The economic burden of excessive sugar intake and the impact of sugar taxes in Canada

by

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Abstract

Consumption of sugars is associated with obesity and various chronic diseases (CD). Excessive sugar consumption leads to economic burdens in terms of health care costs for treatment and management of CDs and costs associated with lost productivity and premature mortality. With increasing concerns about the health and economic consequences of excess sugar consumption, the sugar tax is increasingly considered a population-level policy to curb sugar consumption. Currently, Canada has not yet implemented sugar taxes and other alternative population-level interventions. There is little information about the economic burden of excessive sugar consumption and the impact of the sugar tax in Canada. Thus, this thesis aims to: 1) estimate the consumption and dietary sources of added, free and total sugars in Canada, 2) quantify the economic burden that could be avoided if Canadians comply with existing free sugar consumption recommendations, 3) systematically review and analyze evidence regarding the cost-effectiveness of taxation of sugary foods and beverages, 4) build a model to estimate the potential health and economic impact of sugar-sweetened beverage (SSB) tax in Canada, and 5) estimate the cost-effectiveness of different taxation and subsidy scenarios in Canada.

This thesis consists of five interconnected studies. The first study calculated added, free, and total sugar content of all foods consumed by Canadians using the established nutrient calculation procedures and the 2015 Canadian Community Health Survey–Nutrition dataset. This study reveals that most Canadians consumed more added and free sugars than recommended (less than 5% or 10% of total energy intake). The second study quantified the economic burdens of

excessive free sugar intake using the population attributable fraction method. The findings show that if Canadians were to comply with the free sugar recommendation, an estimated CAD$2.5-5.0 billion in direct health care and indirect costs could have been avoided in 2019. The third study systematically reviewed fifteen sugar tax economic evaluations from six countries. All these studies revealed that the sugar tax is a cost-effective intervention to improve health-related quality of life, save health care costs, and gain tax revenue. In the fourth study, we designed a proportional multi-state life table-based Markov model to simulate the SSB tax in Canada. Compared with the previous studies, the simulation model included more CDs and considered substitute effects of all untaxed products. The fifth study estimated the cost-effectiveness of different sugar taxes and vegetables and fruit (V&F) subsidy scenarios in Canada using the established model built in the fourth study. The results show that all simulated taxes and subsidies were cost-effective, and the combination of taxes and subsidies could maximize health benefits and compensate for the sugar tax burden.

Overall, this thesis fills the research gaps about the sugar content of foods and beverages as well as excessive sugar consumption and its consequent health and economic burden in Canada. It calls the public, researchers, and policymakers' attention to excessive free sugar consumption and potential interventions. This thesis provides profound evidence regarding the impact and cost-effectiveness of different taxes and subsidy scenarios for researchers and policymakers. The findings support the implementation of a policy package that includes sugar taxes and V&F subsidies to maximize health benefits and improve inequity.

Preface

This thesis is the original work of Siyuan Liu with the supervision of Prof. Arto Ohinmaa and Prof. Paul J. Veugelers, conducted at the School of Public Health of the University of Alberta. This thesis received ethical approval (Pro00073295) from the University of Alberta Health Research Ethics Board. This research was funded through an operating grant by the Canadian Institutes of Health Research (grant number 384559) to Paul J. Veugelers. Chapters 5 and 6 were also supported by funds from the Network of Alberta Health Economists.

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Chapter 5 and 6 of this thesis are ready to be submitted for publication. I was responsible for literature review, simulation model design, data analysis, interpretations of the results and preparation of the first draft of the manuscript. Katerina Maximova critically reviewed the manuscript and provided valuable comments. Prof. Arto Ohinmaa and Prof. Paul Veugelers contributed to model concept formation, model design, interpretation of results, and manuscript writing.

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List of Abbreviations

BMI	Body Mass Index
CADTH	Canadian Agency for Drugs and Technologies in Health
CCHS	Canadian Community Health Survey
CD	Chronic Disease
CHEERS	Consolidated Health Economic Evaluation Reporting Standards
CKD	Chronic Kidney Disease
CVD	Cardiovascular Disease
EBIC	Economic Burden of Illness in Canada
GBD	Global Burden of Disease
HRQoL	Health-Related Quality of Life
ICER	Incremental Cost-Effectiveness Ratio
NCI	National Cancer Institute
PAF	Population Attributable Fractions
PIF	Potential Impact Fraction
pYLD	Prevalence Years Lived with Disability
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RR	Relative Risk
SSB	Sugar-Sweetened Beverage
DM2	Diabetes Mellitus type 2
TEI	Total Energy Intake
USDA	the United State Department of Agriculture
V&F	Vegetables and Fruit
WHO	World Health Organization

Chapter 1. General Introduction

1.1 Research background

1.1.1 Chronic diseases prevention and sugar

Chronic diseases (CD) are a leading cause of death worldwide. In addition to a high death toll, CDs, including cardiovascular disease (CVD), heart disease, stroke, cancer, chronic respiratory diseases, and diabetes, account for approximately half of the global disease burden [1]. In Canada, 89% of all deaths [2] and more than CAD$93 billion annual health care costs were attributable to CDs [3]. The prevalence of CDs would continue to rise in both developed and developing countries [4]. Many CDs are related to overweight and obesity. In 2016, 1.9 billion adults and 340 million children and adolescents in the world were overweight or obese [5]. The prevalence of overweight and obesity in Canada is currently among the highest in the world [5, 6]: more than one-third of Canadian adults and almost one in five Canadian children and youth are overweight or obese [7, 8].

The high obesity rate and consequent disease burden call for strategies to reduce obesity and related CDs. Adopting healthy lifestyles that include healthy eating, active living, tobacco abstinence, and responsible alcohol consumption is a practical strategy to prevent CDs. Up to 80% of diabetes mellitus type 2 (DM2) and CVD, and 40% of cancers could be prevented by adopting healthy lifestyles [2, 9]. A healthy diet is the leading modifiable factor of CDs among the aforementioned-health behaviors [2]. Despite a series of healthy eating recommendations that have been issued in Canada to improve health and reduce CDs [10, 11], the majority of Canadian residents do not meet these recommendations [12, 13]. Unhealthy eating was estimated to result in CAD$15.8 billion in direct health care and indirect costs per year [14].

There are many dietary risk factors that contribute to the health and economic burden of unhealthy eating. These risk factors include a diet low in vegetables, fruits, legumes, whole grains, nuts and seeds, and milk, and high in sugar sweetened beverages (SSBs), processed meat, and red meat [4, 15]. Among these dietary factors, a diet high in added and free sugar has been the primary focus in the prevention of obesity and related CDs in the past decade. Free sugars are defined by the World Health Organization (WHO) as: "all monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and fruit juice" [16]. Added sugars are refined sugars added during cooking or manufacturing, excluding naturally occurring sugars in fruit juice [17, 18]. Unlike some nutritious foods (e.g., fruits and milk) that contain naturally occurring sugars that could bring significant health benefits [19], foods with high added and free sugars result in negative health effects. Since added and free sugars contribute to the overall energy composition of the diet, excess sugar intake may lead to a positive energy balance, weight gain, and chronic disease risk increment. In addition, the consumption of excessive sugary products might displace the consumption of nutritious foods and result in nutritionally poorer diets [20].

1.1.2 Consumption of added and free sugars

Many countries have documented added and free sugar consumption [21, 22]. For example, American adults consumed 13% of total energy intake (TEI) from added sugars in 2010 [21], and children in Greece were estimated to obtain 11% of their TEI from free sugars in 2009 [22]. Two studies have quantified added and free sugar intake in Canada; however, their estimations did not consider all food sources of added and free sugar [23, 24]. Before our study, added and free sugar consumption from all food and beverages was not available for Canada. One reason for this gap is that the added and free sugar content of all foods and beverages consumed by Canadians has not been documented. The accurate assessment of added and free sugar content is challenged by the difficulty of differentiating between naturally occurring sugars and sugars added to foods during manufacturing.

The recommended consumption of free sugars from the WHO and Health Canada is less than 10% of the daily TEI, and ideally less than 5% of TEI [16]. Dietary Guidelines for Americans 2015-2020 released by the United States Department of Agriculture (USDA) recommended consuming less than 10% of TEI from added sugars [17]. Some studies have reported compliance with these sugar consumption recommendations [22, 25]. For example, Louie et al. showed that 19% of Dutch residents met the free sugar consumption recommendation (<10% of TEI) [22]. Research from Australia has indicated that 18% of children and adolescents met the added sugar consumption recommendation [25].

The consumption of foods and beverages with added and free sugar is not distributed equally across socio-demographic groups. Research has shown that children and adolescents consume more SSBs than adults in the US [26]. The average consumption of SSBs for males was higher than females in Canada [27]. Additionally, some studies have examined the differences in SSBs consumption among different income subgroups. The studies in the US and France showed higher SSBs consumption in low-income groups [27, 28], and less educated parents and their adolescent children consume more SSBs [26, 27].

1.1.3 Health and economic impact of consumption of sugary foods and beverages

Consumption of foods and beverages with added and free sugars contributes to obesity and related CDs. Considerable evidence has shown the association between the consumption of high added and free sugar products (e.g., SSBs) and weight gain [20, 29, 30]. The SSBs consumption has been estimated to increase the risks of diseases, including high blood lipid levels, visceral adiposity, fatty liver disease, insulin resistance, DM2, CVD, metabolic syndrome, and dental caries [31-37].

The disease risks attributed to the consumption of sugary foods and beverages results in substantial health burdens. Singh et al. [24] have found that consumption of SSBs was related to 184,000 deaths and 8.5 million disability-adjusted life years (DALYs) worldwide in 2010. In Canada, they estimated that consumption of SSBs contributed to 1,598 deaths and 45,474 DALYs [24]. Jones et al. [38] projected the attributable health burden of sugary drinks consumption (including 100% fruit juice) in Canada. Sugary drinks would be responsible for 4.1

million cases of overweight or obesity, 900,000 new cases of DM2, 300,000 new cases of ischemic heart disease, 100,000 new cases of cancer, 40,000 strokes, 63,000 deaths and almost 2.2 million DALYs from 2015 to 2040.

In addition to the health burden, the consumption of sugary foods and beverages leads to a significant economic burden. The global financial burden associated with sugar-related dental diseases was US$172 billion (equal to CAD$167 billion) [39]. Costs from diseases and death attributed to excessive consumption of SSBs were estimated at KRW$ 633 billion (equivalent to CAD$0.7 billion) in 2015 in Korea [40]. In Canada, health care costs due to the consumption of sugary drinks are estimated at CAD$50.7 billion from 2015 to 2040 [38]. Lieffers et al. [41] and Loewen et al. [15] have estimated the annual costs of not meeting the recommendation for SSBs in Canada were CAD$863 million and CAD$ 830 million, respectively.

1.1.4 Interventions to reduce sugar consumption

With increasing evidence supporting the negative health consequence and economic burden attributed to excess sugar consumption, a series of population-level policies have been put forward to curb sugar consumption [42-47]. Some of the available policies focus strictly on overall sugar intake. The others function as a means to reduce sugar intake while promoting other healthy eating behaviors (e.g., V&F subsidies). Compared with isolated initiatives, a combination of well-crafted, mutually supportive policies has been shown to result in larger health benefits [47].

Taxation of sugary foods and beverages is an example of interventions to reduce added and free sugar intake that has received substantial attention in recent years. Sugar taxes reduce sugar consumption by raising the price of sugary products and changing consumer behaviors. More than 40 countries (e.g., Mexico, Denmark and South Africa) have implemented a tax on SSBs or other sugary products [48-52]. Evidence from these countries shows that sugar taxes could effectively reduce SSBs consumption. For example, after implementing a 1 peso per liter excise tax on SSBs in Mexico, purchases of taxed beverages decreased 7.5% per year on average in the first two years [53]. Similarly, the consumption of SSBs decreased by 21% in four months after a US$0.01 per ounce SSBs tax was implemented in Berkley, California [51].

Some interventions focus on increasing consumer awareness and altering consumer perception of foods, for example, public awareness education initiatives, product labelling policies, and dietetic counselling of people at higher risk. School-based health programs can reduce sugar consumption by increasing population knowledge about the negative health impacts of sugar intake. The food and nutrition policy for Nova Scotia public schools introduced in 2006 has significantly decreased SSBs consumption by students [54]. Furthermore, nutrition labelling has also emerged as a prominent policy tool for promoting healthy eating as it provides consumers with information to make healthier food choices [44, 47]. The European Union, Australia and New Zealand have applied simple logos in the front of the package that indicates the content of added sugars [55], which have resulted in a significant decrease in added sugar consumption [56].

Several other policies reduce sugar consumption by changing the accessibility of sugary products. These policies include restricting advertising of sugary products, limiting the availability of sugary products, and offering healthier options instead in public areas (e.g., parks and recreation facilities), workplaces, schools, health care facilities (e.g., hospitals, nursing homes), and government buildings [44, 45, 47]. Additionally, some interventions could reduce sugar consumption by changing the sugar supply chain and decreasing the use of sugar in manufactured foods and drinks. These sugar reduction strategies include legislation limiting the use of free sugar across the food supply chain and industry incentives for product reformulation [57].

Compared with other sugar-reducing strategies, taxation strategy has been observed to be a more cost-effective and feasible priority intervention. Taxation could effectively reduce sugar consumption, improve the health-related quality of life (HRQoL), save health care costs, and generate tax revenues [58-62]. Given that financial and human resources are not unlimited in public health, low cost and high benefits intervention could save more resources to improve other crucial problems in public health. The sugar tax also has a relatively larger impact on population health in the long term compared with other interventions. Unlike some other interventions conducted in a short period and only aimed at specific groups, the sugar tax is usually implemented in a long period and targets the whole population in a country or jurisdiction.

Despite the sugar tax having many advantages, sugar tax has some disadvantages and faces a series of critiques. First, decision-makers hesitate to implement the sugar taxes because the sugar tax is financially regressive and might expand the income inequity [57]. Research has indicated that although lower socioeconomic groups gain greater health benefits from the sugar tax, they would bear more tax burdens than relatively higher socioeconomic groups [63]. Similar to the tobacco tax, the sugar tax might increase inequity and worsen the food insecurity of disadvantaged groups [64]. Furthermore, the sugar tax would damage the interest of some stakeholders (e.g., manufacturers of sugary products, retailers, and taxpayers) and increase conflicts between the government and stakeholders. While the sugar tax could generate tax revenue to support the government initiate more health promotion interventions, the potential tax burden and industry profits damage lead to the resistance by thesis stakeholders [57]. The citizens satisfaction in the government or party might also be decreased due to political opposition to paternalistic policies [46, 47].

Moreover, the compulsory and cross-sectoral natures of the sugar tax challenge the implementation of the sugar tax and increase the intervention costs for the government [65]. Unlike some other policies (e.g., school-based health education programs) that could actively change people's consumption behaviors by improving health awareness, the sugar tax passively changes people's food choices by changing the price of products. The design and implementation of the sugar tax need the cooperation of health and economic sectors; however, the sugar tax might not be the priority for economic sectors because of different performance indicators [65].

Thus, administrative incompatibilities of different sectors can prolong the decision-making process and increase communication and time costs of sugar tax [46, 47].

Because of the above-mentioned disadvantages and barriers of the sugar tax, it may take long before many countries implement a sugar tax. Except for discouraging excess consumption of free sugars in the Canada Food Guide [10, 11], Canada has yet to adopt any population-level policy interventions specifically aiming at reducing the intake of sugars. There are multiple options of sugar taxation, such as SSBs tax, tax on all sugary foods and beverages, and the combination of sugar taxes and other diet-related interventions (e.g., salt tax, fat tax, V&F subsidy). Based on the experience from countries that have implemented sugar taxes, the SBBs tax is the most popular choice because it is relatively easy to implement [46, 51, 53]. Some countries, such as Finland and Norway have implemented the tax on other sugary foods because it could generate more revenue and increase potential impacts on health and dietary patterns [46, 49]. The combination of taxes on unhealthy foods and subsidies on healthy foods have been implemented in some European countries (e.g., Hungary) to control obesity and improve diet behaviors [46]. These food policies implemented in other countries were supported by the profound evidence [46]. However, only two studies have been conducted to estimate the health and economic impact of a simulated SSBs tax in Canada [63, 66]. Thus, more research regarding the effectiveness and equity effect of sugar taxes and other interventions is needed to provide more information to policymakers.

1.1.5 Function and features of sugar taxes

The tax strategies work based on an economic theory that consumer demand for a good adjusts when the price of a good is changed. Taxes on sugary foods and beverages usually are excise taxes rather than sales taxes. Excise taxes on sugary foods and beverages would increase the retail price of these products by adding a fixed tax at purchase. Data from Mexico and France have shown that the excise taxes imposed on drinks with free sugar will pass through to the consumers by manufacturers, distributors, or retailers and appear on price tags [67, 68]. Because foods and beverages with high added and free sugar have relatively higher price elasticity than some addictive products (e.g., tobacco, alcohol and narcotics), the consumer is expected to reduce the consumption of these foods and beverages. Several studies have demonstrated that higher prices are associated with lower demands for sugary products [50, 53].

There are mainly two types of sugar tax: specific excise tax (e.g., dollars per gram of products or nutrients) and ad valorem excise tax (e.g., 20% of the pre-tax price) [69]. Specific excise tax is much easier to administer, but the tax rate requires a regular update or increase for keeping pace with inflation [69]. Although the ad valorem excise tax does not need to change according to inflation, its impact might be decreased if consumers shift to cheaper sugary foods and beverages. Specific excise tax is used more frequently for sugar taxes in the real world. For example, Mexico implemented a 1 peso per liter excise tax on SSBs [53]. Finland introduced € 0.95/kg and € 0.11/L tax on sweets and chocolates and soft beverages, respectively [70].

The impact of sugar taxes is influenced by several characteristics of sugar taxes, including the tax rate, scope of taxable products, and target population. The taxation level influences the impact of sugar taxes through behavior changes of consumers. To sufficiently stimulate changes in consumer behavior, and have meaningful health effects, the WHO recommended that the retail price of SSBs rise by 20% or more [71]. However, most implemented sugar taxes (e.g., SSBs tax in Mexico and some states of the US) are below this level [50, 53, 72]. Notably, to identify a suitable tax level, policy designers should consider the price elasticity and pass-through rate of sugar tax. The own and cross-price elasticity represents the proportional change in the purchase of a product in response to a 1% increase in its price and other substitute products' prices, respectively. The pass-through rate shows the increment degree of the retail price of target products. The scope of the tax is another characteristic that decides the impacts of the sugar tax. While taxing a narrow range of sugary products will reduce the public and industry resistance, it will also decrease the health and economic benefits of the tax because the untaxed substitute products might appeal to consumers and diminish the overall reduction in calorie intake. Research has shown that tax with broader scope could effectively limit consumers from purchasing substitute untaxed sugary products [61, 73].

The impact of sugar tax is also different for people in different socioeconomic subgroups. Most previous studies have shown that the sugar tax resulted in a larger consumption decline and health improvement in the low socioeconomic groups [48, 53, 75]. This is in line with the economic theory that as a rational economic person, the consumers are expected to reduce the consumption of sugary beverages and foods, and low socioeconomic groups with the tightest budget constraints respond greatest to the taxation. Although the sugar tax is health progressive, the lowest socioeconomic group would be disadvantaged by spending a higher proportion of income on the sugar tax [63, 76].

1.1.6 Available modelling structures for the economic evaluation of sugar taxes

Many model structures can be used to evaluate health technologies or policy interventions. Based on Brennan et al.'s taxonomy [77], Briggs et al. [78] put forward a taxonomy of model structures for the economic evaluation of non-communicable disease public health interventions (Table 1). The main model structures are 1) decision trees, 2) comparative risk assessment, 3) Markov models without interaction, 4) system dynamics models, 5) Markov chain models, 6) individual-level Markov models with interaction, and 7) agent-based simulation. They divided model structures by considering the role of expected values, randomness, the heterogeneity of entities, the degree of non-Markovian model structure, potential interactions between individuals, entities, and environment, and how the interactions occur through time.

Decision trees evaluate interventions by outlining simulated decisions, the probability or fraction of various outcomes, and the comparison of valuation of each outcome. Decision trees are transparent and relatively easy to construct and interpret, however, they do not have a time component and do not allow for looping of events and interactions between individuals or population [77, 78]. Comparative risk assessment usually uses the population attributable fractions (PAFs) to estimate the disease outcome changes after an intervention. Comparative risk assessment can simultaneously model multiple diseases and risk factors, but it has the same disadvantages as the decision trees [78]. Compared with decision trees and comparative risk assessment, Markov models without interaction have a time component and looping. Markov models without interaction simulate changes of predefined health or disease states at a specific time interval for a population or individual [78]. However, they assume that individuals have no memory of previous disease states (i.e., the transition probabilities are constant over time).

System dynamics models are a cohort-based approach, which allows the population to interact with each other and the environment. System dynamics models simulate the state of the system (i.e., probabilities) change through the change of the system itself (i.e., the function of the rate of change in the system). Markov chain models also could simulate the interaction between the population. Markov chain models provide the model with some degree of memory through different state transition probabilities that depend on the proportion of different populations in different disease states, and the elapsed time in the model [78]. However, both system dynamics models and Markov chain models can only simulate cohort populations.

The individual-level Markov models with interaction can model individuals. Markov individual event history models also could partly overcome the Markovian assumption by altering transition probabilities as a function of time in a given state. However, Markov individual event history models cannot simulate the interaction within non-health sector systems (e.g., housing and energy sectors) [78]. Discrete event simulation is a flexible model that could simulate a system changing over time with a sequence of discrete individual events [79]. The probability of an event can vary with the time and interactions between individuals and the environment [78]. Similar to the Markov chain model, agent-based simulation models could simulate the interaction between individuals, between individual and environment [78]. However, the agent-based simulation models apply more rules to agents and individual agent characteristics. These models are all complicated, difficult to construct and interpret, and require large computational power [85].

Among these model structures, the simulation Markov model and the simulated patient-level Markov model have been used in the published sugar tax economic evaluation studies [55, 60-63, 66, 74-75, 79-84]. Some studies combine the multistate life tables with the cohort-based simulation Markov models to increase the health and disease states [62, 63, 66, 74, 82, 83]. For example, Jones et al. used a multistate life table Markov model to simulate the BMI-related health and economic impact of taxes on sugary beverages in Canada [83].

Table 1. A taxonomy of model structures

			A	B	C	D
			Cohort/aggregate-level/counts		Individual-level	
			Expected value, continuous state, deterministic	Markovian, discrete state, stochastic	Markovian, discrete state	Non-Markovian, discrete state
1	No interaction	Untimed	Decision tree rollback or comparative risk assessment	Simulation decision tree or comparative risk assessment	Individual sampling model: Simulated patient-level decision tree or comparative risk assessment	
2		Timed	Markov model (deterministic)	Simulation Markov model	Individual sampling model: Simulated patient-level Markov model	
3	Interaction between entity and environment	Discrete time	System dynamics (finite difference equations)	Discrete time Markov chain model	Discrete-time individual event history model	Discrete-time discrete event simulation
4		Continuous time	Systems dynamics (ordinary differential equations)	Continuous time Markov chain model	Continuous time individual event history model	Continuous-time discrete event simulation
5	Interaction between heterogeneous entities/spatial aspects important		x	x	x	Agent-based simulation

Reproduced from Briggs et al. [78]

1.2 Rationale

This thesis fills several research gaps in sugar consumption and the impact of excessive sugar intake and sugar taxes in Canada. First of all, the list of the added, free, and total sugar content of all foods and beverages in Canada was not currently available before this thesis. Although some studies [49] have estimated the free sugar content for a large number of pre-packaged foods in Canada, their work did not include all dietary sources. This thesis presents the added, free, and total sugar content of all foods and beverages consumed by Canadian residents. This data can assist nutritionists and researchers in further research regarding added and free sugar in Canadian products.

Little is known about the current added and free sugars consumption of Canadians. No previous study compared the Canadians' sugar intake with the recommended sugar consumption level. This thesis research was the first to estimate added, free, and total sugar consumption from all foods and beverages and the compliance with sugar intake recommendations for all residents in Canada. The sugar consumption information could help researchers conduct further research about the impacts of excessive sugar consumption and policymakers to articulate intervention targets.

The economic burden of excessive free sugar intake in Canada has not been estimated in published articles. In previous studies, risk factors, including inadequate consumption of V&F [86, 87], dairy foods [15], dietary fiber [88] and nuts and seeds [15], excessive intake of processed meats and red meats [15] have been shown to contribute a substantial economic burden to Canada. However, excessive consumption of free sugar was overlooked when evaluating the impacts of unhealthy eating. Although some studies estimated the fiscal burden of consumption of sugary drinks in Canada [15, 38, 41], these studies did not show the impacts of not meeting free sugar intake recommendations and did not include sugar from other sugary products. Thus, this thesis estimates the direct health care and indirect costs of exceeding the WHO recommended free sugar intake in Canada. The findings related to the burden caused by free sugar intake from all food sources in this thesis could facilitate policy decisions on interventions to reduce free sugar intake.

Although the evidence base is expanding rapidly, no study has synthesized the literature on the cost-effectiveness of sugar taxes. Some systematic reviews and meta-analyses have shown that sugar taxes could effectively curb sugar consumption and alleviate weight gain [89-92]. However, they did not summarize the effects of sugar taxes from the perspectives of the

HRQoLs, health care costs, and cost-effectiveness. Insights into the health benefits, the future cost savings, and the cost-effectiveness of sugar taxes can assist policymakers in the financial planning of health care and comparison of the sugar tax and other interventions (e.g., education programs) in the health care system.

Another gap in the Canadian literature is that the simulation modelling for evaluating the long-term health and economic effects of taxes on all sugary products is not available. The modelling research from other countries ignored some disease risks related to free sugar intake [60-63, 66, 74, 75, 78-81, 84, 93]. The modelling studies recently conducted in Canada did not include all related CDs, such as high blood pressure [82, 83]. Furthermore, price elasticity for alternative products was disregarded in some previous modellings [80, 84, 93]. The cross-elasticity for juice, milk, and diet drinks used in the previous Canadian studies [63, 66] is insufficient to simulate the substitute and compensation effects. Thus, a new simulation model that includes more disease risks and own- and cross-price elasticities for all untaxed products was designed in this thesis.

