Modeling the Impact of Tobacco, Alcohol, and Sugary Beverage Tax Increases on Health and Revenue

Analysis conducted for the Task Force on Fiscal Policy for Health

By Amit Summan and Ramanan Laxminarayan, Center for Disease Dynamics, Economics & Policy

I. Overview

The Task Force on Fiscal Policy for Health commissioned an analysis of the potential impact on health and revenues over a 50-year time horizon if all countries raised excise taxes on tobacco, alcohol and sugary beverages from existing levels to levels sufficient to increase market prices in a range from 20 to 50 percent in 2017 and continuing into the future.

Using mathematical models that incorporated country-level epidemiological, demographic, and consumption data, we estimated the global health and economic effects of tobacco, alcohol, and sugar-sweetened beverage (SSB) taxation.[1] Model outputs included premature deaths averted and increases in tax revenue. Outcomes were aggregated and presented by World Bank country income group classifications: low income (LIC), lower-middle income (LMIC), upper-middle income (UMIC), and high income (HIC). The time horizon for the model was 50 years, with 2017 as the baseline year.

II. Health outcomes

In the baseline scenario, future consumption per capita for each commodity for each country was estimated using published consumption projections; from Euromonitor (Euromonitor International 2018) for SSBs, and from WHO for alcohol (WHO 2016) and tobacco (WHO 2015). Projections were not available for all countries. Therefore, an average trend was calculated for each income group category and was applied to countries that were missing a trend. For SSBs, consumption trend projections were not available for any LICs. Hence, we used we used the estimated LMIC trend for LIC in our modeling. These trends, which were available for between five and fifteen years, were used to estimate a baseline consumption trajectory. We assumed that trends were flat from year 15 through to year 50.

We simulated the health effects of the intervention using a standard, abridged baseline life table and estimated an intervention life table with modified mortality rates. Five-year age intervals were used from ages 15 to 79, with the last age category consisting of individuals 80 years and older. Following other modeling literature (Verguet et al. 2015), we assumed that cohorts born after 2017 were the same size as the current 0 to 5-year-old cohort. Health effects were estimated for populations above the age of 30 according to the data availability of mortality rates and risks for consumption of the commodities modeled. See Tables 1 and 2 for parameters values and sources.

[1] Sensitivity analysis was conducted using the Latin hypercube sampling method on all estimates by drawing independent samples of key parameters of elasticity and relative risk (RR), varied between 20% above and below their mean value using a uniform distribution for SSBs, alcohol, and tobacco, respectively, for 1,000 iterations.

III. Economic Outcomes

We estimated changes in tax revenue for each country over a 50-year period. Consumption levels and patterns (prevalence) were calculated at the beginning of each 5-year sub-period and assumed to hold for the entire sub-period. All results are in 2016 USD, and converted from local currencies at current exchange rates.[2] Future estimates of revenues were discounted at a constant rate of 3%.

The next sections discuss the methodological approaches specific to the modeling of taxation of individual commodities.

IV. Tobacco Taxation

The price change induced by a tax increase was assumed to reduce demand for cigarettes at both the extensive margin (number of smokers) and the intensive margin (number of cigarettes smoked by each smoker). In the model, the number of current smokers decreased in response to a tax increase due to decreased initiation and increased cessation, increasing both the number of former and never smokers. The health effects in our model were attributable to changes in smoking status and not to changes in the intensity of smoking.

Following others, we built on a commonly-used multistate life table modeling approach where we estimated separate life tables for smokers, nonsmokers (never-smokers), and current former smokers (former smokers before the intervention) under a baseline scenario, and intervention life tables for nonsmokers, current smokers, current former smokers, and intervention former smokers (smokers who quit because of the intervention) (Blakely et al. 2015; Mamun 2004; Ozasa et al. 2008). Successive age-sex-country cohorts were fed into the life table structure, and the number of deaths and years of life lived were calculated in the baseline and the intervention scenario over a 50-year period.

