Partial versus General Equilibrium Calorie and Revenue Effects of a Sugar-Sweetened Beverage Tax

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JEL Classification: D11, D12, I18

Abstract

The current obesity crisis in the United States is generating numerous alternative policy options for combating the problem. One alternative that has been widely proposed is an excise or sales tax on sugar-sweetened non-alcoholic beverages. This literature started out within a very simple partial equilibrium framework. Not considering the feedback effects (or general equilibrium effects) across interrelated market is a shortcoming of these partial equilibrium analyses. Our study is carried out to ascertain stochastic partial and general equilibrium calorie, body weight and revenue effects of a tax on sugar-sweetened beverages as well as incidence of such tax. We used Nielsen Homescan data on prices and quantities of selected non-alcoholic beverages purchased over the period January 1998 through December 2008. Probability density functions (pdfs) generated using simulations of calorie outcomes reveal that the calorie reduction due to tax on sugar-sweetened beverages is between 465 and 716 calories per person per month. However, consideration of both direct and indirect effects in generating the effect of the tax on sugar-sweetened beverages reveal reduction as low as 199 calories per person per month and as high as707 calories per person per month.

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Background

The current obesity crisis in the United States is generating numerous alternative policy options for combating the problem. One alternative that has been widely proposed is an excise or sales tax on sugar-sweetened non-alcoholic beverages (see Jacobson and Brownell, 2000; Brownell *et al*., 2009; Chaloupka *et al.*, 2009; Smith *et al*., 2010; Zhen *et al.*, 2011; Dharmasena and Capps, 2011). This literature started out within a very simple partial equilibrium framework where only own-price effects were considered (Jacobson and Brownell, 2000, Brownell *et al*., 2009, and Chaloupka *et al.*, 2009). More recent partial equilibrium work has incorporated the role of cross-price effects as well (Smith *et al*., 2010; Zhen *et al.*, 2011; and Dharmasena and Capps, 2011). Consideration only of own-price effects vis-à-vis consideration of both own-price and cross-price effects resulted in overestimated calorie reductions and consequently reductions in body weight.

A shortcoming of these partial equilibrium analyses is that supply is assumed to be perfectly elastic in each market such that there are no feedback effects across the interrelated markets. An implication of this assumption is that the effects of the taxes are likely to be overstated. In addition, because supply has been implicitly assumed to be perfectly elastic there has been no need to consider the distribution of the tax between producers and consumers (*i.e.* the incidence of the tax) and there has been little consideration of the industry and tax revenue implications. Once supply is allowed to be less than perfectly elastic, then we would expect responses in the prices in the non-taxed markets, as the price in the taxed market changes and thus a total demand response, also known as the general equilibrium demand response (Buse, 1958; Thurman and Wohlgenant, 1989). The general equilibrium demand response takes into account not only own-price and cross-price effects but also feedback effects.

Objectives

Specific objectives of this study are: (1) to ascertain stochastic partial equilibrium calorie, body weight and revenue effects of a tax on sugar-sweetened beverages including the incidence of the tax; and (2) to ascertain stochastic general equilibrium calorie, body weight and revenue effects of a tax on sugar-sweetened beverages including incidence of the tax. Specific categories of non-alcoholic beverages considered are sugar-sweetened beverages (isotonics, regular soft drinks, and fruit drinks), diet soft drinks, high-fat milk (whole and 2% milk), low-fat milk (1% and skim milk), fruit juices, bottled water, coffee and tea.

Analytical Framework

The demand, supply, and tax system can be represented by the following differential system;

(1) $DQ_i = \sum_{j=1}^{n-1} \eta_{ij} DP_j + \eta_{nn} DP_n$ (demand system),

(2) $DQ_i = \epsilon_{ii} Dp_i$ (supply system),

(3) $DP_n = Dp_n + \lambda D\tau$ (taxed price relation) where $\lambda = \tau/(1+\tau)$, and

(4) $DP_i = Dp_i$ for $\forall i \neq n$ (non-taxed price relation),

where *n* is the taxed market, *(n-1)* is the non-taxed market, η_{ij} are own-price and cross-price demand elasticities, ϵ_{ii} is the own-price supply elasticity. We also assume the change in the tax rate to be exogeneously determined. Solving the aforementioned system gives rise to the reduced form price system as follows (in matrix terms),