It is worth noticing that the health and economic impact and cost-effectiveness of the tax on all sugary foods in Canada have not been quantified. While two studies [82, 83] modelled a 20% tax on sugary drinks in Canada, the taxable products in these studies did not include other sugary foods. Because sugary foods have a significantly larger contribution to daily energy intake than sugary drinks [94], the potential impact of a tax on sugary foods is needed to be quantified. Additionally, no study has considered intervention costs and evaluated the cost-effectiveness of a sugar tax in Canada. Insights into the costs of implementing a sugar tax allow policymakers to make resource allocation decisions by considering the current financial status and public needs. Also, the cost-effectiveness analysis allows policymakers to compare the sugar tax with other interventions in the health care system. Thus, this thesis estimates the impacts of a tax on all sugary products from public health care payer perspective.

Before this thesis, no studies have compared the cost-effectiveness and equity effect of different sugar taxes and V&F subsidies scenarios in Canada. Studies from other countries have shown that a tax on sugary foods was more cost-effective than a tax on SSBs [62], and an absolute sugar content tax was more cost-effective than a volume tax and a tiered tax [85]. Although the financial inequity of the SSB tax has been shown in a previous Canadian study [63], the difference in impacts of the tax on all sugary foods and beverages and V&F subsidies among different income groups is unknown. The comparison and combinations of various policy choices can help policymakers find the optimal policy package in Canada.

1.3 Research questions and objectives

To address the identified knowledge gaps and to provide evidence for researchers and policymakers, this thesis aims to address the following questions:

Question 1: What is the added and free sugar content of foods and beverages in Canadians' diet?

Question 2: How much added, free, and total sugar (g/day) do Canadians consume?

Question 3: How many percentages of Canadians consumed the added and free sugar below the recommended levels?

Question 4: How much money could be saved if all Canadians adhere to established sugar intake recommendations?

Question 5: What are the health and economic impact of sugar taxes in the previous economic evaluations?

Question 6: How to evaluate the effects of taxes on all sugary products in Canada using a simulation model?

Question 7: What are the health and economic impacts of sugar taxes and V&F subsidy scenarios in Canada?

Question 8: Whether the sugar taxes and V&F subsidies have different impacts among different income groups?

1.4 Structure of this thesis

This thesis employs a "paper-based" format which includes a general introduction, a series of research related to the economic burden of excessive sugar intake and the impact of sugar taxes in Canada, and a general discussion.

Chapter 1 provides a background of the research, summarizes the rationale of this thesis, and outlines the research objectives and questions. This thesis consists of five studies: Chapter 2, Chapter 3, Chapter 4, Chapter 5, and Chapter 6. In the first study of this thesis (**Chapter 2**), research questions 1-3 are answered. The added, free, and total sugar of all foods and beverages consumed by Canadians listed in the 2015 Canadian Community Health Survey (CCHS) - Nutrition dataset is calculated. The sugar consumption, sources of sugar, and adherence to the added and free sugar intake recommendations in 2015 in Canada are also shown in this study. Based on the calculated sugar values, **Chapter 3** answers Question 4 and shows the estimated direct health care costs and indirect costs of excessive sugar intake in Canada in 2019. **Chapter 4** answers Question 5 by systematically reviewing the economic evaluations of sugar taxes. After quantifying the economic burden of excessive free sugar consumption and analyzing all previous economic evaluations of the sugar taxes, **Chapter 5** applies a newly designed simulation model to estimate the impact and cost-effectiveness of an SSB tax in Canada (Question 6). **Chapter 6** estimated the cost-effectiveness and equity effect of different sugar taxes and V&F subsidy scenarios in Canada (Question 7-8). **Chapter 7** provides an overview of the main findings from this thesis. The implications of these results, pros and cons, policy initiatives, conclusion, and recommendations to the future studies are discussed in Chapter 7.

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Chapter 2. Added, Free and Total Sugar Content and Consumption of Foods and Beverages in Canada

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2.1 Abstract

Background: Consumption of sugars contributes to obesity and various chronic diseases. The U.S. Department of Agriculture and the World Health Organization recommend that added and free sugar consumption be less than 10% of total energy intake (TEI). However, in Canada, the added and free sugar content of foods and beverages is not documented, so Canadians' consumption and compliance with the above recommendations are unknown.

Data and methods: This study calculated the added and free sugar content of all 5,374 foods and beverages recorded in the 24-hour dietary recalls of the 2015 Canadian Community Health Survey – Nutrition using established procedures. The usual intake of added, free and total sugars was estimated with the National Cancer Institute method.

Results: In 2015, residents of Canada consumed an average of 57.1 g/day of added sugars, 67.1 g/day of free sugars and 105.6 g/day of total sugars. This represented 11.1%, 13.3% and 21.6% of TEI for added, free and total sugar intake, respectively. Among all Canadians, 49.0% consumed less than 10% of TEI from added sugars, while 33.8% consumed less than 10% of TEI from free sugars. The food groups with the highest added and free sugar content were desserts and sweets, breakfast cereals, baked products, beverages, and snacks. Desserts and sweets and beverages were the two main contributors of sugar in the Canadian diet.

Interpretation: The majority of Canadians consumed more added and free sugars than recommended. Estimating added and free sugar content and consumption could help researchers assess the health of Canadians and the economic burden of excessive sugar consumption and could help policy makers articulate intervention targets.

2.2 Introduction

In Canada, chronic diseases (CD) account for 89% of all deaths [1] and more than CAD$80 billion in annual health care costs [2]. Adopting healthy lifestyle behaviours, such as healthy eating, has the potential to prevent 80% of diabetes mellitus type 2 (DM2) and cardiovascular disease (CVD), 40% of cancers, and other CDs [1,3]. Despite healthy eating recommendations issued by Health Canada [4], eating habits continue to deteriorate, and overweight prevalence rates continue to increase [5].

Since sugars contribute to the overall energy composition of diet, excess sugar intake may lead to a positive energy balance and weight gain. Considerable epidemiological and experimental evidence has emerged suggesting an association between sugar consumption and obesity, high blood lipid levels, visceral adiposity, fatty liver disease, insulin resistance, DM2, CVD, metabolic syndrome, and dental caries [6-13]. While nutritious foods like fruits and milk contain naturally occurring sugars [14], many other foods and beverages contain added and free sugars that, when consumed in excess amounts, increase calorie intake and displace consumption of nutritious foods [15].

The definitions of added, free and total sugars vary. This study uses the World Health Organization (WHO) definition of free sugars: "all monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates" [6]. Added sugars are defined as refined sugars added during cooking or manufacturing, not including naturally occurring sugars and fruit juice [16,17]. Total sugars are defined as the sum of all naturally occurring and added sugars.

In 2015, the WHO released new recommendations to reduce the consumption of free sugars to less than 10% of daily total energy intake (TEI), and ideally to less than 5% of TEI to achieve additional health benefits [6]. The 2015-to-2020 edition of *Dietary Guidelines for Americans*, released by the U.S. Department of Agriculture (USDA), recommends that Americans consume less than 10% of calories from added sugars.

Various countries have documented added and free sugar consumption. For example, in the United States, added sugars were estimated to comprise 13.1% to 17.5% of TEI among children and 11.2% to 14.5% of TEI among adults [18,19]. Children in Greece were estimated to obtain 11.2% of TEI from free sugars [20]. These population averages exceed the sugar recommendations of the WHO and the USDA and call for interventions to reduce added and free sugar intake. Estimates of added and free sugar consumption are not available for Canada because the added and free sugar content of foods and beverages in Canada is not systematically documented.

In 2004, the average total sugar intake of Canadians was estimated to be 21.4% of daily TEI [21], an estimate that includes both naturally occurring and added sugars. While subsequent work was done to quantify added sugar intake specifically, these estimates did not consider all sources of added sugars [22]. Research showed that 66% of 40,000 packaged food products in Canada contained at least one added sugar [23]. In a recent study, Bernstein et al. [24] estimated the free sugar content of prepackaged foods in Canada using the Food Label Information Program. Although the authors were able to estimate the free sugar content for a large number of prepackaged foods, their work did not include all dietary sources. Therefore, to date, there are no accurate population-based estimates of the added and free sugar content of the Canadian diet.

Given the increasing concerns about the health consequences of excess added and free sugar intake, there is growing interest in applying policies and programs to reduce this consumption. Various jurisdictions have introduced such policies and programs to reduce consumption at the population level [25,26]. For Canada, scientific research into the health effects of excess added and free sugar consumption and the potential benefits of interventions starts with a good understanding of added and free sugar consumption at the population level. Therefore, to provide accurate sugar consumption information for researchers and policy makers, this study aims (1) to document the added, free and total sugar content of foods and beverages consumed in Canada; and (2) to estimate the consumption and dietary sources of added, free and total sugars in Canada.

2.3 Data and methods

2.3.1 Data sources

The 2015 Canadian Community Health Survey (CCHS) – Nutrition is a cross-sectional national survey that was conducted by Statistics Canada and Health Canada from January to December 2015. The survey recruited individuals aged 1 and older living in private dwellings in the 10 Canadian provinces using a multi-stage, clustered design [27]. A national response rate of 61.6% was achieved. The survey's 24-hour dietary recall collected the food intakes of 20,487 respondents, 7,608 of whom completed a second 24-hour dietary recall. These 24-hour dietary recalls were administered using an Automated Multiple-Pass Method [28]. Respondents reported the consumption of 2,784 ingredient-level foods and 2,590 recipe-level foods in the 2015 CCHS – Nutrition. Recipe-level foods are foods that consist of two or more ingredients. A sandwich and Caesar salad are examples of recipe-level foods, and an apple and noodles are examples of ingredient-level foods [27]. The nutrient content of ingredient-level foods was used to calculate the nutrient content of recipe-level foods. The Canada Food Guide file was used to determine the serving sizes [28].

The University of Alberta Research Ethics Board approved this study (Pro00073295). The 2015 CCHS – Nutrition data were accessed through Statistics Canada's Research Data Centres Program.

2.3.2 Estimation of the added and free sugar content of foods and beverages

Statistics Canada calculated the nutrient intake, including total sugar intake, for respondents based on the consumption and nutrient content of the reported foods and beverages. However, this calculation does not include added and free sugar intake, as the added and free sugar content of foods and beverages is not systematically documented in Canada.

In 2015, Louie et al. [17] published a decision tree with a systematic methodology to estimate the added sugar content of foods in Australia. Their 10-step standardized approach had high interrater repeatability and was designed for both national (Australia) and international use [17]. The approach by Louie et al. [17] was adapted for use in Canada. Figure 1 illustrates the decision algorithm of the nine-step approach. Note that 1 of the 10 steps from the Louie et al. approach (step number 4) was omitted because recipe-level foods in the 2015 CCHS – Nutrition dataset used more than one recipe. A brief description of each of the nine steps is provided below. More details on each of the steps are provided elsewhere (Appendix A) [29].

Step 1: Assign 0 g of added and free sugars for ingredient-level foods that contain 0 g in total sugars.

Step 2: Assign 0 g of added and free sugars for ingredient-level foods that are unprocessed or processed without added or free sugars.

Assign 0 g of added sugars for food types such as unsweetened fruit or vegetable juice (including concentrate), unsweetened dairy products, and all fats and oils. Assign 0 g of free sugars for these food types, except for fruit juice and foods with fruit juice.

Step 3: Assign 100% of total sugars as added and free sugars for ingredient-level foods with very little naturally occurring sugars.

Assign 100% of total sugars as added sugars for food types such as sugar-sweetened beverages (SSBs), confectionery, sugars, syrups and sweetener without added fruits, chocolate, and dairy products. Assign 100% of total sugars as free sugars for these food types and for 100% fruit juice and foods that contain fruits.

Step 4: Calculate added and free sugar content by comparing the total sugar content of a food or beverage with the sugar content of an unsweetened version of this food or beverage.

Added sugar and free sugar per 100 g (AS_{100g} and FS_{100g}) were calculated using the formulas: $AS_{100g} = \frac{100 \text{ x } (TS_s - TS_{us})}{(100 - TS_{us})}$, and $FS_{100g} = \frac{100 \text{ x } (TS_s - TS_{us})}{(100 - TS_{us})}$

Where, TS_s is the total sugar content per 100g of the sweetened food or beverage, and TS_{us} is the total sugar content per 100g of the unsweetened food or beverage.

Step 5: Calculate added and free sugar content based on lactose and maltose content.

Where data for lactose and/or maltose was available in the Canadian Nutrient File or the USDA Food and Composition Database, added sugar and free sugar content of ingredient-level foods was calculated using the formulas: $AS_{100g} = TS_{100g} - \text{lactose}_{100g} - \text{maltose}_{100g}$, and: $FS_{100g} = TS_{100g} - \text{lactose}_{100g} - \text{maltose}_{100g}$.

Step 6: Calculate added sugar and free sugar content using content values of similar foods of steps 1 to 5 or other nutrient databases.

Similar foods captured in steps 1 to 5 and in the Food Standards Australia and New Zealand Food Nutrient Database were searched for information on added sugar and free sugar. Foods were considered to be similar if they only differed in water content, if they contained similar ingredients (such as similar vegetables in soup), or if they were calorie/energy reduced or fat reduced. Where a similar food was identified (matching), added sugar and free sugar content of the target food was estimated using the formulas:

$AS_{target} = TS_{target} \text{ x } (AS_{matching}/TS_{matching})$,

and $FS_{target} = TS_{target} \text{ x } (FS_{matching}/TS_{matching})$.

Step 7: Estimate added and free sugar content for ingredient-level foods subjectively based on common recipes and ingredient lists.

Step 8: Assign 50% of total sugars as added and free sugar content for all remaining ingredient-level foods.

Step 9: Calculate added and free sugar content for recipe-level foods using respondent-specific recipes and the above estimated added and free sugar content of ingredient-level foods.

After all ingredient-level foods in the 2015 CCHS – Nutrition were estimated (steps 1 to 8), the added and free sugar content of recipe-level foods was calculated using the following formulas:

$$\mathrm{AS}_{100\mathrm{g}} = \frac{\sum_{i=1}^{j} RW_i \ \mathrm{x}\ AS_i}{\sum_{i=1}^{j} W_i}, \text{ and } \mathrm{FS}_{100\mathrm{g}} = \frac{\sum_{i=1}^{j} RW_i \ \mathrm{x}\ FS_i}{\sum_{i=1}^{j} W_i}$$

Where, RW_i is the raw weight for the ith ingredient in the recipe, W_i is the weight of the ith ingredient after cooking in the recipe, AS_i is the added sugar content per 100 g of the ith ingredient and FS_i is the free sugar content per 100 g of the ith ingredient.

The average added and free sugar content of ingredient-level foods was calculated for 18 food groups (displayed in Figure 2). These food groups were based on the Bureau of Nutritional Sciences (BNS) Food Group Codes and Descriptions [30] and the Canadian Nutrient File (CNF) Food Groups [31].

2.3.3 Estimation of usual intake of added, free and total sugar

The National Cancer Institute (NCI) method was applied to estimate the distribution of usual intake of added, free and total sugar by Canadians [32]. The NCI method assumes that usual intake is equal to the probability of consumption on a given day times the average amount consumed on a "consumption day" [33] and uses repeated 24-hour recalls. Depending on whether certain nutrients are commonly consumed (i.e., daily and by most respondents), this method uses either a one-part or a two-part model [34]. The one-part model considers only the amount of a nutrient consumed and is to be applied to nutrients that are commonly consumed. The two-part model considers both the proportion of the population consuming the nutrient and the amount of the nutrient consumed, and it is to be applied to nutrients that are not commonly consumed. This study assumed that added, free and total sugars were consumed daily and by all members of the population. For the usual intake of added, free and total sugars for each of the 18 food groups, this study considered the proportion of the population that consumed no sugar. A one-part model was applied for food groups where less than 5% of the population consumed no sugar. A two-part model was applied for food groups where more than 20% of the population consumed no sugar. For food groups where 5% to 20% of the population consumed no sugar, both models were fitted, and the model with the best fit was used. For the usual intake of added and free sugars expressed as a percentage of TEI, an extension of the NCI method was used [34, 35].

All analyses included age, sex, the sequence of 24-hour recalls (first recall versus second recall), and the 24-hour recall collection day of the week (weekdays, or Monday to Thursday, versus weekends, or Friday to Sunday) as covariates when accommodating individual-level and within-individual variation. Sampling weights provided by Statistics Canada were used to ensure study estimates apply to residents of Canada (for ease of presentation referred to as Canadians). All statistical analyses were performed using SAS (version 9.4, SAS Institute) software. SAS Macros of the NCI method were available online [36].

2.4 Results

2.4.1 Estimated added, free and total sugar content of foods and beverages

The added and free sugar content of 2,784 ingredient-level foods and 2,590 recipe-level foods consumed in Canada was calculated using the nine-step method. Table 2 shows the sugar content of selected ingredient-level food items recorded in the 2015 CCHS – Nutrition. The table provides one example for each of the 18 food groups. A table with the added, free and total sugar content of all ingredient-level foods is available elsewhere [29]. Recipes (and recipe-level foods) are respondent-specific and subject to restricted release for confidentiality reasons, but they can be calculated from the ingredient-level foods.

2.4.2 Estimated added, free and total sugar content of food groups

For each of the 18 food groups, Figure 2 shows the average added, free and total sugar content of all foods and beverages reported by respondents. Desserts and sweets had the highest added, free and total sugar content, at 37.0, 38.1 and 42.9 g per 100 g, respectively. Except for fruits, all food groups high in total sugar also had high added and free sugar content. Breakfast cereals, baked products, beverages, baby foods and snacks were the food groups that contained high free and added sugar content. Fruit juice had high free sugar content (12.5 g / 100 g) but low added sugar content (1.9 g / 100 g). Fats and oils, meats, sausages and luncheon meats, pasta, grains and flours, eggs, vegetables, spices, soups, sauces and gravies, nuts and seeds, and dairy products had relatively low sugar content.

2.4.3 Estimated added, free and total sugar consumption and adherence to recommendations

Table 3 shows the mean and percentiles of usual added, free and total sugar intake in Canada. Canadians consume daily, on average, 57.1 g of added sugars, 67.1 g of free sugars and 105.6 g of total sugars. On average, added sugars constitute approximately 54.1% of total sugars, and free sugars make up approximately 63.5% of total sugars. The average estimated added, free and total sugar intake contributed to 11.1%, 13.3% and 21.6% of TEI, respectively.

A comparison between added and free sugar consumption and the recommended added and free sugar intake is also presented in Table 3. The USDA recommendation (added sugar intake below10% of TEI) was met by 49.0% of Canadians. A lower percentage of Canadians adhered to the WHO recommendations for free sugars: free sugars made up less than 10% of TEI for 33.8% of Canadians; free sugars made up less than 5% of TEI for 5.4% of Canadians.

2.4.4 Contribution of food groups to added, free and total sugar intake

The contribution of each of the 18 food groups to added, free and total sugar intake is summarized in Figure 3. Desserts and sweets and beverages were the two food groups that contributed the most to added, free and total sugar intake in the Canadian diet. An estimated 67.3%, 57.5% and 41.1% of added, free and total sugar intake, respectively, came from desserts and sweets, and an estimated 17.4%, 17.5% and 12.6% of added, free and total sugar intake, respectively, came from beverages. Other food groups, such as baked products, soups, sauces and gravies, and breakfast cereals, also contributed to added, free and total sugar intake.

There were some differences in the relative contribution of food groups to the intake of added, free and total sugars (Figure 3). Fruits (12.9%) and dairy products (11.6%) were significant sources of total sugar intake, but not primary sources of added and free sugar intake.

2.5 Discussion

This study revealed the added, free and total sugar content and consumption of foods and beverages in Canada. For the majority of Canadians, consumption of added and free sugars exceeded USDA and WHO recommendations. Desserts and sweets and beverages contributed to most of the added, free and total sugar intake of Canadians.

Both the USDA's added sugar definition and the WHO's free sugar definition were applied in the present study. Added sugars differ from free sugars in their exclusion of naturally occurring sugars in fruit juices and fruit juice concentrates. Various studies have not clearly defined added and free sugars [17, 18, 19, 24], whereas the present study and others [37, 38] have demonstrated substantial differences in the consumption of added versus free sugars.

Total sugar intake in Canada was estimated at 110.0 g/day using the 2004 CCHS – Nutrition [21]. This seems higher than the 105.6 g/day that was estimated in this study using the 2015 CCHS – Nutrition. Langlois et al. [39] who studied the temporal changes in total sugar consumption, concluded that the apparent reduction between 2004 and 2015 may actually be caused by misreporting as a result of changes in survey methodology. They also reported that total sugar consumption from foods actually increased between 2004 and 2015, while total sugar intake from beverages decreased [39]. Studies from other countries and of earlier time periods concluded that total sugar intake either decreased or levelled off, both in absolute terms (g/day) and in relative terms (percentage of total sugar in TEI) [40, 41, 42].

To date, very few studies of added and free sugar consumption have been population-based, and very few have reported on compliance with USDA and WHO recommendations. Louie et al. found that 1% of Australian children and youth (aged 2 to 16) consumed added sugars below 5% of TEI, and 18.1% consumed added sugars below 10% of TEI [42]. Sluik et al. revealed that 29% of Dutch residents (aged 7 and older) met the recommendation for added sugars (less than 10% of TEI) and 19% met the recommendation for free sugars (less than 10% of TEI) [38]. The present study's estimates that 49.0% and 33.8% of Canadians met the existing recommendations for added and free sugars, respectively, are notably higher than these Australian and Dutch estimates.

This study revealed that desserts and sweets, breakfast cereals, baked products, beverages, and snacks are food groups with high added and free sugar content. This ranking seems consistent with the ranking by Bernstein et al. for prepackaged foods and beverages [24]. This study also showed that the intake of added, free and total sugars through desserts and sweets was substantially higher than the intake of these sugars through beverages. This appears to be consistent with observations from a review of 11 European studies that concluded that sweet products contributed to a higher proportion of added sugar intake (40% to 50% for children and 36% to 61% for adults) than beverages did (20% to 34% for children and 12% to 31% for adults) [43].

Various countries and jurisdictions have adopted strategies to improve diet quality or reduce energy intake. These include food guides, school nutrition policies, front-of-package labelling, social marketing and various forms of taxation [4, 25, 44, 45]. Several studies have reported on the effectiveness of these interventions and the extent to which they resulted in a decrease in added and free sugar consumption [26, 46, 47]. However, other studies have shown that there remains plenty of room for improvement. For example, economic evaluations revealed that Canada would have avoided health care costs of approximately CAD$863 million in 2014 and

CAD$830 million in 2018 if Canadians had avoided consuming SSBs [48, 49]. The present study's added and free sugar value and consumption estimates may support future research into the health and economic costs associated with the consumption of these sugars. They may also inform potential intervention targets for added and free sugar consumption.

The present study has several strengths. It uses the 2015 CCHS – Nutrition, which is a large population-based survey that included the 24-hour recall data of more than 20,000 respondents, with repeat measures, to allow for the estimation of usual intake. A study limitation relates to the subjective judgment used in steps 6, 7 and 8, as this may have introduced error in the estimates of added and free sugar content. However, these steps did involve a limited number of foods and beverages: Figure 1 shows that they involved 475 (8.8%) of the 5,374 recorded foods and beverages when estimating added sugars and 397 (7.4%) of the foods and beverages when estimating free sugars. In addition, Louie et al. [17] reported high inter-rater repeatability for this methodology. Another limitation relates to the use of 24-hour recalls, which are prone to error, as is every dietary assessment method.

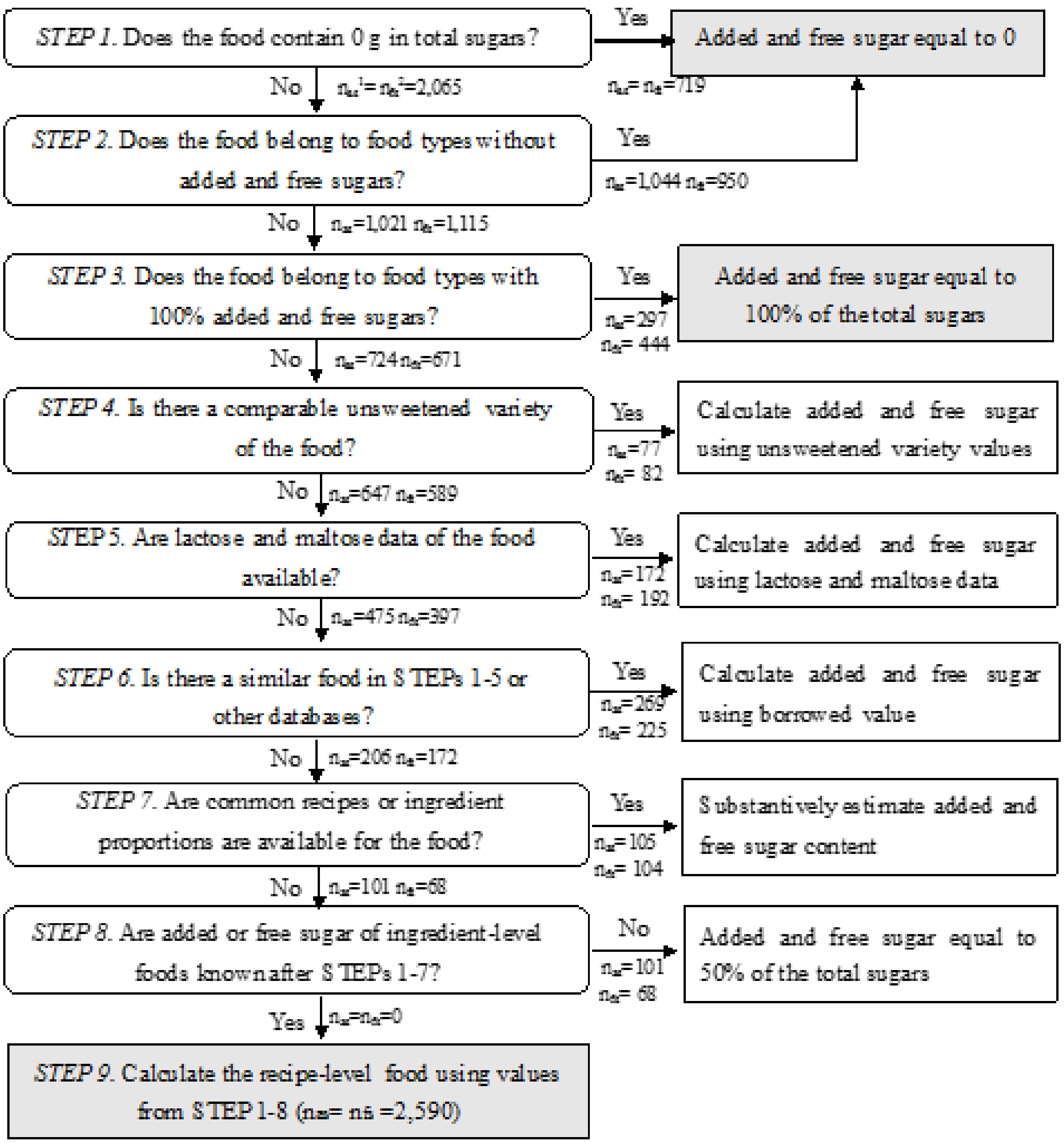

Figure 1. Decision flow chart of a 9-steps approach to assigning added and free sugar content

Notes: n_{as}: the number of food items for added sugar; nfs: the number of food items for free sugar.