To account for the benefits of smoking cessation, we used relative risk estimates for former smokers from Doll and Peto's British Doctors Study (2004). Their study of the long term effects of smoking on mortality found that smoking cessation by age 30 helped avoid almost all of the excess risk of smoking on average, and lifelong smokers lost approximately 10 years of healthy life compared with lifelong nonsmokers.

V. Alcohol Taxation

Following previous alcohol modeling (Brennan et al. 2015), we modelled changes in the price of alcohol resulting from increased taxation to affect drinking intensity. We considered three beverage categories: spirits, wine, and beer. We did not model substitution across beverages because of the lack of consistent evidence on cross-price elasticities across countries. Instead, we simulated tax increases on each beverage that would lead to a uniform price increase across all three beverage categories.

To estimate the health effects of a tax increase on alcohol, we used a similar approach to the tobacco model, constructing separate life tables for drinkers and abstainers. We accounted for the time lag between reduced alcohol consumption and the reduced risk of chronic alcohol-related diseases using estimates from Holmes et al. (2012).

[2] For a description on the construction of life tables, see United Nations (2009) or Gardner and Stewart (1966).

VI. Sugar-Sweetened Beverage Taxation

To model SSB taxation, we adopted an energy-balance approach to simulating shifts in body mass index (BMI) distribution associated with changes in beverage intake (Cabrera Escobar et al. 2013; Manyema et al. 2014; Stacey et al. 2018). A previously estimated factor converting average energy imbalance to change in average body weight, 94kJ/kg, was used to simulate a change in average BMI for each age-sex group (Hall et al. 2011). Data from the Global Burden of Disease study on the prevalence of obesity (BMI>30 kg/m2) and overweight (BMI>25 kg/m2) was used for all of the countries under consideration to construct baseline log-normal BMI distributions. We then re-simulated BMI distributions accounting for bodyweight changes arising from underlying country-specific trends (Alexandratos and Bruinsma 2012) in energy intakes as well as changes in energy intake that may result from the tax.[3]

To translate changes in age-gender BMI distributions into changes in age-gender mortality rates we calculated a potential impact fraction (PIF) which measures the proportional change in risk due to changing risk factor distribution, and used it to scale the prevailing mortality risk in the baseline life table to construct an intervention life table. Similar to the tobacco and alcohol models, for the SSB model we applied the overall relationship found between all-cause mortality and exposure (BMI[4]) to model health effects. We assumed the full benefits of reduced SSB consumption accrued starting 5 years after the tax was implemented. This corresponds to the time it takes for an individual to reach a new equilibrium weight after reducing calories because of the intervention.

We did not consider substitution to alternative beverages because of lack of data on cross-price elasticities, but used a 50% offset factor[5] to account for substitution. The use of a 50% offset factor consistent with the levels of substitution used in other SSB tax modeling (Sánchez-Romero et al. 2016; Wang et al. 2012), where a roughly 40% offset factor has been used.

VII. Estimating Global Effects

To estimate global health effects, we calculated the total health effects per 100,000 individuals by each income group, using the four World Bank country income group classifications (WHO 2018). We then matched countries not covered in our sample by income level to these estimates and imputed the in-sample, weighted health effects to these countries. Parameter and input data were available for countries across all three commodities for estimating health effects: tobacco data was available for countries comprising 92% of the global population; alcohol data, 97%; and SSBs, 95%. To estimate global economic effects, we first matched countries by exposure level (tertiles of smoking prevalence for tobacco, daily alcohol consumption for alcohol, and daily SSB consumption for SSB), region, and income, and imputed in-sample average missing economic parameter data (price and tax) for countries that were missing these data, but had underlying consumption pattern data, and simulated economic effects for these countries. For countries missing both economic and consumption data, we imputed the population-weighted average economic effects calculated at the country's income level. Tobacco, alcohol, and SSB economic parameter data were available for countries representing 82%, 43%, and 83% of the global population, respectively. For SSBs and tobacco we did not have data for countries representing the 9% of the global population in the low-income country group for economic outcome estimates; therefore, for extrapolation to the low-income group, we used lower-middle income country estimates.[6]