(5) $\boldsymbol{DP} = \boldsymbol{A}^{-1}\boldsymbol{\eta}\lambda D\tau = \boldsymbol{\pi} D\tau$,

where $\boldsymbol{DP}$ is the *n* vector of differential price changes, $\boldsymbol{A}^{-1}$is the inverse of the reduced form relationship (nxn) matrix of demand and supply elasticities, $\boldsymbol{\eta}$ is the *n* vector of price elasticities with respect to the n^{th} price and $\boldsymbol{\pi}$ is the *n* vector of reduced form price transmission elasticities from the tax in the n^{th} market to all *n* prices. Consequently, the general equilibrium system of a tax effect on sugar-sweetened beverage consumption, calorie intake, and tax revenue can be written as follows:

(6) $DQ_i = \left[\sum_{j=1}^{n-1} \eta_{ij}\pi_{jn} + \eta_{in}(\pi_{nn} + \lambda)\right] D\tau$ (demand system);

(7) $DC = \sum_{i=1}^{n} \mu_i \left[\sum_{j=1}^{n-1} \eta_{ij}\pi_{jn} + \eta_{in}(\pi_{nn} + \lambda)\right] D\tau$ (Calorie equation)

where $\mu_i$is the calorie conversion parameter;

(8) $DR_n = \left[\pi_{nn} + \sum_{j=1}^{n-1} \eta_{ij}\pi_{jn} + \eta_{in}(\pi_{nn} + \lambda)\right] D\tau$ (tax revenue).

Utilizing this system of equations would allow us to delineate the general equilibrium calorie and revenue effects of an ad-valorem tax on sugar-sweetened beverages.

Data

Initially, monthly household purchases of nonalcoholic beverages (expenditure and quantity information) are generated for each household in the Nielsen HomeScan Panel data over the period January 1998 through December 2008. Next, the expenditure and quantity data are summed over all households for each month for each of the aforementioned nonalcoholic beverage categories. As such, we generate monthly purchase data to arrive at a total of 132 observations for each nonalcoholic beverage category. Quantity data are standardized in terms of gallons per person per month and expenditure data are expressed in terms of inflation-adjusted dollars. We generate unit values (real prices) for each non-alcoholic beverage category by taking the ratio of expenditure to volume. Calorie conversion factors are extracted for each non-alcoholic beverage category from Smith *et al.,* (2010).

Empirical Estimation

We employ the quadratic almost ideal demand system (QUAIDS) to estimate uncompensated own-price and cross-price demand elasticities. Also, we assume a range of supply elasticities to estimate the matrix $\boldsymbol{A}$, which then is used to estimate a range of price transmission elasticities for a given tax rate. Subsequently, we estimate the differential price change ***DP***. Once the ***DP*** is estimated, we used the relations $DP_j = \pi_{jn} D\tau$ and $DP_n = (\pi_{nn} + \lambda)D\tau$ to estimate the demand system, calorie equation and tax revenue capturing calorie and revenue effects of a tax in a general equilibrium setting. To account for elasticity uncertainty, we use a stochastic equilibrium displacement model (SEDM) (see Davis and Espinosa, 1998) and therefore to generate empirical distributions for the quantity, calorie, and revenue effects of the tax.

Stochastic Partial Equilibrium Displacement Model (SPEDM)

To generate SPEDM results, we first assume multivariate prior distributions for own-price and cross-price elasticity estimates obtained from the QUAIDS model. For the preliminary analysis, we assumed truncated multivariate normal distribution for own-price elasticities bounded from above with a zero. Cross-price elasticities are assumed to be distributed multivariate normal. In contrast to Davis and Espinoza (1998), who assumed all elasticity estimates were independent, we incorporate the fact that the estimates from our demand system will be correlated. We generate correlated standard normal deviate to simulate the elasticity estimates assuming the prior distribution. Such correlated standard normal deviates and subsequent simulations are obtained using SIMETAR® software. Once we obtain stochastic elasticity estimates, we can generate stochastic calorie, body weight and revenue effects of a tax on sugar-sweetened beverages.

Stochastic General Equilibrium Displacement Model (SGEDM)

To generate the SGEDM, first we assume multivariate prior distributions for own-price, cross-price demand elasticities generated from QUAIDS model and a range of supply elasticities assumed based on literature. For the preliminary analysis, we assumed truncated multivariate normal distribution for own-price elasticities bounded from above with a zero. Cross-price demand elasticities are assumed to be distributed multivariate normal. Supply elasticities are assumed to be distributed truncated multivariate normal bonded below from zero.

Using aforementioned prior distributions, we are in position to calculate stochastic reduced form relationship (nxn) matrix of demand and supply elasticities depicted by $\boldsymbol{A}^{-1}$. Then we obtain the *n* vector of stochastic reduced from price transmission elasticities from the tax in the n^{th} market to all *n* prices shown by $\boldsymbol{\pi}$. Consequently, we are in position to solve for the general equilibrium tax effect on sugar-sweetened beverage consumption, calorie intake, and tax revenue.