Source: Author's complication based on the 2015 Canadian Community Health Survey – Nutrition content.

Table 2. Added, free and total sugar content of selected ingredient-level foods

Food name	**Added sugar (g/100g)**	**Free sugar (g/100g)**	**Total sugar (g/100g)**
Ravioli, cheese-filled with marinara sauce	1.96	2.16	4.50
Granola bar, chewy, fruit flavour, yogurt coated	18.15	25.26	34.08
Cereal, hot, oats, instant, flavoured, dry	0.70	0.70	1.40
Dessert, frozen, ices, water, lime	30.51	32.60	32.60
Yogurt, goat, fruit flavoured	4.80	7.28	9.60
Juice drink, cranberry and apricot, bottled	0.00	14.59	14.59
Spread, 20% butter / 80% canola oil	0.00	0.00	0.01
Mollusks, oyster, eastern (blue point), wild, raw	0.00	0.00	0.62
Deli-meat, salami (Hungarian), pork and beef, cooked	0.76	0.76	0.76
Nuts, almonds, toasted, unblanched	0.00	0.00	4.79
Beans, baked, canned, with pork and tomato sauce	5.13	5.67	5.67
Cherry, sweet, canned, juice pack, solids and liquid	0.00	4.48	12.31
Snacks, plantain chips	0.46	0.46	0.92
Pomegranate juice, ready-to-drink	0.00	12.65	12.65
Soup, tomato rice, canned, condensed, water added	1.80	2.95	2.95
Babyfood, cereal, rice, with milk powder and fruit, dry	14.54	16.27	29.08
Spices, onion powder	0.00	0.00	6.63
Egg, chicken, dried, whole	0.00	0.00	0.30

Notes: A table with added, free and total sugar content of all 2,784 ingredient-level foods recorded in the 2015 Canadian Community Health Survey – Nutrition is available elsewhere [29]. In addition to added sugars and free sugars, total sugars include mostly naturally occurring sugars such as lactose, fructose and maltose (see text and [29] for details).

Source: Author's compilation based on the 2015 Canadian Community Health Survey - Nutrition content.

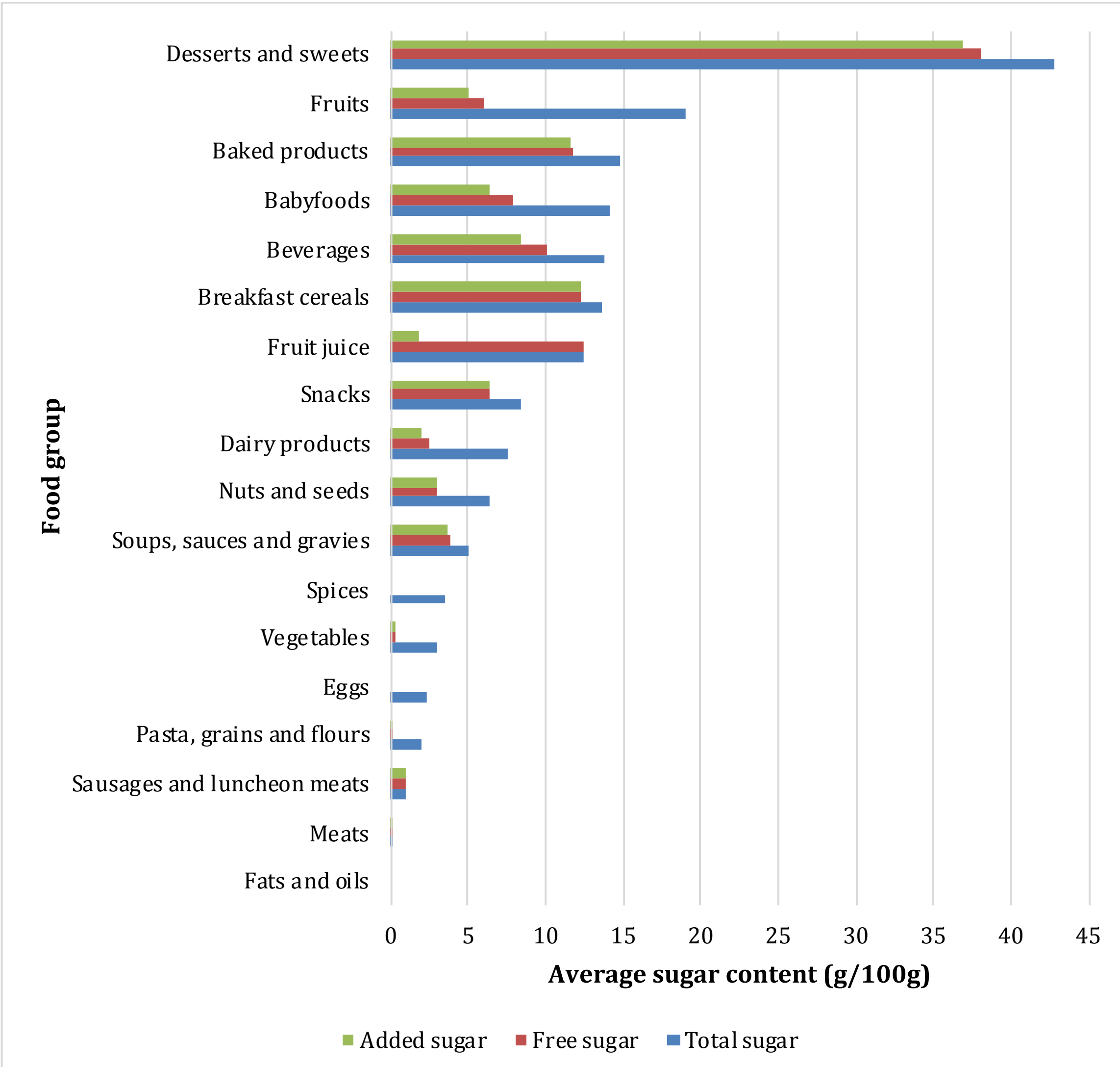

Figure 2. Estimated added, free and total sugar content (g/100 g) of food groups in Canada

Source: Author's compilation based on the 2015 Canadian Community Health Survey - Nutrition content.

Table 3. The distribution of usual intake of added, free and total sugar and adherence to recommendations in Canada in 2015

	Mean	Percentile							Recommendations[4]	
		5th	10th	25th	50th	75th	90th	95th	<5% TEI	<10% TEI
Added sugar intake (g/day)	57.12	13.76	18.54	29.60	47.73	74.20	107.24	132.32	-	-
Free sugar intake (g/day)	67.14	17.74	23.67	37.00	57.98	87.18	122.11	147.76	-	-
Total sugar intake[2] (g/day)	105.61	45.29	54.22	72.39	97.99	130.48	166.59	191.91	-	-
TEI[3] from added sugar (%)	11.05	3.83	4.88	7.05	10.13	14.05	18.35	21.37	10.65	48.97
TEI from free sugar (%)	13.27	4.86	6.15	8.73	12.32	16.77	21.56	24.87	5.44	33.76
TEI from total sugar (%)	21.58	11.27	12.98	16.25	20.56	25.84	31.45	35.25	-	-

[1] g/day: grams per day. [2] Total sugar intake, free sugar intake and added sugar intake were adjusted by inter-individual variation (sequence of the 24-h recall and 24-h recall collection day of the week, and intra-individual variation (age and gender). [3] TEI: total energy intake.

Notes: The U.S. Department of Agriculture recommends that added sugar consumption not exceed 10% of TEI; the World Health Organization recommends that free sugar not exceed 5% and 10% of the TEI.

Source: Author's compilation based on the 2015 Canadian Community Health Survey - Nutrition content.

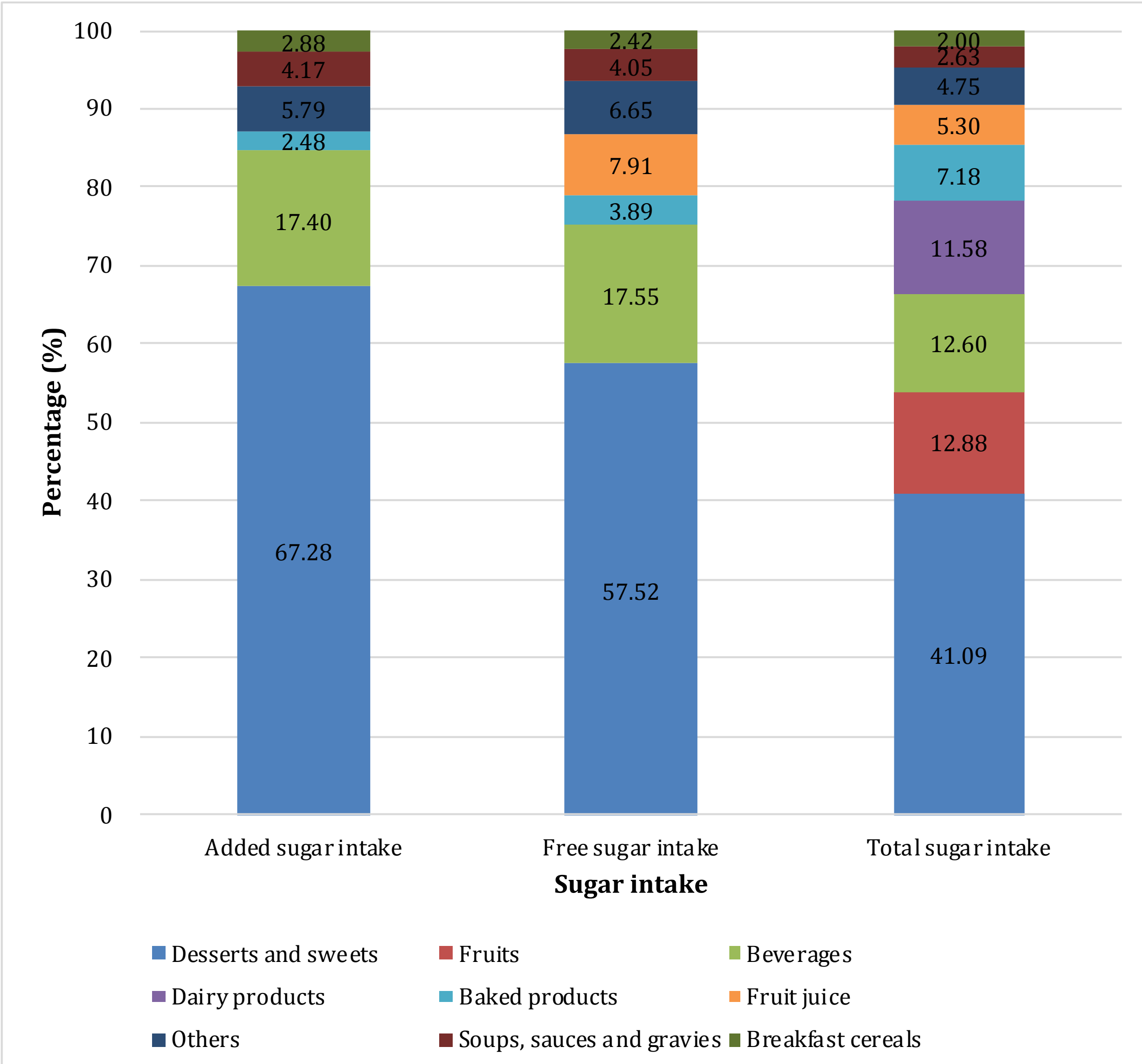

Figure 3. Contribution of food groups to the intake of added, free and total sugars in Canada

Source: Author's compilation based on the 2015 Canadian Community Health Survey - Nutrition content.

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Chapter 3. The economic burden of excessive sugar consumption in Canada. Should the scope of preventive action be broadened?

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3.1 Abstract

Objectives: Excessive sugar consumption is an established risk factor for various chronic diseases (CDs). No earlier study has quantified its economic burden in terms of health care costs for treatment and management of CDs, and costs associated with lost productivity and premature mortality. This information, however, is essential to public health decision-makers when planning and prioritizing interventions. The present study aimed to estimate the economic burden of excessive free sugar consumption in Canada.

Methods: Free sugars refer to all monosaccharides and disaccharides added to foods plus sugars naturally present in honey, syrups and fruit juice. Based on free sugar consumption reported in the 2015 Canadian Community Health Survey–Nutrition and established risk estimates for 16 main CDs, we calculated the avoidable direct health care and indirect costs.

Results: If Canadians were to comply with the free sugar recommendation (consumption below 10% of total energy intake (TEI)), an estimated $2.5 billion (95% CI: 1.5, 3.6) in direct health care and indirect costs could have been avoided in 2019. For the stricter recommendation (consumption below 5% of TEI) this was $5.0 billion (95% CI: 3.1, 6.9).

Conclusions: Excessive free sugar in our diet has an enormous economic burden that is larger than that of any food group and 3 to 6 times that of sugar-sweetened beverages (SSBs). Public health interventions to reduce sugar consumption should therefore consider going beyond taxation of SSBs to target a broader set of products, in order to more effectively reduce the public health and economic burden of CDs.

Keywords: sugar; nutrition; public health; disease prevention; chronic diseases; economic burden; taxation, health care costs; health policy

3.2 Introduction

Chronic diseases (CD) are a leading cause of death in the world [1]. In Canada, CDs, including diabetes, cardiovascular diseases (CVD), and cancer, accounted for 62% of all deaths in 2019 [2]. The treatment and management of CDs were estimated to consume 67% of all direct health care costs, adding up to CAD $190 billion annually [3].

Adopting healthy lifestyles, such as healthy eating, active living, tobacco abstinence, and responsible alcohol consumption, can prevent up to 80% of diabetes mellitus type 2 (DM2) and CVD and 40% of cancers [4]. Among the aforementioned four major lifestyle risk factors for CDs, an unhealthy diet has been shown to have the largest burden [1]. Despite a series of healthy eating recommendations issued in Canada to improve health and reduce CDs [5, 6], the majority of Canadian residents do not meet these recommendations [7-9]. For example, more than three out of four Canadians do not consume enough vegetables and fruit (V&F) [8, 10], and nearly two out of three consume more free sugar than what is recommended [7].

The World Health Organization (WHO) defines free sugars as: "all monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and fruit juice" [11]. They recommend the consumption of free sugars to be below 10% of the daily total energy intake (TEI), and ideally below 5% of TEI [11]. Recently we reported that only 33.8% and 5.4% of Canadian residents met these free sugar recommendations of below 10% and 5% of TEI, respectively, in 2015 [7].

Considering the financial pressures on health care systems, understanding the magnitude of avoidable costs for the treatment and management of CDs is essential to public health decision-makers. Canadian research to date has revealed the economic burden of inadequate intake of V&F [10], dairy products [12], dietary fibre [13], and other healthful foods and food groups [4, 14]. Canadian research has also revealed the economic burden associated with excess consumption of harmful foods and specifically sugar-sweetened beverages (SSBs) and sugary drinks [4, 14, 15]. Considering that only 17.5% of free sugar in the Canadian diet originates from SSBs [7], the economic burden attributable to free sugar from *all* foods and beverages in our diet is likely much higher than that of SSBs, and therefore more relevant to public health decision-makers. However, no study to date has estimated the economic burden of excessive free sugar consumption from all foods and beverages. This study quantifies the direct health care costs (hospital, physician and drug) and indirect costs that could be avoided if Canadians comply with existing free sugar consumption recommendations.

3.3 Methods

We established a methodological approach to quantify the economic burden of the inadequate and excessive consumption of foods and beverages [4, 10, 14]. For the present study, we applied this approach to estimate the economic burden of excessive free sugar consumption. In brief, in this approach, we make use of the vigorous established estimates from the Global Burden of Disease (GDB) report [16] of the risk for CDs associated with the consumption of free sugar and the free sugar consumption of Canadian residents (for ease of reporting referred to as Canadians) to calculate population attributable fractions (PAFs). A PAF represents the fraction of disease (CDs) that is avoided if a population avoids exposure to a certain risk factor: in this study, the excessive consumption of free sugar. Once we have estimated the fraction of CDs that can be avoided, we can calculate what costs can be avoided for the treatment and management of these CDs and lost productivity and premature mortality. Below we provide a description of the approach. For full detail, we refer to our earlier work [4, 10, 14].

3.3.1 Risk for chronic diseases associated with free sugar consumption

We extracted age and sex specific relative risk (RR) estimates for CDs associated with the consumption of SSBs from the 2013 Global Burden of Disease (GDB) report [16] in the absence of established risk estimates for CDs associated with free sugar consumption. We assumed that the risk associated with the consumption of free sugar in our diet is the same as the risk associated with the consumption of the equivalent amount of free sugar from SSBs. A serving of SSBs (226.8g) contains an estimated 22.9g of free sugar [7]. As the WHO recommendations state that the consumption of free sugars is not to exceed 5% or 10% of TEI [11], we used increments of 5% of TEI from free sugar as units for comparisons. We therefore adjusted the age and sex specific RRs obtained from the GDB such that they apply to increments of 5% of TEI from free sugar. We included risk estimates for those 16 CDs for which cost information is available through the Economic Burden of Illness in Canada (EBIC) [17]. These CDs include esophageal cancer, liver cancers, breast cancer, uterine cancer, colorectal cancer, pancreatic cancer, ovarian cancer, kidney cancer, thyroid cancer, leukemia, ischemic heart disease, ischemic stroke, hemorrhage stroke, diabetes, chronic kidney disease (CKD), and low back pain. The risk estimates for these CDs are listed elsewhere [4, 14].

3.3.2 Free sugar consumption of Canadians

We accessed the 2015 Canadian Community Health Survey (CCHS) – Nutrition [18] and used recently published free sugar content estimates [7] to estimate the free sugar consumption of Canadians. The 2015 CCHS – Nutrition (response rate 61.6%) collected 24-hour dietary recalls of 20,487 participants aged above one year living in the ten provinces in Canada, of whom 7,608 completed a second 24-hour dietary recall. The 24-hour dietary recalls were administered using an Automated Multiple-Pass Method. Using both the first and second 24-hour recall data, we estimated usual free sugar consumption and usual total energy intake (TEI) for each age and sex subgroups by applying the National Cancer Institute (NCI) method [19]. Sampling weights that considered initial weights, non-response and post-stratification [18] were applied to ensure estimates are representative of all Canadians. Using the SAS Macros of the NCI method, we obtained the proportion of each age and sex subgroup consuming 0-5%, 5-10%, 10-15%, 25%-20%, 20-25% and 25%+ TEI from free sugars per day. All statistical analyses were performed using SAS (version 9.4, SAS Institute) software.

3.3.3 Avoidable chronic diseases

We calculated the fraction of diseases that could theoretically be avoided by reducing free sugar consumption to an amount below the free sugar recommendations (PAFs) for each of the 16 CDs and every age and sex sub-group based on the above-mentioned risk estimates and consumption levels. We used the method recommended by Krueger et al. [20] that considers multiple risk exposure levels. The PAFs calculation equation is as follow:

$$PAF = \frac{\sum_{i=1}^{n} P_i(RR_i - 1)}{1 + \sum_{i=1}^{n} P_i(RR_i - 1)}$$

Where P_i is the proportion of people in interval i, i (interval) is the consumption of 0-5%, 5-10%, 10-15%, 25%-20%, 20-25% and 25%+ TEI from free sugars per day, RR is the RR for each 5% increase in percentage of TEI from free sugar, $RR_i = RR^{(X_i - L)}$ is the RR for interval i relative to the recommended ratio of free sugar intake to TEI, X_i is the mid value of interval i,

L is the recommended ratio, and n is the number of intervals above or below the recommended free sugar intake.

3.3.4 Avoidable health care costs and indirect costs

We considered hospital, physician and drug costs for the treatment and management of CDs as reported in the 2019 National Health Expenditure Trends [21] and the age and sex specific proportions of each of the 16 CDs from the 2010 EBIC [17] to calculate the direct costs for each of the 16 CDs. We estimated the indirect costs of excessive free sugar intake using the human capital approach [20]. Following this approach, we extracted the ratios of indirect costs (costs associated with short and long-term disability and with mortality) versus direct health care costs for each of the 16 CDs from the 1998 EBIC [22]. We then multiplied these ratios by the 2019 direct health care costs for each age and sex group while assuming these ratios did not change over time and applying the disaggregation step from Krueger et al. [20] to estimate the total avoidable costs. All costs were reported in 2019 Canadian dollars. We conducted a sensitivity analysis by recalculating the above while using the 95% confidence interval lower and upper boundary estimates for risk estimates extracted for the 2013 GBD report [16].

3.4 Results

In Canada, on average women consumed 59.9 grams of free sugar and 1510 kilocalories per day, while men consumed 75.3 grams of free sugar and 2004 kilocalories per day (Table 4). The distribution of free sugar as a percentage of TEI was similar for both sexes with slightly more men (34.2%) then women (32.1%) adhering to the recommendation that free sugar consumption should not exceed 10% of TEI, and slightly more men (6.0%) then women (4.6%) adhering to the stricter recommendation that the consumption of free sugar should not exceed 5% of TEI (Table 4).

Table 5 shows the population attributable fractions, i.e. the estimated percentage of CDs that is avoided if Canadians avoid consuming free sugar in excess of recommendations. The estimates for diabetes (27.0% and 44.8% for the recommendations of <10% of TEI and < 5% of TEI respectively) stood out as the highest of all CDs, followed by cardiovascular and cerebrovascular disease, i.e. ischemic heart disease, ischemic stroke and hemorrhagic stroke combined (5.2% and 10.2% for the recommendations of <10% of TEI and < 5% of TEI respectively). The estimated percentage of diabetes and CVD that is avoided when adhering to free sugar recommendations is similar for women and men (Table 5).

The economic burden of free sugar consumption above 10% of TEI was estimated to be CAD$2.5 billion (95% CI: CAD$1.5 to CAD$3.6 billion) per year (Table 6). This amount included about CAD$1.1 billion per year in direct health care costs and CAD$1.4 billion per year in indirect costs. For free sugar consumption above 5% of TEI, the economic burden was CAD$5.0 billion (95% CI: CAD$3.1 to CAD$6.9 billion) per year which included CAD$2.2 billion per year in direct health care costs and CAD$2.7 billion per year in indirect costs (Table 6). Around 93% of the costs were attributable to diabetes (CAD$2.3 billion and CAD$4.6 billion for consuming free sugar in excess of 10% and 5% of TEI, respectively). Direct health care costs and indirect costs were substantially higher among men than among women (Table 6).

3.5 Discussion

In this study, we revealed that free sugar consumption in Canada contributes enormously to CDs, to costs for the treatment and management of these CDs, and to costs associated with loss of human capital. The estimated reductions in the disease burden if Canadians were to comply with free sugar consumption recommendations are substantial for all CDs but are particularly pronounced for diabetes. Adhering to the recommendation to limit free sugar consumption to less than 10 % of TEI would result in a reduction of approximately 27.0% in the prevalence of diabetes. For the stricter recommendation (<5 % TEI), this reduction would reach as much as

44.8%. The economic burden attributable to free sugar consumption is also substantial for all CDs, with diabetes accounting for the bulk of these costs. For all CDs combined, adhering to the recommendation to limit free sugar consumption to below 10 % of TEI and 5% of TEI would have avoided CAD$2.5 billion and CAD$5.0 billion, respectively, in direct and indirect costs in 2019.

This is the first study to reveal the economic burden of free sugar consumption in Canada. In previous work, using the same methodology and the 2015 CCHS-Nutrition data, we estimated the economic burden for not meeting established recommendations for whole grains to be CAD$3.8 billion, for nut and seeds to be CAD$3.8 billion, for fruits to be CAD$2.5 billion, for vegetables to be CAD$1.7 billion, for processed meat to be CAD$2.2 billion, for milk to be CAD$666 million, for red meat to be CAD$231 million, and for SSBs to be CAD$830 million in 2018 [14]. Notably, our estimate of CAD$2.5 billion for the free sugar recommendation that consumption should be below 10% of TEI is of similar magnitude to those foods with a high economic burden (fruits and processed meats). Our estimate of CAD$5.0 billion for the stricter free sugar recommendation exceeds all abovementioned estimates. In other words, more CDs will be prevented and more costs for treatment and management of CDs will be avoided if Canadians are to comply with this recommendation (free sugar below 5% of TEI) than with any other established dietary recommendation. In Korea, the costs from disease treatment and premature mortality caused by excessive SSBs consumption were estimated to be KRW$ 633 billion in 2015 (approximately CAD$ 19.42 per capita per year) [23]. These costs are much lower than our estimates of the economic burden: approximately CAD$65.44 per capita per year for not consuming below 10% of TEI and CAD$131.87 per capita per year for not consuming below 5% of TEI. However, comparisons with studies from other countries are complicated because of differences in dietary patterns, health care systems, free sugar definitions and research methodology [23, 24].

Our estimate of the economic burden for not adhering to the recommendation for free sugar consumption below 10% of TEI (CAD$2.5 billion per year) is approximately three times higher than the estimate for not adhering to the recommendations for the SSBs intake (CAD$830 million per year) [14]. For the stricter free sugar recommendation, the economic burden estimate (CAD$5.0 billion per year) was about six times higher than that for SSBs. These comparisons suggest a proportionately larger impact of interventions targeting a broader set of products containing free sugar (e.g., confectionery, chocolate, and ice cream) as compared to interventions targeting SSBs and sugary drinks [25].

Using pricing strategies (food taxes and subsidies) is considered a key policy tool to reduce the chronic disease burden and associated health care costs [26]. Jones et al. projected that a 20% tax on SSBs would avoid CAD$7.4 billion in health care costs in Canada between 2016 and 2041 [15]. Coming on the heels of public health successes from taxation of tobacco cigarettes, taxation of SSBs is considered to be most effective in inducing health-promoting changes in sugar consumption and is recommended by the WHO and Dietitians of Canada to influence the demand for foods high in sugar [26-28]. Targeting SSBs has the practical advantages of focusing on a single product or an easy-to-define category of products that are energy-dense and nutrient-poor but with close healthier substitutes (e.g., water), and as such is administratively simple to implement. Where such SSB taxes have been implemented in over 40 countries and cities to promote the reduction in sugar intake at the population level [29], Canada and many other jurisdictions are considering this strategy. However, the sole focus on SSBs comes with the drawback that only a modest portion of all free sugar in Canadians' diet comes from SSBs: Liu et al. recently estimated that of all free sugar that Canadians consume, only 17.5% originates from SSBs [7]. Indeed, the WHO recommendation recognizes that SSB taxation should only be applied in settings where SSB consumption is a significant contributor to free sugars intake (i.e., greater than 20 litres per person per year) [30].