[3] Individuals with a BMI of less than 24 are assumed to fully offset the decrease in SSB consumption due to the tax.
[4] BMI-related diseases include: stroke, ischemic heart disease, hypertensive heart disease, diabetes mellitus, osteoarthritis, postmenopausal breast cancer, colon cancer, endometrial cancer, and kidney cancer (Veerman et al. 2016).
[5] A 50% offset factor means that half the reduced consumption of SSB is being replaced by calories from other beverages or foods.
[6] We also estimated effects for low-income countries using estimates from countries in the lower-middle-income group that represent the bottom 50% of income; we found no significant difference in estimates.

VIII. Limitations

Our analysis has certain limitations, common to studies that model long-term effects. First, our results potentially underestimate the effects of tax increases because: 1) we do not account for morbidity effects, 2) we do not account for externality effects of consumption, such as second-hand smoke or drunk driving deaths, and 3) for the SSB model, we focus only on BMI-related mortality and do not include the direct effect of SSB consumption on diabetes or other non-BMI mediated outcomes, only the indirect effect that occurs through changing BMI.

Second, our parameters on the relative risk of mortality represent an average for all age groups and are not age- or sex-specific for alcohol and tobacco. However, the literature from which we derived our parameters includes these age groups and both sexes in the samples, and adjusts estimates for age and sex.

Third, as with all modelling studies, our simulations were dependent on the parameters used in our analysis. These are the best available estimates from the most recent scientific studies, but identify past relationships between variables estimated over time periods that may not apply going forward due to other secular changes in lifestyle and environmental factors. Large increases in the consumption of sugar-sweetened beverages are a relatively recent worldwide phenomenon; as a consequence, evidence on the health harms of SSBs continues to emerge in contrast to a more established base of international studies of the effects of tobacco and alcohol use.

Further, our consumption data for many interventions were based on household and individual surveys, which may not capture true consumption patterns, given recall bias and underreporting. A related issue is the difficulty of doing very large cross-country analyses. Where possible we have employed country-specific data, including population distribution, mortality, and consumption.

We have used a time horizon of 50 years since many of the health consequences of current tax policies are not observable for decades. Although a 50 year period or similar simulation periods are frequently used in the modeling of non-communicable diseases (Jha, Joseph, and Li 2012; Verguet et al. 2015), there are challenges in assuming static preferences in demand over a long time horizon as well as in predicting changes in other important exogenous factors.

Finally, we have not incorporated substitution effects (between cigarettes and rustic tobacco including bidis in the case of tobacco; between beers, wines, hard liquor and country liquor in the case of alcohol; and between SSBs and other beverages or food). The data needed to support a model of these substitution effects are lacking. For alcohol we increased prices by the same level across all three beverage categories. The SSB model used an offset factor, where 50% of the reduced SSB calories are offset by other calories.

For the most part, the limitations listed above will likely bias results towards finding smaller health impacts of a given tax increase.

Tables and Figures

Table 1: Parameters

Variable		Data source	Value
Tobacco			
Own-price elasticity	Cigarettes: LIC, LMIC, UMIC	Authors' assumptions based on IARC (2011)	−0.5
	Cigarettes: HIC		−0.4
Relative risk of all-cause mortality	Cigarette smoker	Authors' assumptions based on multiple sources (See Table 3)	2.2
	Former smoker	Authors' assumption based on Doll et al. (2004)	See Table 4
Alcohol			
Own-price elasticity	Alcohol: LIC, LMIC, UMIC	Authors' assumption based on Sornpaisarn et al. (2017)	−0.65
Relative risk of all-cause mortality	Daily consumption of grams of pure alcohol	Authors' estimates based on Griswold et al. (2018)	See Figure 1
Sugar-sweetened beverages			
Own-price elasticity	Sugar-sweetened beverages	Authors' estimates based on Cabrera Escobar et al. (2013)	−1.2
Relative risk of all-cause mortality	Body mass index	Authors' estimates based on Aune et al. (2016)	See Figure 2

