_i$, and substituting into (8) gives:

$$\begin{aligned} s_i &= \frac{\gamma_i w_i y / p_i}{\sum_{i=1}^{3} \gamma_i \left(w_i y / p_i \right)} \\ &= \frac{\gamma_i w_i / p_i}{\sum_{i=1}^{3} \gamma_i w_i / p_i} \end{aligned} \tag{12}$$

Clearly it is only necessary to obtain an expression for s_1, since $s_2 = 1 - s_1$. Substitution and rearrangement gives:

$$s_1 = \left[1 + \left(\frac{\gamma_2}{\gamma_1} \right) \left(\frac{w_2}{w_1} \right) \left(\frac{p_1}{p_2} \right) \right]^{-1} \tag{13}$$

Hence, conveniently, only the relative price, p_1/p_2, is needed rather than absolute prices, and the relative calorie content, $\frac{\gamma_2}{\gamma_1}$, is needed rather than absolute amounts.

2.3 The Three Ratios

Equation (13) indicates the importance of three relative values. Clearly $\left(\frac{w_2}{w_1} \right) \left(\frac{p_1}{p_2} \right) = \frac{q_2}{q_1}$, and $\left(\frac{\gamma_2}{\gamma_1} \right) \left(\frac{w_2}{w_1} \right) \left(\frac{p_1}{p_2} \right)$ is simply, $\frac{c_2}{c_1}$, the ratio of calories contributed by good 2 to those of good 1. However, it is useful to retain the form above to show the separate role of relative budget shares, relative prices and relative calorie values.

Substitute (13) into (9) and rearrange to get:

$$\eta_{C,p_1} = e_{2,1} + \frac{e_{1,1} - e_{2,1}}{1 + \left(\frac{\gamma_2}{\gamma_1} \right) \left(\frac{w_2}{w_1} \right) \left(\frac{p_1}{p_2} \right)} \tag{14}$$

Writing $\left(\frac{\gamma_2}{\gamma_1}\right)\left(\frac{w_2}{w_1}\right)\left(\frac{p_1}{p_2}\right) = \prod_{k=1}^{3} r_k$, with $r_1 = \frac{\gamma_2}{\gamma_1}$ and so on, the effect on η_{C,p_1} of a change in any of the ratios can be expressed as:

$$\frac{\partial \eta_{C,p_1}}{\partial r_j} = -s_1^2 \left(e_{1,1} - e_{2,1}\right) \prod_{k \neq j}^{3} r_k \tag{15}$$

Hence, since $e_{1,1} < 0$ and, on the assumption that $e_{2,1} > 0$, $\frac{\partial \eta_{C,p_1}}{\partial r_j} > 0$ and η_{C,p_1} unambiguously rises – and therefore in *absolute terms* become *smaller* – as each of the three ratios, r_k, increases. Furthermore, as expected, η_{C,p_1} is larger in absolute terms for a higher budget share, w_1, of the taxed good relative to the untaxed good, and for a relatively higher calorie content.

Equation (14) can also be used to consider the size of the cross-price elasticity, $e_{2,1}$, required such that any direct effect on calorie intake arising from $e_{1,1}$ is completely eliminated by the substitution towards untaxed goods. Letting $|e_{1,1}|$ denote the absolute value of the own-price elasticity of the taxed good, it can be shown that $\eta_{C,p_1} > 0$ so long as:

$$e_{2,1} < |e_{1,1}| \left\{ \left(\frac{\gamma_1}{\gamma_2}\right) \left(\frac{w_1}{w_2}\right) \left(\frac{p_2}{p_1}\right) \right\} \tag{16}$$

The higher the relative price of the substitute, the smaller its budget share relative to the taxed good, and the higher the calorie content of the taxed good relative to the substitute, the greater is the chance that the direct effect of a tax will outweigh the indirect effect arising from the cross-price elasticity. Of course, in the unlikely case where the second untaxed good is a gross complement, that is, its sign is negative, the indirect effect reinforces the direct effect.