Another drawback of targeting a single product or product group is that it allows consumers to choose alternative sources of free sugar that are not taxed and herewith circumventing the taxation objectives. The findings from this study provide support for broader taxation of a wider range of foods and beverages high in free sugar, which has the potential not only to reduce free sugar consumption at the population level but also to improve the overall quality of the diet [26]. Several countries have or had implemented policies with taxation targets beyond SSBs. For example, Finland, Norway and Hungary had introduced taxation of sweets, chocolate, ice cream, and other sugar-containing foods in addition to SSBs [26, 31]. Although administratively complex, a comprehensive set of pricing policies that includes a broad tax on free sugar content (e.g., a given amount per 100g of sugar contained in certain products), and an excise duty on specific products containing sugar (e.g., a given amount per kg/litre of the specific product) is needed to reach more free sugar consumers and to improve the potential for health promotion.

Finally, building on lessons from successful tobacco control, a comprehensive package of complementary policies in addition to taxation is advocated to effectively reduce sugar consumption at the population level [27, 30]. Taxation of SSBs has been shown to be financially regressive whereby low-income groups bear a larger tax burden [32, 33], calling for policies that sugar tax revenues be reinvested in the production, distribution and marketing of healthful foods to support food security for these low-income groups [34]. Other complementary policies may include regulatory measures (e.g., front-of-package labelling, regulation of health claims, and advertising), legislation limiting or banning use of free sugar across the food supply chain, industry incentives for product reformulation, supportive environments in public institutions (e.g., hospitals, schools, nursing homes) to serve low sugar meals, health education campaigns, and dietetic counselling of people at higher risk [30, 34]. Yet, other interventions, including public awareness education initiatives and product labelling policies have also seen SSBs as their only target in Canada [35, 36].

In the present study we observed that men have a substantially higher consumption of free sugar than women and thus contribute much more to the economic burden of excessive free sugar consumption compared to women. This sex difference is consistent with previous reports on the economic burden associated with unhealthy eating [4, 10, 19, 37]. Though men consumed more free sugar in absolute terms (grams per day), free sugar consumption as a share of TEI was similar for women and men. The observed sex differences in the economic burden are thus not a result of sex differences in compliance with free sugar recommendations. Instead, they originate from a higher prevalence of chronic diseases, and specifically diagnosed and undiagnosed diabetes, among men relative to women [38], and the ensuing higher economic costs attributable to diabetes among men relative to women [39]. Complementary policies that promote healthy eating and active lifestyles, may reduce the prevalence of diabetes and other chronic diseases, and herewith their economic burden and the impact of free sugar on this economic burden. Where these complementary policies specifically target men or are more effective among men than among women, they will reduce the current sex differences in economic burden.

The present study has several strengths. It used the established free sugar definition by the WHO, the 2015 CCHS-Nutrition, Canada's most comprehensive dietary survey of the past decade, and robust estimates of free sugar consumption [7]. With respect to latter, we had considered the free sugar content of each of 5,374 foods and beverages recorded in the 2015 CCHS-Nutrition [7]. We had used both the first and second 24-hour recall and had applied the recommended NCI method so that our estimates are representative for the Canadian population [7]. We believe our estimates of free sugar consumption are therefore more robust then those obtained through an alternative approach that did not make use of the second 24 hour recall and the NCI method, and considered the free sugar content of 177 foods and food groupings [40]. In the absence of established risk estimates for CDs associated with consumption of free sugar in our diet, we assumed that free sugar in our diet exhibits the same risk as the equivalent amount of free sugar in SSB. Future research, however, has to reveal the extent to which this assumption is correct. As a limitation to this study, we should mention that dietary intake is obtained through self-report, which is prone to error. Another limitation is that our economic burden estimates represent underestimations. For the direct health care costs, we considered only hospital, physician and drug costs associated with 16 CDs and not, for example, costs associated with dental caries, mental health and other diseases. Also, the economic burden following the COVID-19 pandemic will likely increase further since people with CDs (diabetes, hypertension, cardiovascular and cerebrovascular disease, chronic obstructive pulmonary disease, cancer) were 2-4 times more likely to have severe COVID-19 symptoms and complications thus increasing the health costs for ICU admission and hospital stays [41, 42]. The public health measures implemented to contain the spread of the virus (i.e., lockdowns) have also increased unhealthy lifestyle behaviors, including free sugar intake [43].

3.6 Conclusion

The findings of this study reveal a staggering impact of excessive free sugar consumption on the chronic disease burden and avoidable health care costs in Canada. The economic burden of not adhering to the recommendations for free sugar intake was larger than that for any other food item and 3 to 6 times larger than that of SSBs. The magnitude of the public health and economic burden attributable to excessive free sugar consumption sound an alarm and expose an area of urgent need for action. Public health interventions to reduce sugar consumption must go beyond taxation of SSBs to target a broader set of products. Public health interventions must also extend beyond taxation to comprise a comprehensive suite of complementary approaches in order to more effectively reduce the public health and economic burden of CDs.

Table 4 The distribution of usual intake of free sugar, total energy, and the percentage of total energy from free sugar by sex in Canada, 2015.

		Percentile							Recommendations	
	Mean	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**	**<5% TEI [a]**	**<10% TEI**
Free sugar intake (gram/day)										
Women	59.9	17.3	22.6	34.4	52.5	77.2	106.5	127.5	-	-
Men	75.3	18.9	25.5	40.6	64.5	98.1	138.5	168.3	-	-
Women and men	67.1	17.7	23.7	37.0	58.0	87.2	122.1	147.8	-	-
TEI (kilocalories/day)										
Women	1510	746	880	1129	1455	1829	2213	2463	-	-
Men	2004	909	1091	1438	1907	2462	3044	3439	-	-
Women and men	1753	791	944	1249	1658	2152	2681	3040	-	-
TEI from free sugar (%)									-	-
Women	13.4	5.1	6.4	9.0	12.5	16.8	21.5	24.7	4.6	32.1
Men	13.2	4.7	6.0	8.7	12.3	16.8	21.6	24.9	6.0	34.2
Women and men	13.3	4.9	6.2	8.7	12.3	16.8	21.6	24.9	5.4	33.8

[a] TEI: total energy intake.

Table 5 The fractions (%) of chronic diseases that are avoided if Canadians would not consume free sugar in excess of recommendations.

	The avoidable fractions (%) of diseases					
	<10% TEI [a] from free sugar			<5% TEI [a] from free sugar		
	Women	Men	Women and Men	Women	Men	Women and Men
Cancer						
Esophagus	0.9	0.8	0.8	1.7	1.6	1.7
Liver	0.5	0.7	0.6	1.0	1.3	1.2
Colorectal	0.2	0.4	0.3	0.4	0.8	0.6
Pancreas	0.2	0.2	0.2	0.5	0.4	0.4
Kidney	0.8	0.6	0.7	1.6	1.1	1.4
Thyroid	0.4	0.5	0.5	0.8	1.0	0.9
Leukemia	0.4	0.2	0.3	0.8	0.4	0.6
Post-Menopausal Breast	0.3	-	-	0.6	-	-
Uterus	1.5	-	-	2.9	-	-
Ovary	0.1	-	-	0.2	-	-
Cardiovascular Diseases						
Ischemic heart disease	1.5	1.4	1.5	3.0	2.7	2.8
Ischemic stroke	1.7	1.5	1.6	3.3	3.0	3.2
Hemorrhagic stroke	2.3	2.0	2.1	4.4	3.9	4.2
Diabetes	27.0	27.2	27.0	44.7	45.1	44.8
Chronic kidney disease	1.6	1.4	1.5	3.1	2.7	2.9
Low back pain	0.3	0.2	0.3	0.6	0.5	0.5

[a] TEI: total energy intake.

Table 6 The economic burden of excessive sugar consumption by chronic disease, sex and age group in 2019 in Canada

	Estimated direct health care costs and indirect costs in 2019					
	Free sugar consumption <10% TEI [a]			Free sugar consumption < 5% TEI		
	Direct Costs	Indirect Costs	Total	Direct Costs	Indirect Costs	Total
Chronic disease						
Cancer						
Esophagus	465,990	2,225,109	2,691,099	996,400	4,757,827	5,754,227
Liver	205,906	983,203	1,189,109	429,501	2,050,875	2,480,376
Colorectal	2,298,749	10,976,565	13,275,315	4,887,054	23,335,762	28,222,816
Pancreas	160,348	765,664	926,012	338,208	1,614,950	1,953,158
Kidney	601,615	2,872,719	3,474,334	1,253,400	5,985,003	7,238,403
Thyroid	390,938	1,866,736	2,257,674	782,896	3,738,343	4,521,240
Leukemia	1,046,917	4,999,048	6,045,965	2,045,863	9,769,027	11,814,889
Post-Menopausal Breast	413,784	1,975,826	2,389,610	853,084	4,073,489	4,926,572
Uterus	1,131,745	5,404,100	6,535,845	2,277,280	10,874,048	13,151,328
Ovary	55,084	263,027	318,111	111,269	531,319	642,579
Cardiovascular and cerebrovascular diseases						
Ischemic heart disease	23,359,119	39,929,872	63,288,991	48,949,863	83,674,464	132,624,328
Ischemic stroke	4,160,043	7,111,142	11,271,185	8,625,915	14,745,063	23,370,978
Hemorrhagic stroke	5,734,612	9,802,694	15,537,306	11,621,550	19,865,775	31,487,325
Diabetes	1,048,970,935	1,244,320,754	2,293,291,689	2,109,852,550	2,502,770,313	4,612,622,863
Chronic kidney disease	9,721,808	3,430,500	13,152,308	19,488,360	6,876,788	26,365,149
Low back pain	4,032,684	20,910,756	24,943,440	8,160,218	42,313,335	50,473,552
Age group						
≤14 years	43,508,259	52,224,382	95,732,641	70,748,253	85,017,154	155,765,407
15-34 years	96,446,377	117,832,929	214,279,306	196,793,417	240,110,909	436,904,326
35-54 years	440,466,289	539,275,782	979,742,071	748,261,431	920,537,258	1,668,798,689
55-64 years	257,354,285	318,606,611	575,960,896	651,993,607	801,635,275	1,453,628,883

65-74 years	169,776,207	209,156,540	378,932,747	362,301,762	447,133,353	809,435,115
75+ years	95,198,861	120,741,470	215,940,331	190,574,942	242,542,423	433,117,365
Sex						
Women	397,680,399	493,792,265	891,472,664	919,996,608	1,135,874,649	2,220,673,411
Men	705,069,878	864,045,449	1,569,115,327	1,300,676,803	1,601,101,724	2,736,976,373
Total	1,102,750,277	1,357,837,714	2,460,587,992	2,220,673,411	2,736,976,373	4,957,649,784

[a] TEI: total energy intake

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Chapter 4. The Cost-effectiveness of Taxation of Sugary Foods and Beverages: A Systematic Review of Economic Evaluations

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4.1 Abstract

Background: With increasing concerns about the health consequences and economic burden of excess sugar consumption, a sugar tax is increasingly considered an effective policy to curb sugar consumption. However, little is known about the cost-effectiveness of sugar taxes. To inform policy decision-makers, we systematically reviewed and analyzed the evidence regarding the cost-effectiveness of sugar taxation.

Methods: We systematically searched six databases (MEDLINE, Web of Science, EMBASE, The Cochrane Library, EconLit and Google Scholar) to identify relevant journal articles. Two reviewers independently scanned and selected all retrieved studies. Only studies that evaluated sugar taxes and applied economic evaluation methods were included. The quality of included studies was assessed using established standards.

Results: Fifteen good-quality studies that originated from the six countries (the US, Australia, South Africa, Canada, the UK and Mexico) were included. These studies revealed that sugar tax improved health-related quality of life. Savings from avoided health care costs and revenue from the sugar taxes (totalling US$87 to US$167,799 million) exceeded intervention costs (US$5 to

US$2,177 million). Each of the 15 studies concluded that sugar tax constitutes a cost-effective intervention that led to cost savings.

Conclusions: Sugar tax is a practical and cost-effective policy option to reduce the health and economic burden resulting from excess sugar consumption. The impact of sugar taxes depends on the target population, time horizons, and other parameters. Economic evaluations of taxation of a broader set of sugary products and a combination of sugar taxation and other interventions are important to further curb sugar consumption.

4.2 Introduction

Excess sugar consumption is a risk factor for obesity and related chronic diseases (CDs) [1]. Various studies have shown the association of sugar consumption with weight gain, high lipid levels, metabolic syndrome, diabetes mellitus type 2 (DM2), cardiovascular disease (CVD), cancers and dental caries [2-7]. Due to these health concerns and associated costs, there is growing interest in policies and programs to curb sugar consumption.

The taxation of sugary foods and beverages has been proposed as a population-level approach to reduce sugar intake [8]. Many countries (e.g., Mexico, Denmark and South Africa) and US jurisdictions (e.g., Berkeley, California) have implemented a tax on sugar-sweetened beverages (SSBs) [9-13]. Studies have demonstrated that sugar taxes increase product prices and decrease sales [14, 15] and revealed their effect on sugar consumption and body weight [16, 17]. Systematic reviews and meta-analyses have shown the effectiveness of sugar taxes in curbing sugar consumption and alleviating weight gain [18-20]. The reduction in SSBs consumption and lower body weight index (BMI) could decrease the risk of diseases [21]. A series of studies have shown that this decrease in disease risks due to the sugar taxes would increase the health-related quality of life (HRQoL) as well as avoid health care costs [22, 23].

Although the evidence base is expanding rapidly, no study has synthesized the literature on the cost-effectiveness of sugar taxes that is critical to policymakers. Insights into the costs of implementing sugar taxes allow policymakers to make resource allocation decisions by considering the current financial status and public needs. Also, insights into the future costs savings resulting from the prevention of disease and avoided health care costs may assist policymakers in the financial planning of health care. Furthermore, cost-effectiveness analysis such as the assessment of the incremental cost-effectiveness ratio (ICER) will allow policymakers to compare the sugar tax with other interventions in the health care system.

For the purpose of informing policy decision-makers, this study aims to systematically review and analyze evidence regarding the cost-effectiveness of taxation policies of sugary foods and beverages. The costs, health benefits and other relevant outcomes of the studies are also summarized and discussed.

4.3 Methods

For the literature review, this study followed the guidelines for the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [24].

4.3.1 Data sources and search strategy

The MEDLINE, Web of Science, EMBASE, the Cochrane Library, EconLit and Google Scholar (the first 15 pages of each search using Google Scholar were examined) databases were searched to identify relevant journal articles (published before August 1, 2020). We developed a search algorithm (Appendix B) with terms related to the subject of investigation (such as 'sugar' and 'tax') and terms related to cost-effectiveness analyses (such as 'QALY' and 'ICER'). Details of the search algorithm are included in the supplementary material.

4.3.2 Studies selection

Objectives for study selection were set by using PICOS (Population, Intervention/indicator, Comparison, Outcomes, Study design) criteria [25]. Studies were included if they: (1) evaluated population-level tax on SSBs or foods, (2) compared with current status or other policy options,

(3) used economic evaluation method, including cost-effectiveness analysis and cost-utility analysis, and (4) were written in English. Based on the guidelines for the economic evaluation of health technologies, studies that did not measure the costs (e.g., health care costs and intervention costs) and HRQoL (e.g., quality-adjusted life years (QALYs) and disability-adjusted life years (DALY)) as outcomes were excluded [26]. The study selection process is shown in Figure 4. All retrieved articles were independently scanned and selected by two reviewers (S.L. and C.L.). They were discussed and resolved through consensus when disagreements occurred.

4.3.3 Data extraction and analysis

Basic study information, including study country and publication year, was extracted. Characteristics and parameters of economic evaluation models were extracted using a standardized extraction table: intervention, target population, time horizon, comparators, model type, outcome measures, research perspective, discount rate, and demand elasticity. The primary outcomes of studies, including costs (e.g., health care costs, intervention costs and tax revenue), HRQoL outcomes (e.g., QALYs and DALYs), cost-effectiveness, and the uncertainty of these estimates were also extracted.

Given the included studies were conducted in different countries and years, costs and cost-effectiveness were converted to 2021 US dollar values using the web-based tool CCEMG-EPPI-Centre Cost Converter [27, 28]. All extracted data of the included studies were synthesized using tables and narrative methods. A meta-analysis could not be performed because of the heterogeneity across studies.

4.3.4 Quality assessment

The quality of included studies was assessed using the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) [29], which is a checklist intended to optimize the reporting of health economic evaluations. The CHEERS include 24 assessment standards organized into six categories: 1) title and abstract, 2) introduction, 3) methods, 4) results, 5) discussion, and 6) other. Each of 24 items was scored using “Yes” (information fully reported), “No” (information not reported), “Part” (information partly reported) and “N/A” (information not applicable). The values of 1, 0 and 0.5 were assigned to “Yes”, “No”, and “Part”, respectively. One reviewer (S.L.) assessed the quality first, which was then checked by a second reviewer (C.L.).

4.4 Results

4.4.1 Study selection process

The PRISMA flow diagram of the literature search is shown in Figure 4. The initial literature search revealed a total of 1178 articles, of which 984 remained after removing duplicates. A subsequent review of titles and abstracts identified 943 articles as not relevant. A review of the full text of the remaining 41 articles by the investigators identified 15 articles that met all inclusion criteria.

4.4.2 Characteristics of included studies

All 15 studies used simulation models to evaluate the cost-effectiveness of the sugar taxes. Characteristics of each of the 15 studies are shown in Table 7. All studies were published between 2013 and 2020. Six of the 15 studies were conducted in the US [22, 23, 30-33], three in Australia [34-36], two in South Africa [37-38], two in Canada [39, 40], and the remaining two the UK [41], and Mexico [42]. Except for Cobiac et al. [35], who simulated tax on SSBs and other sugary products, such as ice cream, all other studies (14) simulated taxation of SSBs only. All 15 studies compared taxation with “business as usual” to estimate the impacts of simulated sugar taxes. Only four studies [22, 23, 32, 35] considered alternative comparators, such as an SSBs ban, vegetables and fruit (V&F) subsidy and taxes on saturated fat.

Five studies [23, 30, 35, 36, 42] evaluated whole populations whereas the remaining ten studies [22, 31-34, 37-41] focused on adults only or specific jurisdictions. The studies considered different outcomes (BMI, diabetes, CVD, stroke, cancer, and other obesity-related diseases) and time horizons (ranging from 10 years to a lifetime), research perspectives (health sector, government and societal), and discount rates (ranging from 0% to 3%). In addition, the studies assumed own-price elasticity for SSBs that ranged from -1.30 to -0.63 (1.30-0.63% decline in intake in response to a 1% increase in price) [22, 30-41]. The cross-price elasticity for juice, milk and diet beverages ranged from 0.21 to 0.69, from 0.02 to 0.15, and from -0.52 to 0.50, respectively [22, 30, 35-40].

4.4.3 Quality assessment of included studies

Quality assessment results based on the CHEERS checklist are shown in Appendix C (Table C1). These 15 studies met the majority recommendations of the CHEERS. Lee et al. [33] and Cobiac et al. [35] had the highest total quality score, at 22. The most frequent partial or not reported items are "Incremental costs and outcomes" and "Discount rate". Some studies also failed to adequately report the "Time horizon", "Choice of model", "Analytical methods", "Estimating resources and costs", "Characterizing heterogeneity" and "Study findings, limitations, generalizability, and current knowledge".

4.4.4 Cost-effectiveness of sugar tax

The findings related to the cost-effectiveness of interventions are summarized in Table 8. All estimated costs and cost-effectiveness are shown in 2021 US dollar values.

Health-related quality of life outcomes

All 15 studies revealed that sugar tax improves HRQoL in their target populations. Those studies that considered a relatively long-time horizon showed greater health gains. A US$0.01 per ounce tax on SSBs in the US would gain 26,000-871,000 QALYs over ten years, and 30,000-

3,400,000 QALYs over a lifetime [22, 23, 30, 31]. A sugar tax on sugary foods in addition to SSB's tended to result in more health benefits. In Australia, a AU$0.47/l tax on SSBs could save 12,000 DALYs over a lifetime, while a tax on all other sugary foods could avert 270,000 DALYs over a lifetime [34-36]. The gender differences in the health implications of sugar taxes were divergent across countries. For example, a 20% tax on SSBs in South Africa would bring more health gains to females (4,000,000 DALYs) than males (2,800,000 DALYs) [37], while a 20% tax on SSBs in Canada were predicted to have more DALYs averted for males than females [41]. Lal et al, and Kao et al. showed that lower-income groups would gain more DALYs than higher-income groups [36, 41].

Health care costs, intervention costs and tax revenue

Health care costs, intervention costs and tax revenue of the simulated sugar taxes are shown in Table 8. All 15 studies evaluated the change in health care costs related to the implementation of the sugar tax. The sugar taxes could avoid health care costs for the health sector or government (ranging from US$87 to US$113,488 million), society (ranging from US$1,435 to US$45,000 million), and private sectors (ranging from US$0 to US$15,600 million). Most studies considered the costs of unrelated diseases due to additional years of life in the estimation of health care costs. These costs were far less than the health care cost offset due to prevented diseases [35].

Nine studies evaluated intervention costs of the sugar taxes ranging from US$5 million (for Maine, the US over 10 years) to US$2,117 million (for the US over 100 years) [23, 30-36, 42]. Tax revenue of the sugar tax was also considered in some studies. For example, Wilde et al. estimated that the US government could collect US$105,736 million in revenue from a tax on SSBs over a period of 100 years [31]. All 15 studies showed that avoided health care costs and revenues from the sugar tax were substantially higher than the intervention costs from the governmental and societal perspectives, which means that the net costs of a sugar tax policy are negative.

Cost-effectiveness

Different methods were used in evaluating the cost-effectiveness of the sugar tax (Table 8). Some studies concluded that the sugar tax was cost-saving based on their observations that the net costs were not positive [37-41]. Other studies found that the sugar tax was cost-saving by evaluating the probability of cost-saving [23, 33, 35]. Five studies used the ICER to assess the cost-effectiveness of the sugar tax [22, 30, 31, 33, 36]. Four other studies showed that sugar tax was cost saving by evaluating the costs saved per dollar spent. The sugar tax in the US, Australia and Mexico was estimated to save US$62, US$69 and US$8 per dollar spent, respectively [23, 30, 36, 42].

Although the included studies varied with respect to setting, target populations, perspectives, time horizons and simulation methods, all revealed that taxes on sugary products were cost-saving and that a sugar tax was more cost-effective compared to no intervention and alternative interventions to reduce sugar consumption and obesity.

Uncertainty of outcomes

Uncertainty intervals (95% UI) for the health and economic estimates were included in each of the 15 studies. Model uncertainty was assessed by modifying key parameters and assumptions, for example, tax level, price elasticities, pass-through rates, and changes in sugar intake. In all scenarios, the sugar taxes appeared cost-effective. The outcomes (including health care costs savings and HRQoL) linearly increased with the tax level increase and were sensitive to discount rates, price elasticities and study assumptions. For example, an assumption that puts limits to the effect of a sugar tax on BMI to the first 10 years could reduce the health impact by 75% [34].

4.5 Discussion

This systematic review synthesized the existing evidence related to the cost-effectiveness of taxation of sugary foods and beverages. Fifteen identified economic evaluations of sugar tax were assessed as good-quality studies. All studies revealed that compared to “business as usual”, sugar taxation was cost saving, and all showed significant health benefits. This makes a sugar tax a promising policy option to reduce the health and economic burden of excessive sugar intake.

All fifteen studies had examined a fixed tax on a specific product (i.e., SSBs or sugary drinks). Lee et al. [33] and Cobiac et al. [35] also examined a tax on the absolute sugar content of products. Setting a fixed tax on SSBs is considered more practical and is, therefore, more commonly applied in the real-world setting [8-13, 45, 46]. For example, Mexico implemented a 1 peso per liter excise tax on SSBs. The fixed tax on SSBs is considered practical in that governments can administer this in a relatively efficient manner, and factories could save on reformation costs. However, a fixed tax on SSBs may prompt consumers to seek alternatives and buy more sugary products that are not taxed [41]. This may reduce both the effectiveness and cost-effectiveness of the sugar tax. Lee et al. [33] illustrated that an absolute sugar content tax on SSBs in the US could generate twice the QALYs and net cost savings compared to a fixed tax on SSBs.

Only one of the fifteen studies [35] simulated a tax on sugary foods in addition to SSBs. This parallels the real-world practice where only a few countries (e.g., Finland and Norway) impose taxes on sweets, chocolate, ice cream, and other sugar-containing foods [45, 46]. Part of the reason is that the increment in the price of more products will lead to larger resistance from consumers, retail, and producers [47]. However, considering that the added and free sugar intake from other sources is substantially higher than that of SSBs [12, 33], we recommend extending the scope of taxable products as means to further improve health outcomes and reduce costs. Research from Australia confirmed that taxation on sugar-containing foods could avert more DALYs and save more disease costs than a tax on SSBs [35].

In addition to simulating the impacts of a sugar tax on whole populations, some studies [23, 30, 36, 41] have evaluated the differential impacts on socioeconomic subpopulations. These revealed for Canada, the US and Australia a regressive income impact whereby lower socioeconomic groups were disadvantaged in terms of contributing a higher proportion of their income to the sugar tax relative to higher socioeconomic groups [48-50]. This income regressivity could also be found in other product taxes, such as alcohol tax [51]. However, it is worth mentioning that sugar taxes have a progressive health effect: lower socioeconomic groups would gain more health benefits than higher socioeconomic groups after imposing sugar taxes [36, 41]. Earmarking tax revenues could offset the regressive income effect such that low-income groups could gain further health benefits [23, 30, 36].

Four studies [22, 23, 32, 35] compared the sugar tax with other interventions. Basu, et al. [22] and Long et al. [32] illustrated that SSBs tax was more cost-effective than other types of interventions aimed at reducing the consumption of SSBs (including SSBs bans and restrictions). Compared with other interventions for reducing obesity (e.g., V&F subsidy, reduce tax subsidy of TV advertising, early care and education policies, and active physical education policies), taxes on SSBs were estimated to gain more health benefits and save more health care costs [22, 23, 32, 35]. A tax on the sugar content of sugary foods appeared to have more health gain and disease costs offsets than other taxes for improving diet and population health (i.e., saturated fat tax and excess salt tax) [35].