LIC = low-income countries; LMIC = lower-middle-income countries; UMIC = upper-middle-income countries; HIC = high-income countries

Table 2: Input Sources

Input	Source	Year data collected	Link
Baseline mortality rates	Global Burden of Disease	2016	http://ghdx.healthdata.org/gbd-2016/data-input-sources
Population	UN World Population Prospects	2017	https://esa.un.org/unpd/wpp/
Income groups	World Bank	2016	https://blogs.worldbank.org/opendata/new-country-classifications-2016
Tobacco			
Prices	WHO	2016, 2017	http://www.who.int/tobacco/global_report/en/ http://www.euromonitor.com/
Tax rates		2016	http://www.who.int/tobacco/global_report/en/
Smoking prevalence and trends	WHO	2015–2025	http://apps.who.int/iris/bitstream/handle/10665/156262/9789241564922_eng.pdf?sequence=1
Smoking death rates	Global Burden of Disease	2016	http://ghdx.healthdata.org/gbd-2016/data-input-sources
Cigarette consumption	Euromonitor	2017	http://www.euromonitor.com/
Alcohol			
Prices	WHO; Euromonitor; OECD	2012–2017	http://www.who.int/gho/en/ http://www.euromonitor.com/ http://www.oecd.org/ctp/consumption/consumption-tax-trends-19990979.htm
Tax rates		2008–2017	
Drinking prevalence and trends	WHO	2016	http://www.who.int/gho/en/
Grams of pure alcohol consumption	WHO		
Alcohol death rates	Global Burden of Disease	2016	http://ghdx.healthdata.org/gbd-2016/data-input-sources
Sugar-sweetened beverages			
Prices	Blecher et al.; Euromonitor	2017	https://www.cdc.gov/pcd/issues/2017/16_0406a.htm#1
Consumption	Global Burden of Disease	2010	http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124845#sec024
Overweight and obese prevalence	Global Burden of Disease	2013	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4624264/
Height	NCD Risk Factor Collaboration	2016	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4961475/
Calorie consumption trends	UN FAO	2015– 2050	http://www.fao.org/fileadmin/templates/esa/Global_persepctives/world_ag_2030_50_2012_rev.pdf

Table 3: Tobacco smoking and all-cause mortality

Country	All-cause mortality (reference: never smokers)	Smoking habit	Sex	Age	Source
China	1.26	current smoker and former smoker, >30 pack years	Male	40+	Gu et al. (2009)
	1.38		Female	40+	
	2.42	current smoker	Male	35+	Lam (1997)
	2.32		Female	35+	
United States	2.8	current smoker	Male	55+	Thun et al. (2013)
	2.76		Female	55+	
	1.47	former smoker	Male	55+	
	1.45		Female	55+	
	1.18	current smoker, early smoking initiation before age 13 years	Both	30+	Choi and Stommel (2017)
	1.19	former smoker, early smoking initiation before age 13 years	Both	30+	
	1.94	current smoker, 1-14 cigarettes /day	Female	34+	Dam et al. (2008)
	2.32	current smoker, >15 cigarettes /day			
	1.52	former smoker			
	2.81	current smoker	Female	-	Kenfield (2008)
Meta-Analysis (cross country)	1.83	current smoker	Both	60+	Gellert, Schöttker, and Brenner (2012)
	1.34	former smoker		60+	
	1.3	current smoker, 1-9 cigarettes/ day	Male	40+	Jacobs (1999)
	1.8	current smoker, > 10 cigarettes/day			

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