Results and Discussion

Our study is the first in the literature to address the effects of a sugar-sweetened beverage tax in a general equilibrium setting taking the incidence of the tax into account. We would expect general equilibrium effects to be smaller than partial equilibrium effects. Also, since we are using a stochastic equilibrium displacement model approach, we are in a position to derive an empirical distribution for the change in calorie intake, weight outcomes as well as for changes in revenue.

Stochastic Partial Equilibrium Calorie Outcomes

Probability density functions (pdfs) generated using simulations of calorie outcomes reveal that the average reductions in calories considering only the direct effects (only taking into account the own-price elasticities of demand) are 586 calories. The 95% upper and lower quantile value for this estimate are 716 and 465 calories respectively. However, consideration of both own-price and cross-price elasticities (both direct and indirect effects) in generating the effect of the tax on sugar-sweetened beverages reveal considerably different values for mean and upper and lower quantiles. They are 450, 707 and 199 calories respectively. Looking at the mean values for both direct and indirect effects reveal that calorie outcomes are over estimated if only direct effect of tax is considered vis-à-vis both direct and indirect effects. It is interesting to note that the upper quantile values are almost the same for both effects, however the lower quantile varies notably.

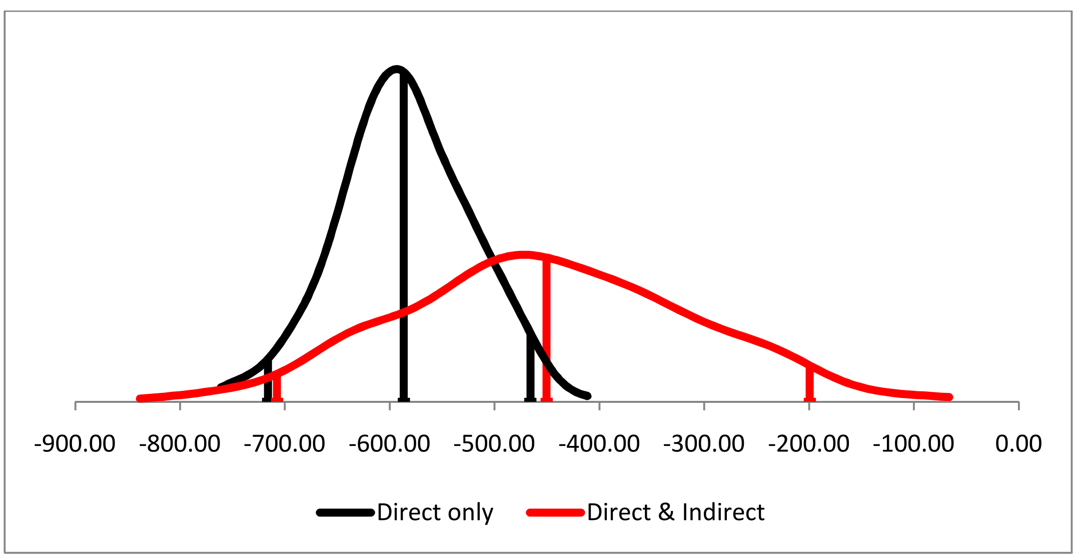

Figure 1: PDF Approximations of Calorie Effects of a Sugar-Sweetened Beverage Tax

Stochastic Partial Equilibrium Weight Outcomes

Probability density functions (pdfs) generated using simulations for weight outcomes reveal that the average reduction in body weight considering the direct effects is 2.01 pounds per person per year. The 95% upper and lower quantile value for this estimate are 2.4 and 1.6 pounds respectively. However, consideration of both direct and indirect effects in generating the effect of the tax on sugar-sweetened beverages reveal considerably different values for mean and upper and lower quantiles. They are 1.5, 2.6 and 0.7 pounds per person per year respectively. Looking at the mean values for both direct and indirect effects reveal that weight outcomes are over estimated if only direct effect of tax is considered vis-à-vis both direct and indirect effects. It is interesting to note that the upper quantile values are almost the same for both effects, however the lower quantile varies considerably.