The impacts of sugar taxes shown in the reviewed studies vary because of the differences in taxation policies, health care systems, and consumption levels of SSBs among others. Even if simulating the tax in the same context, varying outcome measures, target populations and time horizons across the studies contributed to differences in costs and HRQoL estimates. Studies in larger populations and longer time horizons tended to estimate pronounced gains in HRQoL and savings in health care costs. Further, studies considered different diseases in their models which contributed to differences in HRQoL and cost estimates. Uniformity in the use of health outcomes, time horizons, policy levels and other parameters will benefit this research field in that it will better allow for cross-study comparisons. Importantly, in striving for a uniform set of health outcomes one should aim for all obesity-related and non-obesity-related diseases identified by the Global Burden of Disease (GBD) [52]. None of the fifteen studies considered all these outcomes, and as such, all have underestimated the total avoided health care costs.

Price elasticity is the degree to which the purchase behaviour for something changes as its price rises. It is a critical parameter that determines the impact of sugar taxes. The reviewed articles assumed own-price elasticity and cross-price elasticities in their simulations of the reduction in consumption of sugary products and changes in the consumption of other foods and beverages. Except for Cobiac, et al. [35], the studies considered the own-price elasticity of SSBs and cross-price elasticities of fruit juice, milk and diet drinks and ignored the compensatory substitutions of other foods with sugars. This would lead to overestimating the potential effect of sugar taxes on calorie intake and obesity. Further, most reviewed articles borrowed the price elasticities from the published literature and specifically the literature on demand changes in real-world settings [8, 26]. The accuracy of economic evaluations could be greatly increased if they use price elasticity estimates specific to sugar consumption and specific to local settings [53].

The present systematic review has several strengths. The review used the systematic method to identify, search, and select the studies that are relevant to the sugar tax economic evaluations. Many valuable published articles and grey literature were identified and included in this study. Furthermore, we assessed the quality of all selected economic evaluations using the CHEERS checklist. The quality scores assist researchers, readers and policy decision makers to make critical judgments of the findings of the individual studies. To our knowledge, this is the first study to synthesize the evidence on cost-effectiveness of sugar tax. The synthesized information that shows benefits to health and cost savings advances our understanding of the potential impact of sugar taxes and assist public health decision-makers in prioritizing taxation of sugary foods and beverages. The combination of a sugar tax and other population interventions, such as financial incentives, school nutrition policies, front-of-package, and menu labelling, are advocated to reduce sugar consumption [54]. More work is needed to evaluate the impacts of a comprehensive intervention package.

The varying health outcomes, target populations and time horizons of the fifteen studies along with parameter differences in simulation modelling resulted in considerable differences in the estimated costs and health benefits. This heterogeneity across studies hampered a meaningful meta-analysis. We note that one may view a meta-analysis as a redundant exercise in light of the fact that each of the fifteen studies had concluded that a sugar tax constitutes a cost-effective intervention leading to cost savings in their respective settings. Another limitation of this literature review is limited number (three) of evaluations conducted in low- and middle-income countries, where consumption patterns and obesity-related health conditions are particularly concerning. Thus, more research is advocated to assess the impact of sugar taxes in low- and middle-income countries.

4.6 Conclusion

This review shows that a sugar tax is a cost-effective policy option to decrease the health and economic burden associated with excess sugar intake. The estimated impact level of sugar taxes depends on the health outcomes, target populations, time horizons and parameters in a simulation model. Though policymakers should exercise caution when interpreting research results conducted in other countries and settings, in the absence of local evidence, it is reassuring that this review revealed that each of the 15 studies concluded that sugar taxes constitute cost-effective interventions that led to cost savings. To further reduce sugar consumption and gain health and economic benefits, the scope of taxable products should be further investigated and the combination of sugar taxes with other public health interventions be considered.

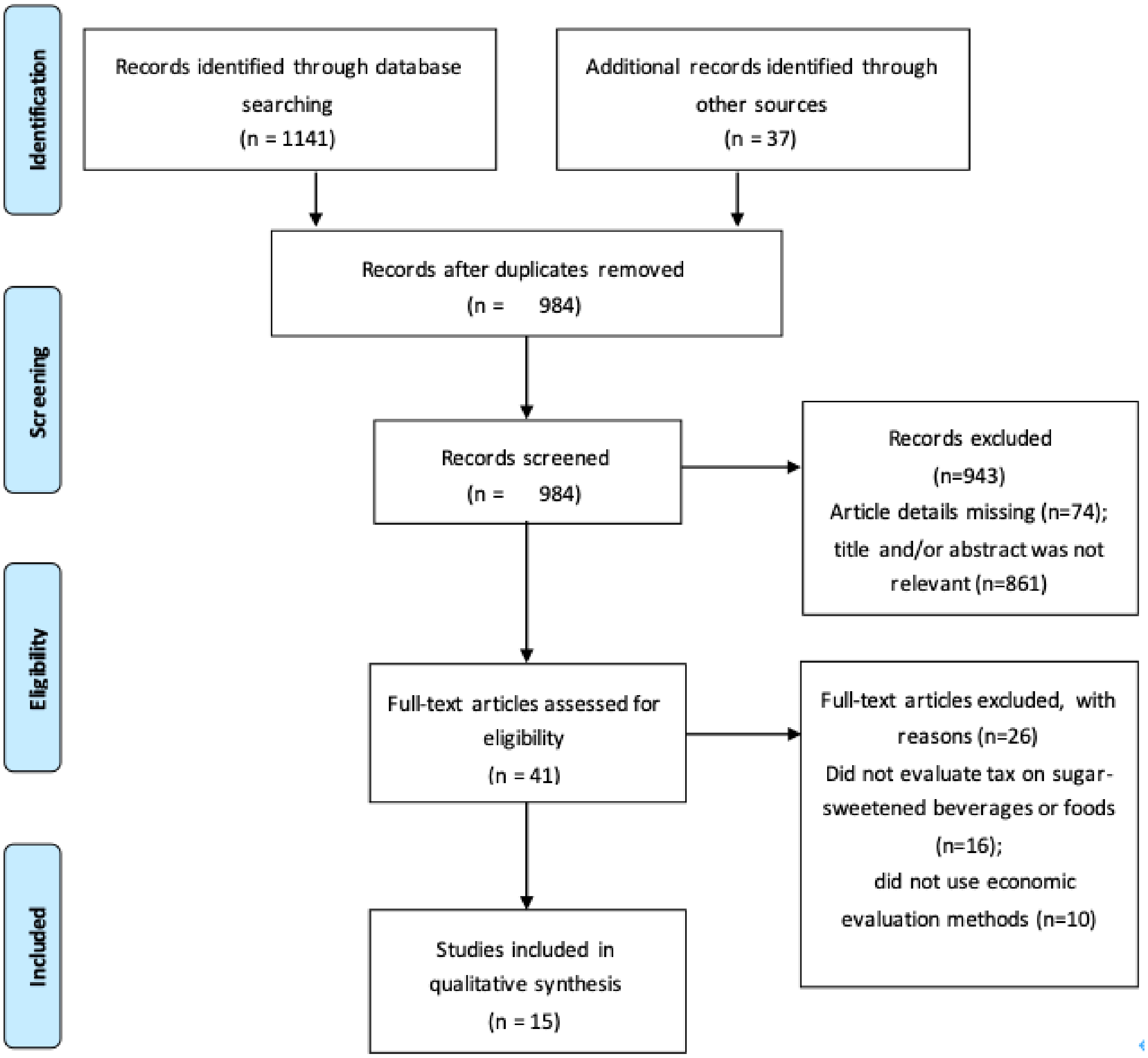

Figure 4 PRISMA flow diagram of the literature search process.

Table 7 Characteristics summary of studies on the cost-effectiveness of the sugar tax

Study/ Country/ Year	Intervention	Target population	Time horizon	Comparators	Model type	Health outcome measure	Perspective	Discount rate	Demand elasticity
Basu, et al. [22] U.S. 2013	A US$0.01 per ounce tax on SSBs	Adults aged 25-64 years old	10 years	1) Without interventions, 2) SSBs ban, 3) Vegetable subsidy, 4) Vegetable reward, 5) Budget increase, 6) Budget increase + cycle change	Stochastic, discrete-time microsimulation model	BMI, diabetes, and CVD mortality	Government	3%	1) Own-intake elasticity for SSBs: -1.0, 2) Cross-elasticity for juice, milk and diet beverages: 0.64, 0.13 and -0.52
Gortmaker, et al. [23] U.S. 2015	A US$0.01 per ounce excise tax on SSBs	Whole population	10 years	1) Without intervention, 2) Eliminating tax subsidy of TV advertising to children (TV AD), 3) Early care and education policy change (ECE), 4) Active physical education (Active PE)	Markov cohort simulation model	BMI, obesity-related diseases	Societal	3%	N/A
Long, et al. [30] U.S. 2015	A US$0.01 per ounce national excise tax on SSBs	Whole population	10 years	Without intervention	Markov cohort simulation model	BMI, obesity-related diseases	Societal	3%	1) Own-price elasticity of demand for SSBs: -1.22, 2) Cross-price elasticity of demand for milk and juice: 0.15, 0.69

Wilde, et al. [31] U.S. 2019	A US$0.01 per ounce national tax on SSBs	Adults aged 35 to 85 years old	Lifetime	Without intervention	Microsimulation model (CVD PREDICT)	BMI, CVD and diabetes	1) Health care sector, 2) Societal, 3) Distinct perspectives of the 9 stakeholder groups	3%	Own-price elasticity for SSBs: –0.66
Long, et al. [32] U.S. 2019	An excise tax of US$0.01/oz of SSBs	Whole population in Maine, U.S.	10 years	1) Without intervention, 2) Remove SSBs as Supplemental Nutrition Assistance Program (SNAP) eligible products	microsimulation model	BMI	N/A	3%	Own-price elasticity: -1.22
Lee, et al. [33] U.S. 2020	1) A US$0.01/oz tax on SSBs, 2) A tiers tax on SSBs, 3) A tax on absolute sugar content of SSBs (US$0.01 per teaspoon of added sugar) tax on SSBs	Adults aged 35-80 years old	10 years and lifetime	Without intervention	Microsimulation model (CVD PREDICT)	BMI, CVD, diabetes	1) Heath care, 2) Government, 3) Societal	3%	Own-price elasticity: -0.67
Veerman, et al. [34] Australia 2015	A 20% caloric tax on SSBs	Adults aged ≥20 years old	Lifetime	Without intervention	Proportional multistate life table model	BMI, obesity-related diseases	Health sector	3%	Own-price elasticity for soft drinks: -0.63
Cobiac, et al. [35]	1) A AU$0.47/l tax on sugar-sweetened soft drinks, energy drinks,	Whole population	Lifetime	1) Without intervention, 2) Taxes on saturated fat, 3) Taxes on salt, 4)	Proportional multistate	BMI, dietary-related	Health sector	3%	Food price elasticity and cross-price elasticity

Australia 2016	cordials, and fruit drinks, 2) A AU$0.94/100 ml tax on ice cream containing >10 g of sugar per 100 g of ice cream; a AU$0.85/100 g tax on sugar content in excess of 10 g per 100 g of all other products			A subsidy on fruits and vegetables	life table model	diseases, DM2			values from Ni Mhurchu et al. [42]
Lal, et al. [36] Australia 2017	A 20% tax on SSBs	Whole population	Lifetime	Without intervention	Markov cohort model	BMI	Societal	3%	Own- and cross-price elasticities of demand values from Sharma et al. [43]
Manyema, et al. [37] South Africa 2015	A 20% tax on SSBs	Adults aged ≥15 years old	20 years and lifetime	Without intervention	Proportional multistate table-based Markov model	BMI, DM2	N/A	0%	1) Own-price elasticity for SSBs: -1.30, 2) Cross-price elasticity for milk, fruit juice and diet drinks: 0.13, 0.39 and -0.42
Manyema, et al. [38] South Africa 2016	A 20% tax on SSBs	Adults aged ≥15 years old	20 years	Without intervention	Proportional multistate life table-based model	BMI, stroke	Health sector	0%	1) Own price elasticity for SSBs: -1.30, 2) Cross-price elasticity for milk, fruit juice and diet drinks: 0.13, 0.39 and -0.42
Collins, et al. [39] UK 2015	A 20% tax on SSBs	Adults	20 years	Without intervention	Simulation model	BMI, diabetes,	N/A	N/A	Price elasticity of demand: -0.691

						CVD, and cancer			
Jones, et al. [40] Canada 2018	A 20% tax on SSBs and sugary drinks (including 100% fruit juice)	Adults aged ≥20 years old	25 years	Without intervention	Multistate life table Markov model	BMI, BMI-related diseases, DM2	Health sector	3%	1) Own price elasticity: -1.20, 2) cross-price elasticity for 100% juice, milk and diet drinks: 0.21, 0.09 and -0.30
Kao, et al. [41] Canada 2020	A 20 % tax on sugary drink	Adults aged ≥20 years old	lifetime	Without intervention	Multistate life table Markov model	BMI, BMI-related diseases, DM2	Health sector	1.5%	1) Own price elasticity: range from -0.8715 to -0.9178, 2) cross-price elasticity for milk: range from 0.0227 to 0.0799, 3) cross-price elasticity for diet drinks: range from -0.0695 to 0.5025
Basto-Abreu, et al. [42] Mexico 2019	1) A 1 peso per liter tax on SSBs, 2) A 2 peso per liter tax on SSBs	Population ages 2-100 years old	10 years	Without intervention	A cohort simulation model	BMI, obesity-related diseases	N/A	3%	1) Own-price elasticity for 1 peso per liter tax: -0.76, 2) Own-price elasticity for 2 peso per liter tax: -1.52

BMI body mass index, CVD cardiovascular disease, N/A not applicable, SSBs sugar-sweetened beverages

Table 8 The cost-effectiveness of taxation of foods and beverages

Sugar tax	Health-related quality of life outcomes (95%CI [a] /UI [b])	Health care costs, intervention costs and tax revenue (US$ million, 95%CI/UI)	Cost-effectiveness analysis (95%CI/UI)
A US$0.01/oz tax on SSBs [22] U.S. 10-years	QALYs [c] saved: 26,000 (20,000 to 33,000)	1) Medical costs: -110 (-155 to -80); 2) Tax revenue: -15,234 (-17,671 to -13,132); 3) Total costs: -15,344 (-17,826 to -13,213)	Cost-effectiveness ratio (US$/QALY): -600,946 (-875,838 to -404,845)
A US$0.01/oz excise tax on SSBs [23] U.S. 10-years	1) DALYs [d] averted: 101,000 (34,800 to 249,000); 2) QALYs gained: 871,000 (342,000 to 2,030,000)	1) Health care costs: -26,649 (-61,993 to -10,535); 2) First year intervention cost: 57 (41 to 75); 3) Ten-year intervention costs: 452; 4) Net costs: -26,197 (-61,541 to -10,027); 5) Tax revenue: 14,115 per year.	1) Probability of net cost saving: 100%; 2) Net cost saved per $ spent (US$): 62 (24 to 158)
A US$0.01/oz national excise tax on SSBs [30] U.S. 10-years	1) Total life years saved: 32,300 (11,100 to 80,100); 2) Total DALYs averted: 101,000 (34,800, 249,000); 3) Total QALYs gained: 871,000 (342,000 to 2,030,000)	1) Healthcare costs: -26,649 (-61,993 to -10,535); 2) First year intervention costs:58 (41, 74); 3) Ten-year intervention cost: 486 (347, 623); 4) Annual revenue: 14,115 (10,072 to 15,922); 5) Net costs: –26,197 (–61,541 to –10,027)	1) Healthcare cost savings per $ intervention cost (US$): 62 (24 to 158); 2) ICER [e] : Net cost per LY [f] saved, Net cost per DALY averted, Net cost per QALY gained: Cost-saving
A US$0.01/oz national tax on SSBs [31] U.S. Lifetime	Aggerate QALYs saved: range from 30,000 (20,000 to 210,000) to 3,400,000 (1,850,000 to 4,770,000)	1) health care costs: range from -51,775 (-74,832 to -29,259) to 0 (0 to 0); 2) Intervention costs for societal: 2,117 (1,990 to 2,221); 3) Tax revenue for government: 105,736 (99. 638 to 111,293); 4) Net money cost: range from -122,603 (-125,526 to -120,233) to 50,602 (42,179 to 58,644)	1) ICER: Net money cost/QALY (US$/QALY) for consumers: range from 24,240 (13,632 to 43,484) to 50,934 (30,308 to 88,846); 2) Net money cost/QALY for societal: cost saving
A US$0.01/oz excise tax on SSBs [32] U.S. 10-years	QALYs saved: 3,560 (1,450 to 8,360)	1) Health care costs: -87 (-207, -35); 2) Intervention costs: 5 (3, 7); 3) Net costs: -83 (-200, -31)	Cost per QALY saved: Cost saving

A US0.01/oz tax on SSBs [33] U.S. Lifetimes	QALYs saved: 2,440,000 (2,400,000–2,480,000)	1) Health care costs: –58,123 (–59,077 to –57,168); 2) Intervention costs: 1,697 (1,676 to 1,718); 3) Industry reformation costs: 0; 4) Net costs: –56,426 (–57,380 to –55,471).	1) ICER (US$/QALY): Cost saving; 2) P(<US$50,000/DALY) compared with no intervention: 100%.
A tired tax on SSBs (<5 g of added sugar per 8 oz [tier 1]: no tax; 5–20 g/8 oz [tier 2]: US$0.01/oz; and >20 g/8 oz [tier 3]: US$0.02/oz) [33] U.S. Lifetimes	QALYs saved: 4,850,000 (4,780,000–4,920,000)	1) Health care costs: –113,488 (–114,549 to –111,367); 2) Intervention costs: 1,697 (1,676 to 1,718); 3) Industry reformation costs: 456 (456–467); 4) Net costs: –111,367 (–112,427 to –109,245).	1) ICER ($/QALY): Cost saving; 2) P(<$50,000/DALY) compared with volume SSBs tax: 96.1%.
A tax on absolute sugar content of SSBs (US$0.01 per teaspoon of added sugar) [33] U.S. Lifetimes	QALYs saved: 5,020,000 (4,960,000–5,090,000)	1) Health care costs: –113,488 (–115,609 to –112,427); 2) Intervention costs: 1,697 (1,676 to 1,718); 3) Industry reformation costs: 1,220 (1,199–1,230); 4) Net costs: –111,367 (–112,427 to –109,245).	1) ICER (US$/QALY): Cost saving; 2) P(<US$50,000/DALY) compared with tiered SSBs tax: 51.7%.
A 20% tax on SSBs [34] Australia. Lifetime	Gains of HALYs [g] :112,000 (73,000 to 155,000) for men and 56,000 (36,000 to 76,000) for women	1) Health care cost: -504 (-720, -305); 2) Intervention cost: 23	Cost saving
A AU$0.47/l tax on sugar-sweetened soft drinks, energy drinks, cordials, and fruit drinks [35] Australia. Lifetime	DALYs averted: 12,000 (2,100 to 21,000)	1) Diet-related disease costs: -174 (-323, -37); 2) Other disease costs: -58 (-99, -17), 3) Intervention cost: 18 (12, 26)	1) For diet-related diseases: Median CER: dominated, P(<$US50,000/DALY): 99%, P(dominant): 98%, 2) For all diseases: Median CER: dominant, P(<US$50,000/DALY): 99%, P(dominant):99%
A AU$0.94/100 ml tax on ice cream containing >10g/100g of ice cream; a AU$0.85/100g	DALYs averted: 270,000 (250,000 to 290,000)	1) Diet-related disease costs: -3,312 (-4,140 to -2,567); 2) Other disease costs: 1,076 (994 to 1,242); 3) Intervention cost: 18 (12, 26)	1) For diet-related diseases: Median CER: dominated, P(<US$50,000/DALY): 100%,

of sugar tax on sugar content >10g/100g of all other products [35] Australia. Lifetime			P(dominant): 100%, 2) For all diseases: Median CER: dominant, P(<US$50,000/DALY): 100%, P(dominant):100%
A 20% tax on SSBs [36] Australia. Lifetime	1) Total HALYs saved: 175,300 (68,700 to 277,800); 2) Total years of life saved: 111,700 (43,600 to 175,800)	1) Total healthcare costs: -1,435 (-2,272 to -538); 2) Out-of-pocket healthcare costs: -250 (-395 to -94); 3) Intervention cost: 99 (76 to 134); 4) Tax revenue: 532 (288 to 925)	1) Healthcare cost savings per capita (US$): 69 (26 to 108); 2) ICER: Net cost per HALY saved: cost saving
A 20% tax on SSBs [37] South Africa. Lifetime.	1) DALYs male: 2,800,000 (1,900,000 to 4,000,000); 2) DALYs female: 4,000,000 (2,600,000 to 6,000,000)	1) Healthcare costs for male: -4,273 (-6,647 to -2,374); 2) Healthcare costs for female: -11,751 (-16,142 to -7,359)	Cost saving
A 20% tax on SSBs [38] South Africa. 20-years	Total stroke-related DALYs averted: 550,000 (361,000 to 767,000)	Health care costs: -1,187 (-1,709 to -878)	Cost saving
A 20% tax on SSBs [39] UK. 20-years	QALYs gained /year: 40,908 (6,923 to 81,816)	Total health cost /year: -26 (-52 to -4)	Cost saving
A 20% tax on SSBs [40] Canada. 25-years	DALYs averted: 314,326 (256,268 to 376,504)	1) Health care costs: -6,925 (-8,294 to -5,689); 2) Total tax revenue: 23,830	Cost saving
A 20% tax on sugary drinks [40] Canada. 25-years	DALYs averted: 460,812 (390,171 to 535,277)	1) Health care costs: -10,051 (-11,726 to -8,494); 2) Total tax revenue: 32,760	Cost saving
A 20% tax on sugary drinks [41] Canada. Lifetime	1) Total DALYs averted: 690,000; 2) DALYs averted for different income quintiles: from 125,000 to 156,000	1) Health care costs for different income quintiles: from 1,980 to 2,270; 2) Total annual tax revenue: 1,400; 3) Annual tax revenue for different income quintiles: range from 264 to 299	Cost saving

A 1 peso/l tax on SSBs [42] Mexico 10-years	1) DALYs averted: 5,840 (3,090 to 9,040); 2) Life-years gained: 918 (493 to 1,420); 3) QALYs gained: 55,300 (42,500 to 68,700)	1) Total obesity-related costs: -104 (-168, -54); 2) Net health care cost: -103 (-167 to -53); 3) Intervention cost: 27.27	Cost saved per dollar invested (US$): 4 (2, 7)
A 2 peso/l tax on SSBs [42] Mexico 10-years	1) DALYs averted: 10,200 (5,400 to 15,900); 2) Life-years gained: 1,610 (900 to 2,470); 3) QALYs gained: 92,100 (71,500 to 115,000)	1) Total obesity-related costs: -180 (-292, -92); 2) Net health care cost: -179 (-92, -290); 3) Intervention cost:27.27	Cost saved per dollar invested (US$): 8 (4, 13)

[a] 95%CI: 95% confidence interval. [b] 95%UI: 95% uncertainty interval. [c] QALYs: quality-adjusted life years. [d] DALYs: disability-adjusted life years. [e] ICER: incremental cost-effectiveness ratio. [f] LY: life year. [g] HALY: health-adjusted life years.

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Chapter 5. Modelling the Health and Economic Impact of Sugary Sweetened Beverage Tax in Canada

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5.1 Abstract

Background: With the increasing concerns about the health and economic burden attributed to sugar-sweetened beverages (SSBs) consumption, the SSB tax has been put forward and implemented in many countries to control SSBs consumption. Many previous economic evaluations of SSB tax showed that SSB tax is cost-effective, however, the impact of SSB tax varied. Most previous SSB tax models have not considered the substitute effect of other foods and did not include all related chronic diseases (CDs) in the model. Thus, this study aims to design a comprehensive model to estimate the impact and cost-effectiveness of the SSB tax in Canada.

Methods: A proportional multi-state life table-based Markov model was chosen to estimate the impacts of sugar taxes in Canada. The health-related quality of life (including disability-adjusted life years (DALYs) and quality-adjusted life years (QALYs)), the costs (including health care costs and intervention costs), and the tax revenue were the main health and economic outcomes. We compared the simulated SSB tax with the current practice from the public health care payer perspective, and the tax was applied to the 2015 adult Canadian population up to 100 years. The economic model was built following the guidelines from the Canadian Agency for Drugs and Technologies in Health.

Results: After implementing a CAD$0.015/oz SSB tax, 282,104 cases of overweight and obesity, 210,542 cases of diseases, and 2,189 deaths could be prevented over the next 25 years. The simulated SSB tax has the potential to avert 2.3 million DALYs, gain 1.5 million QALYs, and save CAD$32,583 million health care costs in a lifetime period. The incremental cost-effectiveness ratio for the SSB tax was CAD$ -24,933/QALY. The SSB tax with different tax levels (CAD$0.01/oz and CAD$0.02/oz) remained cost-effective.

Conclusion: Implementing the SSB tax in Canada is a potential cost-effective policy option for reducing obesity and related CDs. The model built in this study provides a more accurate estimate for the health and economic impact of SSB tax and could be used to estimate other sugar tax options.

Keywords: Obesity; Chronic diseases; Sugar tax; Economic evaluation; Simulation modelling

5.2 Introduction

Unhealthy eating is a leading risk factor for obesity and related chronic diseases (CDs), such as diabetes mellitus type 2 (DM2) [1]. It contributes to 32% of deaths and 21% of the global risk-attributable disease burden [2, 3]. In Canada, the treatment and management of CDs attributed to unhealthy eating behaviours cost an estimated CAD$15.8 billion annually [4]. In order to decrease the health and economic burden, cutting down on unhealthy foods (e.g., fat, processed meats, and sugar-sweetened beverages (SSBs)) and promoting the consumption of healthy foods (e.g., V&F and nuts) has become a top priority.

The SSBs are beverages containing free sugars, including carbonated soft drinks, ready-to-drink sweetened tea and coffee, energy drinks, sports drinks, flavoured bottled water, sweetened milk and drinkable yogurt, fruit drinks, and 100% fruit juice [5]. Among dietary risk factors, the attributable burden of high SSBs consumption significantly increased over the past decades [2]. This increase attracts substantial public attention to take actions to reduce SSBs consumption. Many countries have implemented SSBs reduction policy programs, such as SSB tax, public awareness initiatives, and SSB labelling policies [6-8]. Research suggests that these interventions resulted in the increment in SSBs price and reduction in consumption [9, 10].