3 Illustrative Examples

To give some idea of the potential effect of allowing for the second good that is both a substitute for the first (taxed) good and is relatively high in calories per unit, suppose that the absolute value of the own-price elasticity, $|e_{1,1}|$, is equal to 0.8. This is within the range reported in a number of studies of sugar-sweetened beverages. Suppose also that the relative price, $p_1/p_2 = 0.8$, so that the price per unit of good 2 is higher than that of good 1. The order of magnitude of budget shares appears to vary substantially between countries and demographic groups. For present purposes, suppose good 2 has a budget share of $w_2 = 0.03$.

Figure 1: Variation in η_{C,p_1} with $e_{2,1}$

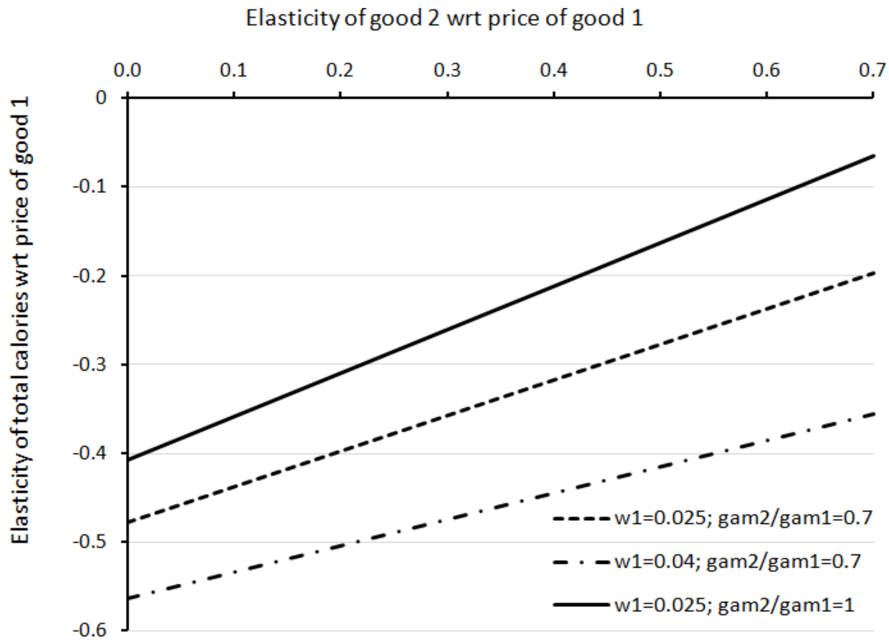

Figure 1 shows the variation in η_{C,p_1} with $e_{2,1}$ for different combinations of w_1, the budget share of the taxed good, and of the ratio γ_2/γ_1. From equation (14) these profiles are obviously linear, and the relevant elasticity η_{C,p_1} increases – that is, it decreases in absolute terms – as the cross-price elasticity, $e_{2,1}$, increases. Clearly, the higher the budget share and the relative calorie content of the taxed good 1, the greater is the effectiveness of the tax in reducing calorie consumption. But for all combinations shown in Figure 1, the effectiveness of the tax is substantially reduced as the cross-price elasticity increases. In view of the limited empirical information about this elasticity, further empirical work is warranted.

4 Conclusions

The aim of this paper has been to demonstrate the potential importance of allowing for substitution effects in considering the effectiveness of imposing a tax on a commodity (or group) having a high sugar content, when non-taxed commodities exist and also have relatively high calorie content. A framework was presented which allows the role of relative budget shares, relative calorie content of goods and relative prices to be clearly seen. Importantly, in determining the elasticity of total calorie consumption with respect to changes in the price of taxed SSBs, the absolute amounts (of prices, budget shares, and calorie content) for each commodity group are not required. It was demonstrated that the focus of attention needs to be much wider than a simple concentration on the own-price elasticity of demand for the commodity group for which a sumptuary tax is envisaged.

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