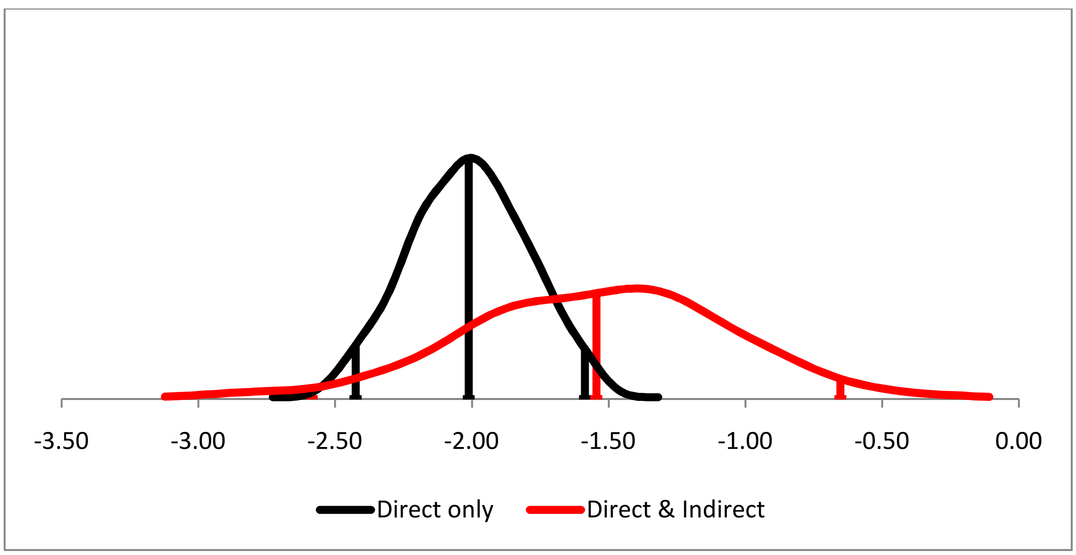

Figure 1: PDF Approximations of Weight Effects of a Sugar-Sweetened Beverage Tax

Conclusions

Probability density functions (pdfs) generated using simulations of calorie outcomes reveal that the calorie reduction due to tax on sugar-sweetened beverages is between 465 and 716 calories per person per month. However, consideration of both direct and indirect effects in generating the effect of the tax on sugar-sweetened beverages reveal reduction as low as 199 calories per person per month and as high as707 calories per person per month. Probability density functions (pdfs) generated using simulations for weight outcomes reveal that the reduction in body weight considering the direct effects is in between 2.4 and 1.6 pounds per person per year respectively. This result when considering both direct and indirect effect is in between 2.6 and 0.7 pounds per person per year.

It is interesting to note that the upper bound is almost the same for both effects, however the lower bounds vary considerably. Similar analysis will be done for SGEDM and stochastic calorie, weight and revenue outcomes will be generated.

References

Brownell, Kelly D., T. Farley, W.C. Willett, B.M. Popkin, F.J.Chaloupka, J.W. Thompson, D.S. Ludwig. 2009. "The Public Health and Economic Benefits of Taxing Sugar-Sweetened Beverages", *The New England Journal of Medicine*, Health Policy Report, 1-7.

Buse, R. C., (1958) "Total Elasticities. A Predictive Device." *Journal of Farm Economics,* 40(4):881-891

Chaloupka, F.J., L.M. Powell, and J.F. Chriqui. 2009. " Sugar Sweetened Beverage Taxes and Public Health", research brief, Robert Wood Johnson Foundation and School of Public Health, University of Minnasota

Davis, G.C., and M.C. Espinoza. (1998) "A Unified Approach to Sensitivity Analysis in Equilibrium Displacement Models." *American Journal of Agricultural Economics* 80(4):868-879

Dharmasena, S., O.Capps, Jr. (2011) "Intended and Unintended Consequences of a Proposed National Tax on Sugar-Sweetened Beverages to Combat the U.S. Obesity Problem." forthcoming *Health Economics*

Jacobson, M.F., and K.D. Brownell. 2000. "Small Taxes on Soft Drinks and Snack Foods to Promote Health", *American Journal of Public Health,* 90(6):854-857.

Smith, T.A., B-H Lin, and J-Y Lee. 2010. "Taxing Caloric Sweetened Beverages: Potential Effects on Beverage Consumption, Calorie Intake and Obesity" ERR-100, U.S. Department of Agriculture, Economic Research Service.

Thurman, W.N., and M.K. Wohlgenant. (1989) “Consistent Estimation of General Equilibrium Welfare Effects.” *American Journal of Agricultural Economics* 71(4):1041-1045

Zhen C, Wohlgenant MK, Karns S, Kaufman P. (2011) Habit formation and demand for sugar-sweetened beverages. American Journal of Agricultural Economics 93(1): 175–193.