To date, there are over 40 countries that have implemented taxation of SSBs [10-12]. For example, Mexico implemented a 1 peso per liter excise tax on SSBs [6]. Compared with other policy options, the taxation strategy has been shown to be a cost-effective and feasible priority intervention [13-15]. The SSB tax could effectively reduce obesity and related CDs, improve the health-related quality of life (HRQoL), save health care costs, and generate tax revenues [10, 16-19].

Although all previous studies have a consistent conclusion, the magnitude of health and economic impacts of SSB taxes are variant due to the differences in the design of SSB tax, modelling methods, and parameters between studies [20]. The price elasticities and the number of CDs included in the model were two important parameters. Including more CDs and SSBs substitutes in the model could more accurately estimate the impact of sugar taxes. However, most previous SSB tax simulation studies only considered the limited substitutes (including water, plain milk, and diet beverages) and did not include all potential CDs related to SSBs consumption and body mass index (BMI) [21, 22]. Thus, in this study, we built a new model with more CDs and price elasticities to estimate the health and economic impact of SSB tax in Canada.

5.3 Methods

5.3.1 Model overview

In this study, we built a proportional multi-state life table-based Markov model to simulate the impacts of SSB tax on the 2015 Canadian adult population over their lifetime from the public health care payer perspective. The "business as usual" was modelled as a comparator based on the guidelines from the Canadian Agency for Drugs and Technologies in Health (CADTH) [23]. The health outcomes (e.g., disability-adjusted life years (DALYs) and quality-adjusted life years (QALYs)) and cost outcomes (including health care costs, tax revenue and intervention costs) were discounted at 1.5%. Model quality was checked using the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) [24]. The CHEERS Checklist could be found in Appendix D Table D1.

The baseline population was modelled as a closed cohort that replicated the 2015 adult Canadian population (20 years and above). The population aged over time until everyone was dead or reached the age of 100 years. Three parameters: population size, all-cause mortality rate, and the rate of prevalence years lived with disability (pYLD) were used to build the life table. These parameters were interpolated to 1-year age and sex group using the epidemiology software DisMod II (EpiGear, Version 1.05, Brisbane, Australia) based on the data from Statistic Canada [25, 26] and the Global Burden of Disease (GBD) Results Tool [27]. The life table only considers the age and sex of the population, ignoring other characteristics, such as education, ethnicity, and income.

The model diagram of sugar taxes for the intervention population is depicted in Figure 5. Taxation design, model selection, detailed parameters (e.g., pass-through rate and price elasticities), data sources and outcomes of the model are described in the next sections.

5.3.2 Intervention specification

In this study, we simulated flat taxes levy on the weight of SSBs. We simulated the CAD$0.01/oz, CAD$0.015/oz, and CAD$0.02/oz tax on all sugary beverages. The tax levels were set based on the implemented sugar taxes [13, 14, 17]. The simulated tax level is similar to the SSB tax implemented in Mexico (CAD$0.01/oz) [13] and Hungary (CAD$0.02/oz) [13]. The CAD$0.015/oz tax on SSBs was set as the base case, while all other taxes were shown in the scenario analysis.

5.3.3 Model type selection

There are various available model structures for the economic evaluation of sugar taxes [28]. In this study, we determined the model type using a flowchart adapted from Brennan et al. (Figure 6) [29]. Selection questions in Brennan et al.'s study were revised based on the taxonomy of model structure put forward by Barton et al. [30]. Questions related to interactions between individuals, the timing for costs or health outcomes, the knowledge of variability, and patient heterogeneity were considered in the selection process.

Based on the flowchart, we first considered whether interactions between individuals are important or not. Because the simulated SSB tax impacts disease risks rather than communicable disease risks, interactions between individuals are not important. The second question is about the importance of the timing for costs or health outcomes. Because we simulated the health and economic burden of SSB tax in Canada for a lifetime horizon, untimed models (i.e., decision trees or comparative risk assessment) were not selected. The third question is whether the knowledge of variability is important or not. Due to the decision-makers prefer to know the variability in the results rather than only mean outputs, stochastic models are better than deterministic models. The fourth question is about the importance of patient heterogeneity. Considering the differences in the history of diseases and co-morbidity are not important for this study, the patient-level Markov model was not selected. After finishing these selection steps, the simulation Markov model was selected as the most suitable model type for this study (Figure 6).

In addition, to increase the number of possible disease states, we combined the multistate life tables with Markov models. The transition probabilities were assumed to not change with the past states or time. Although the cohort state-transition model is restricted by the Markovian property, the multistate life table is a reasonable choice to simulate the effects of SSB tax. It is because the research model conceptualization involves a series of health states, interactions between individuals are not relevant, and the target population is a homogeneous cohort in a continuously longer time horizon [31, 32]. Furthermore, state-transition models are simple to develop, debug, communicate, analyze, and readily accommodate the evaluation of parameter uncertainty [31, 33].

5.3.4 Change in price of SSBs

After implementing the SSB tax, the manufacturers, distributors, and retailers would pass the sugar tax to consumers by increasing the product prices [34, 35]. The pass-through rate was expected to be heterogeneous across brands, retail groups, package size, and regions because companies and retailers might absorb some of the tax cost or increase the product price above the tax rate [34, 35]. Based on the price change of SSBs in Mexico [34] and France [35] and the pass-through rate used in the previous SSB tax simulation [20], we assumed the SSB tax would be 100% pass-through to consumers. The 80% and 120% pass-through rates were modelled in the sensitivity analysis. According to SSBs price on a Canadian grocery store website [36] and the consumer price index [37], we estimated the model baseline average SSBs prices in Canada to be CAD$0.35/100g. The CAD$0.01/oz, CAD$0.015/oz, and CAD$0.02/oz tax would increase mean around 10%, 15%, and 20% increase in SSBs price, respectively.

5.3.5 Change in consumption of SSBs and energy intake

The baseline consumption of SSBs and energy intake of Canadian residents were estimated based on the 24-hour dietary recalls of the 2015 Canadian Community Health Survey (CCHS) – Nutrition [38]. We estimated the mean and standard error of SSBs consumption and energy intake per day per person for each 10-year age and sex sub-group. Proportional sampling weights were applied to ensure estimates were representative of all residents of Canada.

The changes in consumption of SSBs and total energy intake (TEI) were assumed as a one-time reduction in one year and lasted for a lifetime, in line with the previous SSB tax model [20]. We used both the own- and cross-price elasticities of demand to measure the changes in consumption corresponding to the changes in the SSBs price. The own- and cross-price elasticity represents the proportional change in the purchase of a product in response to a 1% increase in its price and price of other products, respectively.

Because Canadian price elasticities were not available for most food categories consumed by Canadians [39], we used more recent own- and cross-price elasticities from New Zealand (Appendix D, Table D2) [40]. The price elasticities from New Zealand have comprehensive food categories, which include nearly all food categories consumed by Canadians [41]. Another reason for applying the price elasticates from New Zealand to the current study was that both New Zealand and Canada are classic immigrant countries with similar histories (i.e., British colonization) and economic levels. Although foreign price elasticities have been adapted in the previous SSB tax evaluations [17, 42], we also applied price elasticities from the US [43] in sensitivity analysis to estimate the changes in outcomes due to the choice of different price elasticities.

5.3.6 Change in body mass index

We extracted the baseline BMI by age and sex from the 2015 CCHS – Nutrition data and weighted them by the 2015 Canadian population. Proportional weights were calculated using the weight variable for measured height and weight. Considering the temporal change of BMI, we incorporated the model with the predicted BMI trends (Appendix D, Table D3) [44]. The changes in BMI attributed to the SSB tax were calculated using the energy equation in Swinburn et al.'s studies [45, 46]. The prevalence and prevented cases of overweight ($25<BMI\leq30$) and obesity ($BMI>30$) due to SSB taxes were also estimated.

5.3.7 Change in disease risks

In the simulation model, we included 27 BMI-related and two non-BMI-related CDs [2]. The CDs mediated by the BMI include esophageal cancer, colon and rectum cancer, liver cancers, gallbladder and biliary tract cancer, pancreatic cancer, breast cancer (premenopausal), uterine cancer, ovarian cancer, kidney cancer, thyroid cancer, non-Hodgkin's lymphoma, multiple myeloma, leukemia, ischaemic heart disease, ischaemic stroke, hemorrhagic stroke, hypertensive heart disease, atrial fibrillation and flutter, asthma, gallbladder and biliary diseases, Alzheimer's disease and other dementias, DM2, chronic kidney diseases (CKD), cataract, low back pain, gout, and osteoarthritis. The non-BMI-mediated CDs (related to SSBs) include DM2 and ischemic heart disease.

Relative risks (RRs) of these diseases for people aged 20 and above were from the 2017 GBD [2]. The potential impact fraction (PIF), defined as the proportional change in disease risk due to change in exposure to a related risk factor, was used to estimate the changes in disease incidence attributed to the changes in BMI or SSBs consumption [47]. Microsoft Excel and addins: Risk Factor (EpiGearXL 5.0) from EpiGear (Brisbane, Australia) were used to calculate the PIFs. The detailed formula of PIF was presented as follows.

$$PIF = \frac{\int_l^h RR\ \ (x)P(x)dx - \int_l^h RR\ \ (x)P^*(x)dx}{\int_l^h RR\ \ (x)P(x)dx}$$

Where x denotes the exposure levels the risk factor can take on, RR(x) is the RR function, P(x) is the original risk-factor distribution, P*(x) is the risk-factor distribution after the SSB tax, dx denotes that the integration is done with respect to x, and l and h are the integration boundaries [47].

Each disease was modelled separately in the model using an established disease model with four states (healthy, diseased, dead from disease and dead from all other causes) [48]. We collected the transition hazards between these four states of incidence, remission, case fatality and mortality from all other causes were collected from the Statistic Canada and the GBD Result Tool (Appendix D, Table D4) [28, 49-53]. These parameters were interpolated and smoothed to 1-year age and sex group using the DisMod II. The conceptual disease model is shown in Figure 7 [54]. Disability weights for DALYs calculation were borrowed from the WHO [55]. Corresponding changes in disease-specific incidence, prevalence and mortality for a lifetime were calculated in the life table model.

5.3.8 The cost-effectiveness analysis

Averted DALYs and saved QALYs were estimated in the proportional multi-state life table. Figure 8 shows the schematic of a proportional multi-state life table [56]. We used the disease-specific mortality combined with all other causes of mortality from the population to estimate the overall morbidity and mortality in the total population. The DALYs were constructed from the burden of disease from premature death (years of life lost) and the disabling results of illness (years lived with disability). The QALYs were estimated based on shifts in obesity prevalence and published QALY weights related to obesity by age and sex for adults [57].

The cost outcomes of the simulation model include health care costs, tax revenue and intervention costs. We calculated the differences in the direct health care costs (including hospital care, physician care, drug, other institutions, other professionals, capital, public health, administration, and the other health spending) between the interventions and the current practice. Data from the 2010 Economic Burden of Illness in Canada (EBIC) dataset [58] and methods from Jones [21] were used in the calculation. We did not include indirect costs in this study following the previous studies [20]. Detailed health care cost inputs can be found in Appendix D, Table D5.

Tax revenue was calculated based on the consumption of SSBs. Due to the absence of data regarding the costs of implementing sugar tax in Canada, the intervention costs were 2% of tax revenue based on the previous studies and data from the US operating a sugar tax [19, 59]. All cost estimations were presented in 2015 Canadian dollars [37]. Additionally, we computed the incremental cost-effectiveness ratios (ICERs) for each intervention compared with the no intervention scenario. The ICERs were calculated by dividing the difference in expected health care costs by the difference in expected health outcomes. We did not include the tax revenue and intervention costs because we used the public health care payer perspective.

5.3.9 Uncertainty and sensitivity analysis

We conducted a Monte Carlo simulation with bootstrapping (2000 iterations) while incorporating probabilistic uncertainty from model inputs (including mean BMI, RRs, the effect of change in energy intake on weight, free sugar intake and price elasticity of demand) using the Ersatz (Version1.34). Uncertainty intervals (95% uncertainty intervals (UI)) were calculated for reflecting parameter uncertainties. In addition, we conducted sensitivity analyses to assess the effect of modifying key assumptions and parameters on the results. Parameters vary as followed: (1) the BMI trend estimates (BMI remain at 2015 levels), (2) pass-through rate (80% and 120%), (3) discount rate (3%), and (4) price elasticities from the US [43].

5.4 Results

5.4.1 Health benefits of the SSB tax

After one year of the implementation of a CAD$0.015/oz (base case) SSB tax, SSBs consumption was estimated to reduce by 17%. On average, the TEI would decrease by 19.25 kcal (95%UI: 18.73, 19.80) for males and 12.28 kcal (95%UI: 11.93, 12.63) for females. The SSB tax produced a reduction in BMI of 0.18 (95%UI: 0.18, 0.19) for males and 0.14 (95%UI: 0.14, 0.15) for females. Compared with adults, children and adolescents showed more decrement in SSBs consumption, TEI, and BMI due to SSB tax (Appendix E Table E1, Table E2). The SSB tax was estimated to reduce the mean prevalence of overweight and obesity by 0.91% for males and

0.68% for females. After implementing the SSB tax, 160,567 and 121,537 cases of overweight and obesity could be prevented for males and females, respectively. The simulated SSB tax was projected to prevent a total of 210,542 (95% UI: (195,995, 223,869) new cases of CDs and 2,189 (95% UI: 1,866, 2,447) deaths over the next 25 years (2016-2041) The prevented incident cases and deaths over 25 years for each disease can be found in Appendix E Table E3.

5.4.2 Cost-effectiveness of the SSB tax

Table 9 shows the health impact, costs, and cost-effectiveness of a CAD$0.015/oz SSB tax. As a result of the SSB tax, the Canadian adult population were estimated to avert 2,291,373 (95% UI: 2,005,544, 2,559,716) DALYs and to save 1,509,349 (95% UI: 1,345,378, 1,655,787) QALYs over a lifetime period. The overall lifetime direct health care cost savings attributable to the SSB tax were CAD$37,548 million (95% UI: CAD$34,155, 39,784 million). Males were estimated to have more health benefits and health care costs offsets than females (Table 9). The SSB taxes was cost-effective with negative ICER (CAD$-24,933/QALY, 95% UI: -27,569, -23,043).

Table 9 also shows that the simulated SSB tax was projected to generate $44,016 million (95% UI: CAD$43,346, 44,620 million) tax revenue over the lifetime period. The costs of the government to implement the SSB tax were estimated at CAD$880 million (95% UI: CAD$867, 892 million).

5.4.3 Scenario analyses

Figure 9 shows the impact of the CAD$0.01/oz and CAD$0.02/oz SSB tax in Canada. In general, the higher-level tax could bring more health benefits and save more costs for the treatment and management of CDs. The CAD$0.02/oz SSB tax was estimated to avert 27% more DALYs and gain 26% more QALYs than the CAD$0.015/oz SSB tax. The CAD$0.01/oz SSB tax was estimated to avert 36% fewer DALYs and gain 34% less QALY than a CAD$0.015/oz SSB tax. The combined health care costs saving, tax revenue, and intervention costs for the CAD$0.01/oz and CAD$0.02/oz SSB tax were estimated at CAD$55,364 million and CAD$104,202 million, respectively.

5.4.4 Sensitivity analyses

The results of univariate sensitivity analyses with comparisons to base case tax scenarios (Table 10) show that after removing the BMI trend over time, the health benefits and health care cost offsets changed minimally. When the SSB tax did not pass to consumers completely (i.e., 80% pass-through rate), health benefits and health care cost savings would decline by around 20% accordingly. Passing more tax to consumers (i.e., 120% pass-through rate) was estimated to gain around 20% more DALYs, QALYs and health care cost offsets.

The discounting rate had a substantial impact on outcomes (Table 10). There was about a 50.5% decline in DALYs averted, a 49.2% reduction in QALYs gained, and a 38.7% of decrement in health care cost offset when outcomes discount rate was increased from 1.5% to 3% in the lifetime period. Price elasticities also have unignorable impacts on outcomes of simulated sugar taxes. When we applied the US price elasticities, the outcomes of the SSB tax would decrease by around 17%.

5.5 Discussion

This study showed that a CAD$0.015/oz SSB tax in Canada would decrease SSBs consumption, TEI, and BMI. These changes would reduce 282,104 cases of overweight and obesity, prevent 210,542 new cases of CDs, avert 2.3 million DALYs, and gain 1.5 million QALYs over the lifetime of the adult population. From a public health care payer's perspective, the simulated SSB tax was cost-effective with CAD$ -24,933/QALY ICER, and it would save CAD$37,548 million in health care costs. The simulated tax has the potential to generate CAD$43,136 million in net tax revenue for implementing SSB tax over the lifetime period.

The findings in the current study support the conclusions of previous Canadian [21, 42] and international economic evaluations: the sugar tax on SBBs is a cost-effective policy to improve population health [20]. The implementation of the SSB tax would lead to substantial health benefits for Canadian society. The intervention costs were only 1% of the combined health cost offsets and tax revenue. Compared with findings of the previous economic evaluation studies where SSB tax has the potential to avert 5,840 to 2,800,000 DALYs and save CAD$10.7 to CAD$105 billion in health care costs [20], the estimated outcomes of SSB tax in the present study were at the higher level. Furthermore, consistent with the previous Canadian SSB tax evaluations [21, 42], this study indicates that males were estimated to reduce more SSBs consumption and energy intake and gain more health benefits and cost savings than females after implementing SSB tax.

The variation in outcomes of the SSB tax among previous studies came from the differences in many factors, such as target population, time horizon, included diseases, etc. [20]. The SSB tax simulated in this study has relatively higher impacts on outcomes partly because we estimated the SSB tax for all adult populations over lifetime horizons in Canada. Some previous studies only estimated SSBs tax for the working-age population aged 25 to 64 over a shorter period (e.g., ten years) [20]. In addition, the different number of CDs included in the SSB tax model would lead to different outcomes. Compared with the previous Canadian study that used the same population and simulation method [24, 57], the same level (20%) SBB tax simulated in this study would avert three times more DALYs and health care costs. The main reason is that we included all the RRs of diseases related to BMI and the SSB consumption from the 2017 GBD studies in the simulation model [48]. Unlike many previous modelling studies of the SSB tax (including two Canadian studies [21, 42]) that only included part of related diseases [20], our estimation could avoid underestimation of the health and economic benefits of the SSB tax.

The price elasticities of SSBs are significant factors in the sugar taxes simulation. In this study, we used both the own- and cross-price elasticities of SSBs. The own-price elasticities showed that SSBs are elastic, and SSB tax could effectively reduce SSBs consumption. The cross-price elasticities reflected the complement consumption of all untaxed foods and beverages in Canada. It helped us more accurately estimate the changes in TEI, BMI, and BMI-mediated disease risks attributed to the SSB tax. In this study, we used price elasticities from New Zealand [40] because Canada did not have comprehensive price elasticities that covered all food categories consumed by Canadians. The sensitivity analysis using price elasticities from the US [43] showed that the SSB tax remained highly cost-effective when applying different price elasticities. The variations in health and economic outcomes due to applying different price elasticities were lower than in other parameters.

Some other key assumptions and parameters are worth to be noticed. First, we assumed that the BMI of the modelled population would change following the predicted historic BMI trends [44]. The trend was estimated using the existing age and sex regression coefficient derived from the CCHS 2001-2018 [44]. Considering the BMI might not change following this trend for the next 80 years, we conducted the sensitivity analysis to test the impact of this BMI trend by removing it from the model. Second, we assumed 100% of the SSB tax would be passed to the consumers and showed on the price tags due to the lack of Canadian data showing the price changes due to SSB tax. To reflect how pass-through rate changes outcomes of SSB tax, we assumed 80% and 120% tax were passed to consumers in the sensitivity analysis based on the data from other countries that have implemented SSB tax and previous SSB tax simulation model [34, 35]. Third, we used the health and economic outcomes discount rate of 1.5% yearly based on CADTH guidelines [26]. Because some economic evaluation guidelines in other countries recommend a 3% discount rate [60], we used it in the sensitivity analysis. Except for the discount rate, these assumptions had relatively small impacts and would not change the interpretation of the results.

This model provides a good reference for future research that evaluates similar policies or programs. The SSB tax model built in this study has several strengths. We designed different levels of SSB tax in the scenario analysis to provide more information about the impact of the tax level. We estimated both DALYs and QALYs as health outcomes of sugar taxes in the model. It allows us to calculate ICERs and compare different policies and international studies. Moreover, this study conducted an age and sex-specific analysis. The results reflected the difference in the impact of SSB tax comes from the different individual-level characteristics of consumers [22]. For example, the younger age groups showed more changes in SSB consumption, TEI, and BMI due to the SSB tax. Additionally, we included all related CDs identified by the 2017 GBD [2] and considered both the own and cross-price elasticities of a wide range of relevant Canadian food and beverage items. It avoided the bias in the estimation of impacts of SSB tax in most previous Canadian and international studies.

Several limitations warrant consideration. Firstly, the price elasticities of demand from New Zealand used in the model lead to bias. Based on the sensitivity analysis, we found that this bias is small and would not impact the high cost-effectiveness of the SSB tax. We also assumed that CDs included in the model were independent of each other. Although it can avoid double counting and simplify the model structure, the assumption ignores the comorbidities of CDs. It might lead to underestimation of outcomes and ICERs of SSB tax. In addition, we used the 24h dietary recalls from the 2015 CCHS – Nutrition dataset, which is the best and largest survey available in Canada. However, it is prone to error as every dietary assessment method. We also assumed that the dietary pattern would change as a one-time in one year, which might result in overestimating the long-term outcomes. More future studies that estimate the long-term impact of the sugar taxes on demand are needed. Lastly, due to the data restriction of disease risks, we only estimated the health impacts of SSB taxes on Canadian adults aged 20 years and above. The current study is unable to reflect changes in DALYs, QALYs and health care costs attributed to SSB taxes for children and adolescents. Due to the very low prevalence of CDs among those age groups, the impact of this age-group exclusion on the results could be negligible.

5.6 Conclusion

The implementation of the SSB tax in Canada would be a cost-effective policy option to reduce obesity and related CDs and improve quality of life. The combination of SSB tax revenue and health care costs was much higher than intervention costs. The SSB tax simulation model that includes all related CDs identified by the 2017 GBD and the substitute effects of all untaxed products could be used in future research to explore the impact of other sugar tax options.

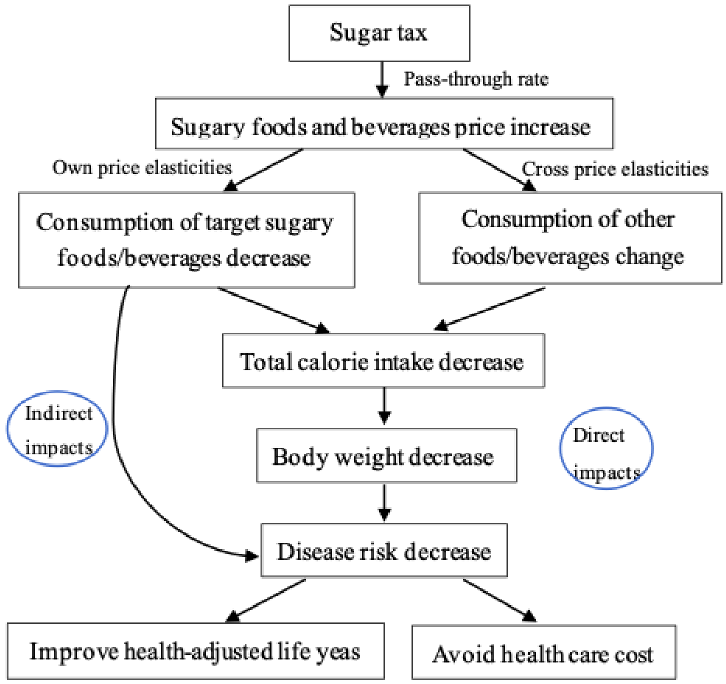


Figure 5 The model diagram of a simulated sugar tax for the intervention population

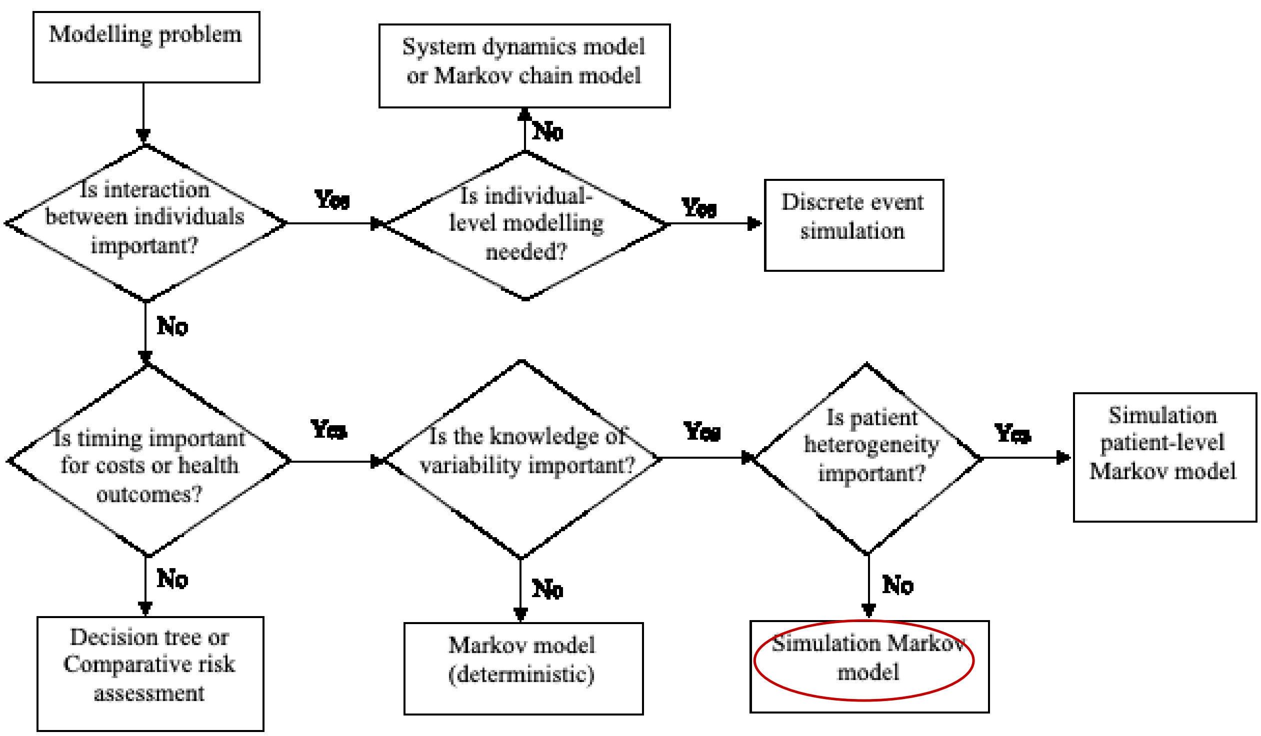
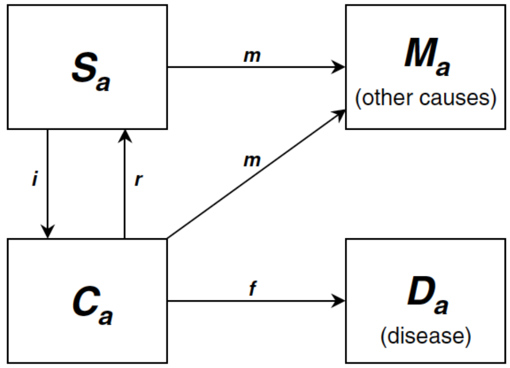
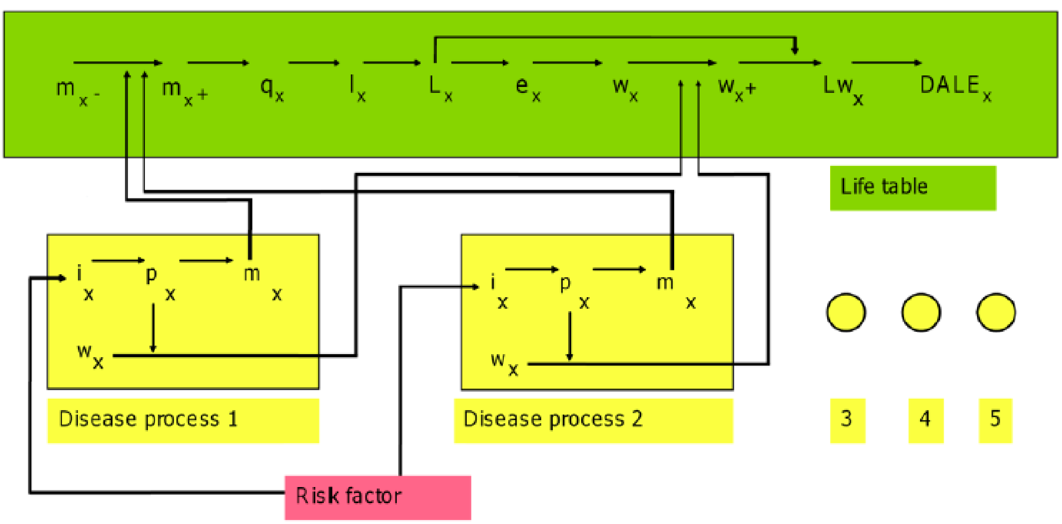


Figure 6 Model type selection flowchart for the economic evaluation of a sugar tax. Adapted from Brennan et al. [29].



S: number of healthy people (i.e., without the disease under consideration); C: number of diseased people; D: number of people dead from the disease; and M: number of people dead from all other causes, with an age subscript. There are four transition hazards: i: incidence, r: remission, *f*: case fatality, and m: all other mortality.

Figure 7 The conceptual disease model. Adapted from Barendregt et al. [54].



x is age; i is incidence; p is prevalence; m is mortality; w is pYLD; q is probability of dying; l is number of survivors; L is life years; Lw is disability-adjusted life years; e is life expectancy and DALE is disability-adjusted life expectancy, and where '-' denotes a parameter that specifically excludes modelled diseases, and '+' denotes a parameter for all diseases (i.e., including modelled diseases).

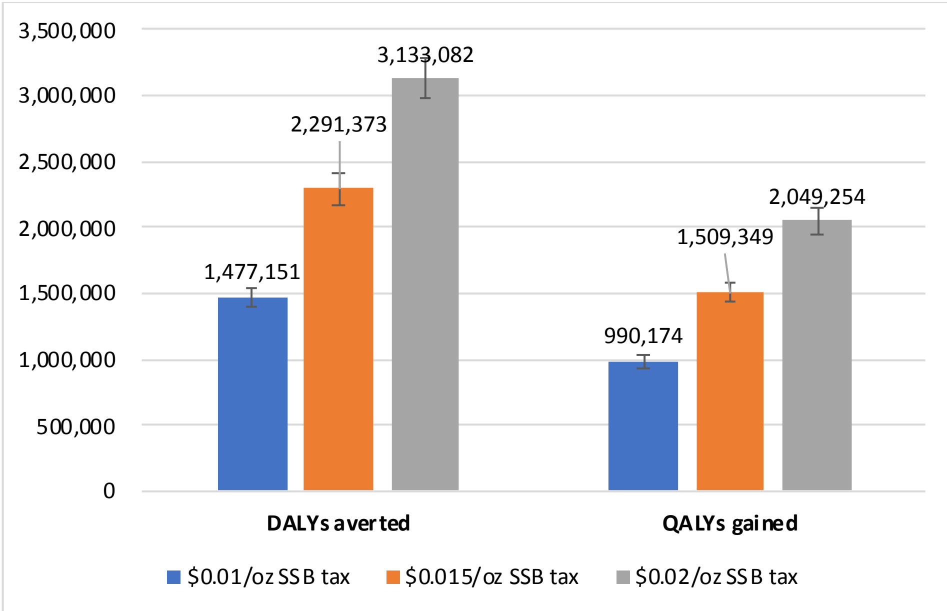
Figure 8. The schematic of a proportional multi-state life table. From Lee et al. [56].

Table 9 Lifetime population health impact, costs, and cost-effectiveness of a CAD$0.015/oz SSB tax in Canada

	Females	Males	Females and Males
Health outcomes			
DALYs[1] averted	895,316	1,396,057	2,291,373
	(795,638, 992,823)	(1,209,906, 1,566,893)	(2,005,544, 2,559,716)
QALYs[2] gained	573,750	935,599	1,509,349
	(520,936, 623,612)	(824,442, 1,032,175)	(1,345,378, 1,655,787)
Health care cost offset (CAD$ millions)	14,801	22,747	37,548
	(13,620, 15,717)	(20,535, 24,067)	(34,155, 39,784)
ICER[3] (CAD$/QALY)	-25,850	-24,369	-24,933
	(-28,668, -23,741)	(-26,874, -22,605)	(-27,569, -23,043)
Tax revenue (CAD$ millions)	17,378	26,675	44,016
	(16,889, 17,693)	(26,076, 27,028)	(43,346, 44,620)
Intervention costs (CAD$ millions)	348 (338, 354)	534 (522, 541)	880 (867, 892)

Values are presented as mean (95% uncertainty interval). [1] DALYs: Disability-adjusted life years; [2] QALYs: Quality-adjusted life years; [3] ICERs: Incremental cost-effectiveness ratio. All values were discounted by 1.5% to their present values (2015).

(A). DALYs averted and QALYs gained



(B) Health care cost offsets, tax revenue, and intervention costs (CAD$ million)

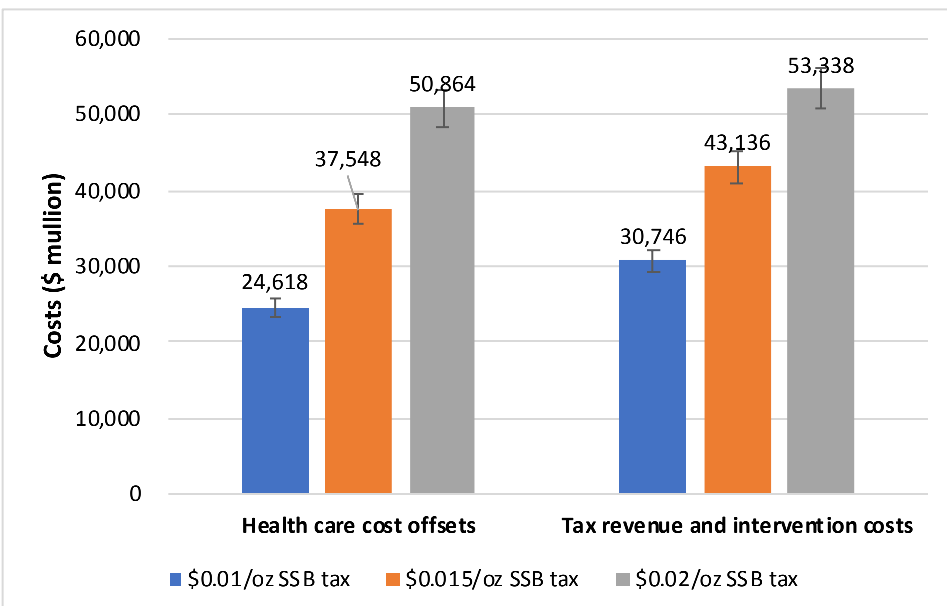


Figure 9 The comparison of CAD$0.01/oz, CAD$0.015/oz, and CAD$0.02/oz SSB tax for a lifetime period. (A) DALYs averted and QALYs gained; (B) Health care cost offsets, tax revenue, and intervention costs.

DALY: Disability-adjusted life years. QALY: quality-adjusted life years. Error bars represent 95% uncertainty intervals.

Table 10 Sensitivity analyses for a CAD$0.015/oz SSB tax in Canada in the lifetime period

	Lifetime DALYs averted		**Lifetime QALYs gained**		**Health care cost offsets (CAD$ million)**		**Tax revenue and intervention costs (CAD$ million)**	
A CAD$0.015/oz SSB tax - base case	2,291,373		1,509,349		37,548		43,136	
1) BMI remain at 2015 levels	2,291,250	-0.5%	1,514,604	-0.3%	37,333	-0.6%	42,913	-0.5%
2) Tax pass-on 80%	1,774,659	-22.6%	1,181,832	-21.7%	29,602	-21.2%	35,751	-17.1%
3) Tax pass-on 120%	2,842,662	24.1%	1,859,558	23.2%	46,085	22.7%	49,202	14.1%
4) Health gains and costs discounted by 3%	1,133,389	-50.5%	766,270	-49.2%	23,031	-38.7%	28,371	-34.2%
5) Price elasticities from the US	1,899,407	-17.1%	1,245,633	-17.5%	31,838	-15.2%	44,052	2.1%

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Chapter 6. The Cost-Effectiveness of Sugar Taxation and Vegetables and Fruit Subsidy Scenarios in Canada

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6.1 Abstract

Background: Several countries and jurisdictions have introduced a tax on sugar-sweetened beverage (SSB) to curb sugar consumption. With only a small portion of all sugar originating from SSBs, the benefit of this tax is limited while introducing a disproportional tax burden to low-income groups. In the present study, we illustrate the impact of taxation on SSBs and other sources of free sugar along with subsidies on healthful foods in terms of health benefits, cost-effectiveness, and socioeconomic inequities, to provide public health decision makers with policy options for chronic disease prevention.

Methods: Based on consumption patterns obtained from the 2015 Canadian Community Health Survey-Nutrition and a proportional multi-state life table-based Markov model, we simulated three tax scenarios: 1) a CAD$0.75/100g sugar tax on SSBs; 2) a CAD$0.75/100g free sugar tax on all sugary foods; and 3) a 20% subsidy on vegetables and fruit (V&F).

Results: Over the next 25 years, the tax on SSBs, tax on sugary foods, and subsidy on V&F could prevent 28,921, 233,427 and 551 cases of type 2 diabetes, respectively. These three scenarios would avert 752,353, 11,414,760, and 29,447 disability-adjusted life years (DALYs), respectively, and save CAD$12,942, 136,985, and 442 million health care costs, respectively, over a lifetime. Although the lowest income quintile would bear the highest tax burden in sugar taxes (0.80% of income, CAD$119/person/year), this would be more than compensated by a coinciding subsidy on V&F (1.30% of income, CAD$194/person/year).

Conclusion: The health and economic benefits of the tax on sugary foods are markedly higher than those on the SSBs alone, whereas the subsidy on V&F will bring additional health benefits and compensates for a disproportional tax burned for low-income groups. We recommend public health decision makers consider combinations of sugar taxes and V&F subsidies to curb sugar consumption, reduce future health care costs, and mediate socioeconomic inequities.

Keywords: Chronic diseases; Fiscal Policy; Sugar tax; Economic evaluation; Equity; Public Health; Health Promotion; Simulation Modeling; Sugar; Vegetables and Fruit

6.2 Introduction

Various studies have established the putative role of sugar consumption for weight gain, high lipid levels, metabolic syndrome, diabetes mellitus type 2 (DM2), cardiovascular disease (CVD), various cancers, and dental caries [1-6]. Taxation of sugar is one of several public health approaches to reduce sugar consumption, prevent the aforementioned conditions and diseases, and to avoid associated health care costs. [7]. Various countries and jurisdictions have implemented a tax on sugar-sweetened beverages (SSBs) [2, 8-12], and studies have confirmed the benefits of this tax for health-related quality of life (HRQOL), disease prevention and reductions in health care costs [13]. SSBs represent only one source of sugar in the diet. Many other food items contribute to excess sugar consumption. The World Health Organization (WHO) introduced the term free sugars as a means to quantify excess sugar consumption. They define free sugar as "sugar added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and fruit juice" [14]. In Canada, 17.5% of free sugar comes from SSBs [15] thus a tax on SSBs would only apply to a small share of free sugar in the diet. Where a few countries (e.g., Finland and Norway) have introduced a tax on sugary foods beyond the tax on SSBs [8, 12, 16], to date, no country or jurisdiction has introduced a tax capturing all sources of free sugar.

Taxation of foods and beverages will increase the costs to the consumer and herewith the likelihood that pricier healthful foods for some consumers will no longer be affordable [12]. In addition, some studies on taxation of SSBs have revealed that socioeconomic disadvantaged groups in fact bear a higher tax burden relative to wealthier groups [17, 18]. Utilizing the revenues from a tax on sugar towards subsidies on healthful foods (e.g., vegetables and fruit (V&F)) may come with additional health benefits while mediating the tax burden for socioeconomic disadvantaged groups [12]. However, no earlier work has confirmed or illustrated this.

In the present study we estimate the impact of taxation on SSBs and all sources of free sugar along with subsidies on V&F in terms of health benefits, cost-effectiveness, and socioeconomic inequities, to provide public health decision makers with policy options to curb sugar consumption, reduce future health care costs, and mediate socioeconomic inequities.

6.3 Methods

6.3.1 Taxation and subsidy scenarios

In this study, we designed three taxation and subsidy scenarios: 1) a CAD$0.75/100g free sugar tax on SSBs, 2) a CAD$0.75/100g free sugar tax on all sugary foods, 3) a 20% subsidy on V&F. The tax on sugary beverages and foods were specific taxes levied on the amount of free sugars contained in sugary products. We modelled and presented the tax on SSBs and tax on sugary foods separately to compare the impact of these two taxes. The tax levels were set based on the implemented sugar taxes or existing simulated sugar taxes [7, 8, 20]. In addition, we simulated a 20% subsidy for V&F since the V&F subsidy has shown to be highly beneficial for population diet, and low-income groups would gain more health benefits from it [12]. The V&F subsidy level was set based on the recommendation from the WHO to make sure it could change consumption behaviors [21].

6.3.2 Modelling framework

This study used an established proportional multi-state life table-based Markov model (Chapter 5) to simulate the impacts of sugar taxes on the 2015 Canadian population over their lifetime from the public health care payer perspective (Appendix D, Figure D1). The health outcomes (i.e., DALYs and quality-adjusted life years (QALYs)) and costs (including health care costs, tax revenue and intervention costs) were modelled by comparing "business as usual" and different sugar tax scenarios [22]. The discount rate of these outcomes was 1.5%. The sugar taxes model diagram, model selection, detailed parameters (e.g., pass-through rate and price elasticities), formulas, and data sources were depicted in our previous study (Chapter 5). We also simulated the impacts of V&F subsidies. The model diagram of V&F subsidies for the intervention population is depicted in Appendix D Figure D2. The simulation method, data sources, and key assumptions of models are shown below.

6.3.3 Change in dietary pattern and related diseases

The baseline product prices, free sugar intake, energy intake, and consumption of V&F were from a Canadian grocery store website and the 2015 Canadian Community Health Survey (CCHS) – Nutrition dataset [23, 24]. We estimated the changes in the dietary pattern assuming that the taxes and subsidies would pass through 100% to consumers, in line with the previous studies [13]. We estimated the changes in consumption of products after price changes using the established own- and cross-price elasticates from New Zealand that followed the same type of food categories as the CCHS database [26]. The pre- and post-tax prices of main food categories with free sugar are shown in Appendix D Table D6. The baseline BMI by age and sex were extracted from the 2015 CCHS – Nutrition dataset and were incorporated in the model with the predicted BMI trends [26]. The changes in BMI attributed to the sugar tax were calculated using the energy equation from Swinburn et al [27, 28].

For the sugar taxes, relative risks (RRs) of 27 body mass index (BMI)-related and two non-BMI-related diseases (i.e., DM2 and ischemic heart disease) were included in the simulation model from the 2017 Goble Burden of Disease (GBD) [29]. We assumed that a serving (2.5 g) of SSBs contains 0.253g of free sugar [15]. For the V&F subsidy, we included RRs of 11 non-BMI-related diseases (e.g., lip and oral cancer, ischaemic heart disease, and DM2) from the 2017 GBD [29] in the model. The potential impact fraction (PIF) was calculated to estimate the proportional change in disease risks due to change in BMI, free sugar intake, and consumption of V&F [30]. Corresponding changes in disease-specific incidence, prevalence and mortality for a lifetime were calculated in the life table model [31] that replicated the 2015 adult (20 years and above) Canadian population. The life table was built based on population size, all-cause mortality rate, and the rate of prevalence years lived with disability (pYLD) using data from Statistic Canada [32, 33] and the Global Burden of Disease (GBD) Results Tool [34].

6.3.4 The cost-effectiveness analysis

In the life table, the overall morbidity and mortality in the total population were estimated by combining the disease-specific mortality with all other causes of mortality. The diseases were modelled separately in a disease model using DisMod II [35]. The DALYs were estimated based on premature death (years of life lost) and the disabling results of illness (years lived with disability) from the WHO [36]. The gained QALYs were estimated based on shifts in obesity prevalence using published QALY weights related to obesity [37]. Due to CDs related to a diet low in V&F are not BMI mediated, this QALY weight was not used in the V&F subsidy model.

The direct health care cost offsets attributed to taxes and subsidies were estimated using disease costs from the 2010 Economic Burden of Illness in Canada (EBIC) dataset [19, 38] and prevented cases of diseases. Tax revenues and subsides were calculated based on the consumption of related foods and beverages. Following the previous studies and data from the

US operating fiscal policies [39, 40], the intervention costs were estimated as 2% of tax revenue or subsidies. All cost estimations were presented in 2015 Canadian dollars, and all outcomes were discounted at 1.5% [41]. The incremental cost-effectiveness were calculated by dividing the changes in expected health care costs by the changes in expected QALYs for sugar taxes and DALYs for the V&F subsidy.

6.3.5 Socioeconomic gradients analysis

We estimated health and economic outcomes, tax burden, and subsidies among different income groups in Canada to examine the effect of simulated taxes and subsidies on equity. Based on the household income distribution provided by the 2015 CCHS – Nutrition, the consumption of V&F, free sugar intake, energy intake, and BMI for five income quintiles were estimated separately. The 2015 population was divided into five quintiles by sex and 5-year age groups using the ratios from the 2016 Census data [42]. The mortality rate for each quintile was obtained based on the ratios from Statistic Canada [43]. The own-price elasticities for each quintile were extracted from Mhurchu et al. (Appendix D, Table D7) [25]. Data sources and direct health care cost inputs for these diseases are present in Appendix D (Table D8, Table D9).

6.3.6 Uncertainty and sensitivity analysis

To generate uncertainty intervals (95% uncertainty intervals) for primary outcomes, we conducted a Monte Carlo simulation with bootstrapping (2000 iterations) using the Ersatz (Version1.34). In addition, we conducted sensitivity analyses to assess the changes in outcomes for different levels of sugar taxes (i.e., CAD$0.5/100g and CAD$1/100g). We also estimated the changes in outcomes if we modified key assumptions and parameters of the model, including no BMI trend, 80% and 120% pass-through rate, 3% discount rate, and another set of price elasticities from the US [44].

6.4 Results

6.4.1 The effect of taxes and subsidies on dietary pattern

On average, the simulated CAD$0.75/100g free sugar content tax on sugary beverages was estimated to reduce free sugar consumption by -1.60 g/day (95%UI: -1.64, -1.56) for males and -0.98 g/day (95%UI: -1.01, -0.96) for females. The simulated CAD$0.75/100g free sugar content tax on sugary foods has the potential to decrease -6.73 g/day (95%UI: -6.87, -6.58) free sugar intake for males and -5.81 g/day (95%UI: -5.92, -5.71) for females. The subsidy on V&F would result in consumption of V&F increase by 50.37 g/day (95%UI: 50.08, 50.80) and 51.64 g/day (95%UI:51.20, 52.23) for males and females, respectively.

The changes in free sugar intake and V&F consumption for each age and sex group were shown in Appendix E, Table E4. For the SSB tax, the younger age groups had bigger impacts on free sugar intake, while for the sugary food tax, the age-specific differences were small and didn't follow any particular pattern for both males and females. For the V&F subsidy, consumption of V&F increased slowly by age until middle age and then started to decrease in older adults for both males and females.

6.4.2 The effect of taxes and subsidies on related diseases

On average, a CAD$0.75/100g free sugar content tax on sugary beverages produced a reduction in BMI of 0.07 (95%UI: 0.07, 0.07) for males and 0.06 (95%UI: 0.06, 0.06) for females (Appendix E, Table E5). The SSB tax was estimated to reduce the mean prevalence of overweight by 0.09% and the prevalence of obesity by 0.23% (Figure 10). The 30,873 cases of overweight and 81,338 cases of obesity could be prevented after the implementation of the SSB tax (Table 11).

Changes in BMI, prevalence and prevented cases of overweight and obesity for tax on sugary foods were larger than changes for tax on SSBs. After implementing a CAD$0.75/100g free sugar content tax on sugary foods, the average BMI decreased by 1.16 (95%UI: 1.15, 1.17) and 1.17 (95%UI: 1.16, 1.18) for males and females, respectively (Appendix E, Table E5). It would result in a 1.73% and 4.20% reduction in the prevalence of overweight and obesity, respectively (Figure 10), equating to prevent 618,745 cases of overweight and 1,501,092 cases of obesity (Table 11). For both SSB tax and tax on sugary foods, males contributed to over a half of prevented cases of overweight and obesity.

The prevented incident cases and deaths over the next 25 years (2016-2041) from the main disease categories are shown in Table 12. Appendix E Table E6 shows the detailed information for each disease. The simulated tax on sugary beverages was projected to prevent a total of 84,033 (95% UI: (78,182, 89,353) new cases of chronic diseases (CDs) over a 25-year period. Three diseases contributed 67.67% of prevented new cases of diseases: DM2 (28,921, 95% UI:

27,775, 29,876), gallbladder and biliary diseases (16,815, 95% UI: 15,863, 17,745), and ischaemic heart disease (11,132, 95% UI: 9,559, 12,426).

Compared with the tax on sugary beverages, the tax on sugary foods was estimated to prevent substantially more (12 times) new cases of CD (1,048,728, 95% UI: 987,650, 1,108,408). Between 2016-2041, the CAD$0.75 free sugar content taxes on sugary beverages and sugary foods were estimated to prevent 876 (95% UI: 750, 978) deaths and 8,621 (95% UI: 7,758, 9,419) deaths, respectively. The CVDs constituted the highest proportion of total prevented deaths (67.11%), followed by cancers (28.81%). The simulated subsidy on V&F have potential to prevented 1,312 cases of CD (95% UI: 1,220, 1,385) and 47 deaths (95% UI: 46, 50) over the next 25 years (Table 12).

6.4.3 The cost-effectiveness of taxes and subsidies

As a result of a tax on free sugar content of all sugary beverages and foods, the Canadian adult population were estimated to avert 12,167,113 (95% UI: 11,646,318, 12,634,738) DALYs and to save 8,213,942 (95% UI: 7,928,738, 8,475,521) QALYs over a lifetime period. About 6% of the estimated DALYs and QALYs were from the tax on sugary beverages, while the remaining 94% was from the tax on sugary foods (Table 13). The overall lifetime direct health care cost offsets of the simulated sugar taxes were estimated to be CAD$149,927 million (95% UI: CAD$146,340, 153,431 million). Most (91%) of health care savings were from the tax on sugary foods. Both taxes on sugary beverages and sugary foods are cost-effective. The incremental cost-effectiveness ratios (ICERs) were CAD$-24,227/QALY (95% UI: CAD$-26,055, -22,722/QALY) for the tax on sugary beverages, and CAD$-17,842 /QALY (95% UI: CAD$-18,479, -17,211/QALY) for the tax on sugary foods. The sugar taxes were projected to generate $133,497 million (95% UI: CAD$130,589, 136,445 million) tax revenue over the life period. The total costs of government to implement the taxes were estimated at CAD$2,669 million (95% UI: CAD$2,612, 2,728 million).

Table 13 also shows that the simulated subsidy on V&F could avert 29,447 (95% UI: 25,948, 36, 781) DALYs and 442 million (95% UI: 415, 478) health care costs for the adult population over their lifetime period. The V&F subsidy would be cost-effective with CAD$-15,281/DALY (95% UI: -16,255, -13,546). Around 266,703 million (95% UI: 264,288, 270,646) funding were needed from the government to support the subsidy over the lifetime period. If this program cost was included in the economic evaluation, the incremental cost per DALY would be CAD$9,504,603/DALY (95% UI: 8,232,277, 10,520,765).

6.4.4 The effect of taxes and subsidies on different socioeconomic gradient

Table 14 shows the impacts of a CAD$0.75/100g free sugar content tax on all products and a 20% subsidy for V&F by income quintiles. After implementing the simulated taxes and subsidies, the two lowest income quintiles would gain greater health benefits, with around 45% of averted DALYs and 47% of healthcare cost offsets. For each quintile, the estimated lifetime subsidies of V&F (52, 55, 60, 62, 67 billion) were higher than the estimated lifetime sugar tax burden for Canadians (32, 32, 36, 35, 36 billion) (Table 14). Although the lowest income quintiles would pay the highest proportion of income in sugar tax (0.80%, CAD$119/person/year), they would gain the highest proportion of income in V&F subsidy (1.30%, CAD$194/person/year), and their relative gain was highest among income groups. However, high-income groups would get the highest absolute monetary gain after considering both sugar taxes and subsidies.

6.4.5 Sensitivity analyses

The results of univariate sensitivity analyses compared with simulated taxes were shown in Appendix E, Table E7. Different tax levels would change around 30% of the outcomes of simulated sugar taxes. Removing the BMI trend over time has minimal impact on the health benefits and health care cost savings. Different pass-through rates (80% and 120%) would change outcomes by around 20%. Discounting rates and price elasticities are two parameters that had substantial impacts on the health and economic outcomes of simulated sugar taxes. There was about a 50% decline in DALYs and QALYs and a 40% of decrement in health care cost offset when outcomes discount rate was increased from 1.5% to 3% in the lifetime period. Applying the US price elasticities would lead to the outcomes of the sugar taxes changing by around 20% to 40%.

6.5 Discussion

This study shows that taxes on sugary foods and beverages and subsidies on V&F in Canada would decrease free sugar consumption and increase V&F consumption. The dietary pattern change would reduce 2 million cases of overweight and obesity, prevent 1 million new cases of CDs, avert 12 million DALYs, and gain 8 million QALYs over the lifetime of the adult population. From a public health care payer's perspective, the simulated free sugar content taxes were cost-effective, and it would save CAD$149,927 million in health care costs. The low-income groups gain more health benefits and pay the highest proportion of income in the sugar tax. The V&F subsidies could compensate for the sugar tax burden and lead to more health benefits.

One significant finding in this study is that the impact of the simulated sugar tax on sugary foods was much larger than that of the SSB tax in Canada. The estimated changes in TEI due to the tax on sugary foods were almost five times higher than that for the tax on SSBs. The tax on sugary foods would more effectively impact all age groups, while the SSB tax would work most effectively for younger age groups. Because the middle age and older populations have higher risks to get chronic conditions [14], tax on sugary foods would have bigger health and healthcare cost implications in those age groups. The estimated averted DALYs and saved QALYs for the tax on sugary foods was around 15 times larger than the estimate for the tax on SSBs. For the health care cost savings, the economic estimate of a tax on sugary foods was about 11 times higher than that for tax on SSBs. It is consistent with an Australian study, which indicated that changes in TEI for sugar tax were around nine times higher than SSB tax [20]. A tax on sugary foods would result in more DALYs averted (22 times) and diet-related disease costs saved (19 times) than the tax on SSBs [20]. While SSB tax has been implemented in several countries, few countries focus on sugary foods [8]. The scope of sugar taxes needs to be expanded to all sugary foods to maximize the health benefits and health care cost savings.

This study is the first to simulate various sugar taxes and V&F subsidy scenarios in Canada. We separately modelled these three scenarios (i.e., SSB tax, tax on sugary foods, and V&F subsidies) because they have different advantages. The SSB tax is the most popular policy of these three scenarios, and it has been implemented in over 40 countries [12]. The tax on all sugary foods could result in substantial health benefits, health care costs offsets, and tax revenue. The V&F subsidy has been shown as one of the most effective fiscal policies to induce health-promoting changes in consumption and improve inequity [45]. In line with the previous studies [20, 46], the simulated V&F subsidy would avert DALYs and save health care costs. The combination of all taxes and subsidies showed the largest health benefits and health care cost offsets in this study. However, if we considered the program costs, the sugar taxes were more cost-effective than the V&F subsidy. The program costs of the V&F subsidy were around two times more than the sugar tax revenues. A lower subsidy rate might help the government achieve cost neutrality [12].

Before this study, no study has evaluated the impact of taxes on all sugary foods and V&F subsidies among different income groups in Canada. Consistent with the previous Canadian SSB tax economic evaluation [17], the current study showed that the people with lower income would gain more health benefits and health care cost offsets from sugar taxes and bear more sugar tax burden related to their income. It is because low-income groups with the tightest budget constraints would change more consumption after taxation due to higher price elasticities for sugary products than high-income groups. The differences in health benefits and tax burden among different quintiles for tax on sugary foods were much higher than the tax on SSBs. The higher difference in health benefits is beneficial to improve health equity. However, the higher difference in tax burdens would intensify wealth inequity. The higher tax burden for disadvantaged groups would further worsen their food insecurity status [47].

Considering the sugar taxes are financially regressive, the combination of a well-crafted, mutually supportive policy package is needed to achieve larger health benefits and improve inequity [47]. Consistent with previous studies [12], our study showed that V&F subsidy is a policy choice that could bring health benefits and reduce inequity. The low-income groups had higher elasticities of V&F [25] and thus gained more health and economic benefits than high-income groups. Combining sugar taxes and V&F subsidies is a potential method to resolve the financial regressivity of sugar taxes and compensate sugar tax burden. Notably, although the changes in the percentage of income for low-income groups were larger than high-income groups, the absolute subsidy values for low-income groups are lower than high-income groups. The difference in net subsidy values between the highest and lowest groups was CAD$40/person/year. Although this gap is not high, it would increase the income gap. More policies specifically targeted at low-income groups might help narrow this income gap [12, 46].

It is worth noticing that this study simulated taxes on the free sugar content of products rather than ad valorem taxes (i.e., 20% tax on SSBs) used in many previous simulation studies [17]. The ad valorem tax does not need to be inflation-adjusted since it depends on the product price, but it leads to challenges when applied to cheaper sugary foods and beverages [8]. After implementing the ad valorem excise tax, consumers might buy cheaper sugary products to decrease tax liability rather than buy products without free sugar because the absolute price increase is smaller for them [17]. The absolute sugar content taxes modelled in this study make products with higher sugar content have higher tax rates than lower sugar content products. It could facilitate consumers and manufacturers shift to lower or no free sugar content products to decrease tax liability [8]. Thus, we recommend the policymaker design the sugar tax based on the free sugar content of products.

The findings in this study provide robust evidence and quantified economic arguments for decision makers to design and implement sugar taxes. Understanding the impact of different policy scenarios and disparities among different population subgroups could help policymakers better redistribute the sugar tax revenues and improve inequity. Based on our estimation, we recommend implementing the policy package that includes taxes on the free sugar content of all sugary foods and beverages and subsidies for V&F to achieve larger health and economic benefits and improve inequity. The scope, level, and target population of the tax and subsidy need to be carefully considered by policymakers to better direct benefits to low-income groups [47]. Because of the fiscal realities of the COVID-19 pandemic, a sugar tax may be increasingly viewed as a fiscally feasible choice to improve the health status of Canadians. Although combing the sugar tax and V&F subsidies could partly attenuate potential concerns as regards tax burden and regressivity of sugar taxes, the sugar tax might continue to be resisted by manufacturers of sugary products, retailers, and taxpayers [12, 48]. The primary reasons are industry profits damage and political opposition to paternalistic policies. To open the policy window, coupling the sugar tax policy to an alternative problem that more closely aligns with the current political agenda is required [49]. Because CDs have increased fasts during the recent decade and quality of life has not continued to improve with the increases in life expectancy, we could foster the sugar tax by framing issues related to the prevention of CDs and the improvement of healthy life expectancy [14, 50].

This study has several strengths. First, we used an established simulation model that included all the diseases related to BMI and the free sugar intake and the own- and cross-price elasticities of all sugary and non-sweetened products. It makes the estimations in this study more accurate. In addition, we compared the cost-effectiveness and equity of different sugar tax scenarios in the simulation. The findings can help policymakers find the optimal choice by combining it with a V&F subsidy and potential other policies that could avert the sugar tax burden for lower-income groups. It could help dispel doubts about the financial regressivity of sugar taxes. This study contains some limitations and assumptions. In addition to the model assumptions mentioned in our previous study (including BMI trend, pass-through rate, and disease independent with each other) (Chapter 5), this study assumed the RRs for SSBs to be equal to the RRs for free sugar because the RRs for free sugar are not available. We also assumed the dietary pattern of the target population would change following the price elasticates from New Zealand. Based on the sensitivity analysis that applies the elasticities from the US, the high cost-effectiveness of simulated sugar taxes would not be changed when using different price elasticities. Additionally, one limitation of this study is the bias of the 24h dietary recalls from the 2015 CCHS – Nutrition dataset. It is prone to error as every dietary assessment method. The findings of this study are only applicable for people aged 20 years old and above in Canada due to the data restriction of disease risks. We also did not estimate the QALYs and ICERs of V&F subsidy due to the lack of QALYs weight for related CDs. This study alternatively showed the cost per DALYs for the V&F subsidy.

6.6 Conclusion

This study provides more evidence related to the cost-effectiveness and equity effect of tax on all sugary foods and beverages and subsidies on V&F in Canada for researchers and policymakers to design and implement the sugar tax. To maximize the health and economic benefits and improve equity, we suggest policymakers implement the policy package that includes the tax on all sugary foods and beverages and V&F subsidies.

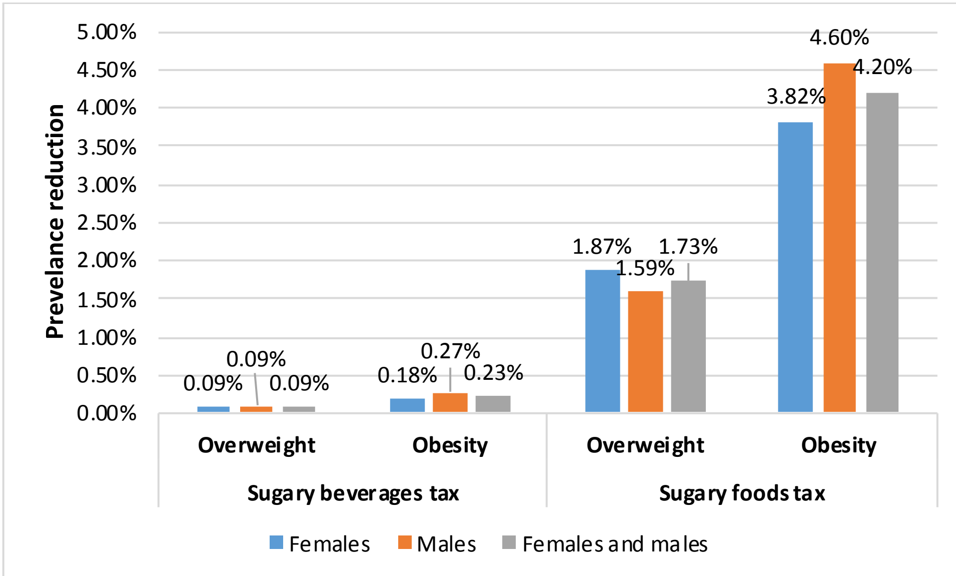

Figure 10 The reduction in prevalence of overweight and obesity due to the CAD$0.75 tax on free sugar content of beverages and foods in Canada

Table 11 Prevented cases of overweight and obesity due to the CAD$0.75 tax on free sugar content of beverages and foods in Canada, one year after implementation

	Females	Males	Females and males
Tax on sugary beverages			
Prevented cases of overweight	15,448	15,425	30,873
Prevented cases of obesity	32,933	48,405	81,338
Prevented cases of overweight and obesity	48,381	63,829	112,210
Tax on sugary foods			
Prevented cases of overweight	336,789	281,956	618,745
Prevented cases of obesity	686,566	814,526	1,501,092
Prevented cases of overweight and obesity	1,023,355	1,096,482	2,119,837

Table 12 Prevented disease incident cases and deaths due to the CAD$0.75 tax on free sugar content of beverages and foods and a 20% subsidy for vegetables and fruit, 2016-2041

	Incident cases		**Deaths**	
	Mean	95%UI[1]	Mean	95%UI[1]
Tax on sugary beverages				
Diabetes mellitus type 2	28,921	(27,775, 29,876)	32	(31, 33)
Cancers	1,144	(997, 1,292)	114	(96, 132)
Cardiovascular diseases	12,914	(11,242, 14,298)	722	(617, 805)
Other conditions	41,054	(38,168, 43,887)	8	(6, 8)
Tax on sugary foods				
Diabetes mellitus type 2	233,427	(228,557, 237,777)	232	(227, 236)
Cancers	26,531	(23,368, 29,796)	2,622	(2,258, 2,999)
Cardiovascular diseases	111,557	(102,845, 119,305)	5,651	(5,169, 6,053)
Other conditions	677,213	(632,880, 721,530)	116	(104, 131)
Subsidy for vegetables and fruit				
Diabetes mellitus type 2	551	(505, 575)	1	(1,1)
Cancers	20	(17, 21)	6	(6, 7)
Cardiovascular diseases	741	(698, 789)	40	(39, 42)

[1] 95%UI: 95% uncertainty interval.

Table 13 Lifetime population health and economic impact of the CAD$0.75/100g free sugar content taxes on all beverages and foods and a 20% subsidy for vegetables and fruit in Canada

	Tax on sugary beverages	**Tax on sugary foods**	**Subsidy for vegetables and fruit**
DALYs[1] averted	752,353 (682,549, 811,215)	11,414,760 (10,963,769, 11,823,523)	29,447 (25,948, 36,781)
QALYs[2] gained	534,779 (494,117, 569,320)	7,679,163 (7,434,621, 7,906,201)	-
Health care cost offset (CAD$ millions)	12,942 (12,433, 13,390)	136,985 (133,907, 140,041)	442 (415, 478)
ICER[3] (CAD$/QALY)	-24,227 (-26,055, -22,722)	-17,842 (-18,479, -17,211)	-
Cost/DALY (CAD$/DALY)	-17,208 (-18,664, -15,951)	-12,005 (-12,497, -11,544)	-15,281 (-16,255, -13,546)
Sugar tax revenue **(**CAD$ millions)	49,776 (48,410, 51,122)	83,721 (82,179, 85,323)	-
Vegetables and fruit subsidy (CAD$ millions)	-	-	261,474 (259,106, 265,339)
Intervention costs (CAD$ millions)	995 (968, 1,022)	1,674 (1,644, 1,706)	5,229 (5,182, 5,307)

Values are presented as mean (95% uncertainty interval). [1] DALYs: Disability-adjusted life years; [2] QALYs: Quality-adjusted life years, estimated only for sugar taxes; [3] ICERs: Incremental cost-effectiveness ratio. All values were discounted by 1.5% to their present values (2015).

Table 14 Lifetime population impacts of the CAD$0.75/100g free sugar content tax on all products and a 20% subsidy for vegetables and fruit in Canada, by income quintiles

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Sugar taxes					
DALYs[1] averted	3,170,458 (3,065,824, 3,298,633)	2,016,072 (1,894,393, 2,123,505)	1,991,001 (1,893,937, 2,090,061)	1,949,191 (1,849,385, 2,038,901)	2,331,820 (2,203,852, 2,429,216)
Health care cost offset (CAD$ millions)	38,407 (37,116, 39,510)	23,255 (22,619, 23,665)	23,346 (22,621, 23,789)	18,881 (18,251, 19,478)	28,640 (27,628, 29,470)
Lifetime tax revenue (CAD$ million)	32,019 (31,820, 32,209)	32,485 (32,388, 32,645)	36,268 (36,124, 36,437)	35,036 (34,799, 35,223)	35,612 (35,433, 35,747)
Annual tax burden (CAD$/person)	119 (119, 120)	120 (120, 120)	131 (131, 132)	126 (125, 127)	125 (123, 127)
Tax burden as percentile of income	0.80% (0.80%, 0.81%)	0.46% (0.46%, 0.47%)	0.39% (0.38%, 0.39%)	0.29% (0.29%, 0.29%)	0.17% (0.16%, 0.17%)
Vegetable and fruit subsidies					
DALYs averted	10,346 (9,409, 12,705)	8,701 (6,874, 11,251)	4,444 (3,937, 5,261)	5,623 (5,386, 5,898)	4,850 (4,392, 5,869)
Health care cost offset (CAD$ millions)	151 (144, 164)	75 (72, 85)	32 (26, 36)	20 (16, 26)	26 (20, 33)
Lifetime subsidy (CAD$ million)	52,178 (51,413, 53,209)	55,097 (53,646, 56,486)	59,854 (58,809, 60,898)	62,148 (60,982, 63,400)	67,194 (65,762, 68,520)
Annual subsidy (CAD$/person)	194 (191, 198)	202 (197, 207)	214 (211, 218)	224 (220, 228)	234 (229, 239)
Subsidy revenue as percentile of income	1.30% (1.28%, 1.33%)	0.78% (0.76%, 0.80%)	0.63% (0.62%, 0.64%)	0.52% (0.51%, 0.53%)	0.31% (0.31%, 0.32%)

Values are presented as mean (95% uncertainty interval). [1] DALYs: Disability-adjusted life years. All values were discounted by 1.5% to their present values (2015).

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Chapter 7. Discussion and Conclusion

7.1 Overview of research

The motivation of this research is to provide more evidence for the public, researchers, and policymakers and improve their understanding of the impact of excessive sugar consumption and the cost-effectiveness of sugar taxes in Canada. Five studies comprise the body of this thesis that focuses on a novel aspect of unhealthy behaviors: a diet high in added and free sugars.

The first study (Chapter 2) laid the foundation of the thesis by listing the added, free, and total sugar content of all foods and beverages in the Canadian diet. The 2,784 ingredient-level foods and 2,590 recipe-level foods consumed by Canadian residents were reported. Among these foods, desserts and sweets, breakfast cereals, baked products, beverages, baby foods, and snacks were identified as high free and added sugar content foods. The first study also showed the sugar consumption levels and adherence to sugar intake recommendations from the World Health Organization (WHO) and the United States Department of Agriculture (USDA) [1, 2]. On average, Canadians consumed 57.1 g of added sugars (11.1% of total energy intake (TEI)), 67.1 g of free sugars (13.3% of TEI) and 105.6 g of total sugars (21.6% of TEI) in 2015. Only 51.0% of Canadians met the added sugar intake recommendations, and fewer people met the free sugar intake recommendations, at 33.8% and 5.4%, respectively, for two recommended levels (below 10% and 5% of TEI). In addition, the contributors of added and free sugar consumption were estimated in the first study. Desserts and sweets (67.3%, 57.5% and 41.1% of added, free, and total sugar) and beverages (17.4%, 17.5% and 12.6% of added, free and total sugar intake) were two main contributors to the sugar intake.

Based on the finding of the first study (Chapter 2), the second study (Chapter 3) estimated the economic burden of excessive free sugar consumption in Canada. If all Canadians adhere to the free sugar recommendation (consumption below 10% and 5% of TEI) [1], estimated CAD$2.5 to 5.0 billion in direct health care and indirect costs could have been avoided in 2019. Compared with the economic burden of consumption of sugar-sweetened beverages (SSBs) estimated in previous similar Canadian research [3, 4], the second study showed that the excessive free sugar intake from all sugary foods and beverages would lead to much larger (3 to 6 times) economic burden. The second study also reported the average free sugar consumption by age and sex. As expected, men have a higher prevalence of chronic diseases, specifically diagnosed and undiagnosed diabetes, and contribute much more to the economic burden of excessive free sugar consumption than women. In addition, the second study presented the avoidable percentage of chronic diseases (CDs) attributable to excessive free sugar intake. Around 27.0%-44.8% of diabetes mellitus type 2 (DM2) and 5.1%-10.2% of cardiovascular diseases (CVDs) could be avoided if all Canadians consumed free sugar below the recommended level. The substantial health and economic burden of excessive free sugar consumption show the necessity of paying attention to a diet high in added and free sugar and call for actions to reduce sugar consumption.

Taxation of products with free sugar is one of the interventions that could reduce sugar consumption and the associated burden. The third study (Chapter 4) systematically summarized the health and economic impact and cost-effectiveness of sugar taxes conducted in different countries. The 15 good-quality economic evaluation studies of sugar tax were selected through a systematic selection process. The research revealed that sugar tax could improve health-related quality of life (HRQoL) in the long term and save health care costs and collect tax revenues (totaling US$87 to US$167,799 million). The sugar tax was a cost-effective intervention and was more cost-effective than other interventions to reduce obesity (e.g., SSBs bans and restrictions, vegetables and fruit (V&F) subsidy, and early care and education policies). This study also showed that the estimated impacts of sugar taxes were significantly varied due to the difference in the research context, scope of tax, and simulation model parameters. The averted disability-adjusted life years (DALYs) and saved disease costs associated with the taxation of sugary foods were larger than that for SSBs. This difference is because of the discrepancy in percentages of free sugar contribution for SSBs and other foods (Chapter2). It props up the estimation of taxation of sugary foods and beverages in Canada to provide reliable evidence for policymakers.

The findings of the first three studies showed the necessity, feasibility, and priority of implementing taxation of foods and beverages in Canada. Considering that previous Canadian studies only focus on evaluating the impact of SSBs tax [5, 6], the fourth and fifth study (Chapter 5 and 6) designed a simulation model to estimate the cost-effectiveness of taxes on sugary foods and SSBs separately and in combination. Chapter 5 mainly developed a more comprehensive model and showed the detailed model assumptions and methods using a simulated SSB tax. Compared with previous sugar tax models (Chapter 4), the model in this study included relative risks of all CDs related to the SSBs consumption and BMI and considered the substitute effect of all untaxed foods and beverages. A CAD$0.015/oz SSB tax has the potential to avert 2.3 million DALYs, gain 1.5 million quality-adjusted life years (QALYs), and save CAD$32,583 million health care costs in a lifetime period. The estimated impact of SSB tax in Chapter 5 was much larger than the previous equivalent Canadian SSB tax.

Chapter 6 estimated the cost-effectiveness and income effect of different sugar taxes and V&F subsidy scenarios. Consistent with the findings of the third study (Chapter 4) and the previous studies [7], these two studies suggested that all sugar tax and V&F subsidy scenarios were cost-saving. The combination of the CAD$0.75/100g tax on the free sugar content of sugary foods and beverages and 20% V&F subsidy could avert around 12 million DALYs and save 8 million quality-adjusted life years (QALYs) and CAD$150 billion health care costs. The estimated changes in HRQoL and health care costs for free sugar content tax on sugary foods was around 15 and 11 times larger than the estimate for an SSBs tax. It echoed the earlier arguments that interventions to reduce sugar consumption should not ignore the foods with substantial free sugar content. We also found that the people in the lowest income quintiles would gain the highest health benefits and health care cost offsets, while they would bear the highest tax burden in sugar tax (0.80% of income, CAD$119/person/year). This tax burden could be compensated by the V&F subsidy (CAD$193.71/person/year), and the lowest income groups would gain the highest proportion of income in the V&F subsidy (1.30% of income).

7.2 Significance of research findings and policy recommendations

The rationales of this thesis have been elaborated in the general introduction section. This thesis is the first to list added and free sugar content of all foods and beverages consumed by Canadians and is the first to estimate the compliance rate of sugar intake recommendations in Canada. The systematic review in this thesis is also the earliest to summarize evidence about the cost-effectiveness of sugar taxes. The simulation studies in this thesis fill the research gaps about the impacts of excessive free sugar consumption and taxation of all sugary foods and beverages and V&F subsidy in Canada.

In addition to filling the research gaps, the findings of this research are significant for improving population health and facilitating policy initiatives. This thesis provides more information about free sugar content and sources of free sugar consumption for Health Canada to improve the Canada Food Guide. For many countries, including Canada, we have a long way to go before implementing a long-term population-level intervention to control free sugar consumption. Thus, providing detailed dietary advice is a feasible action and usually the first step to reducing free sugar consumption. Some recommendations about free sugars have already been released by Health Canada [8, 9]. Following the free sugar recommendation from WHO [1], the Canada food guide recommended Canadians consume less than 10% of TEI and ideally less than 5% of TEI from free sugar [8]. The Canada food guide also listed some unhealthy food categories (including sugary drinks, confectioneries, and sugar substitutes) [8]. To help the public better understand foods with high free sugar, detailed information about the average free sugar content of different food categories can be added to the food guide. For example, the average free sugar content of not-recommend food groups, such as desserts and sweets (38.1g/100g), sugary drinks (10.1g/100g), and sweetened breakfast cereals (12.2g/100g), could be listed in the food guide based on the findings of this thesis. Furthermore, the contributions of different food groups in free sugar intake from this thesis could also be presented in the food guide. For instance, a figure or table showing significant contributors of free sugar consumption in the Canadian diet (i.e., desserts and sweets (57.5%), sugary beverages (17.5%), fruit juice (7.9%), etc.) would help the public know what food categories are significant barriers of reducing free sugar consumption.

One significant impact of this thesis is attracting more attention from the public, researchers, and the Canadian government to the foods with added and free sugar. Most research and implemented interventions (e.g., taxations and education programs) only focus on the SSBs [9-11]. Although these interventions could effectively reduce SSBs consumption and improve health status [4, 5, 12-14], they ignore other sugary foods, which contribute most of the sugar in Canadians' diet (82.6%, 74.6%, and 82.1% for added, free, and total sugar respectively). To maximize the impact of the interventions, extending the targeted products from SSBs to all beverages and foods with free sugar is a preferred action. This thesis supports this initiative by estimating that more health and economic burden of excessive free sugar consumption were from sugary foods (e.g., sweets and desserts) (CAD$2.5 to 5.0 billion per year), compared to SSBs (CAD$830 million per year). The simulation study of sugar taxes also substantiates that the changes in free sugar intake and TEI attributed to the tax on sugary foods are higher and more evenly distributed to all age groups than the SSB tax. Taxing on all sugary foods and beverages would more effectively impact all age groups and result in an astonishing increase in health and economic benefits (averted DALYs increased from 0.5 billion to 12.0 billion; health care cost offsets increased from CAD$10.9 billion to CAD$155.3 billion).

To further improve people's diets and prevent CDs, this thesis recommends implementing taxation on the free sugar content of all sugary products and combining multiple policies (e.g., V&F subsidies) as a package in Canada. In all previous studies and the fourth and fifth studies in this thesis, the sugar tax was illustrated to effectively reduce sugar consumption and increase health and economic benefits [15]. The taxation of all sugary products has been shown as a priority in reducing free sugar consumption because it is more cost-effective than other potential interventions (e.g., early care and education policies and front-of-package and menu labelling) [7]. However, decision-makers might not only choose one policy to reduce sugar consumption. The combination of the free sugar content tax and other interventions (e.g., financial incentives) aimed at improving diet and related CDs could bring more health benefits and health care cost offsets [7, 16]. The fifth study in this thesis shows that a policy package with multiple interventions could achieve larger health benefits than a sole policy [17].

This thesis calls for the Canadian government to consider potential barriers and solutions when implementing a sugar tax. The sugar tax is usually resisted by stakeholders, such as manufacturers of sugary products, retailers, and taxpayers [18]. The primary reasons are potential tax burden, industry profits damage, and political opposition to paternalistic policies [18]. Based on the experience of tobacco control, some measures are helpful to eliminate these resistances, for example, involving stakeholders in the policymaking process, declaring the harm of excessive sugar consumption, and transformation and upgrading of industries that produce sugary products [19]. The financial, human capital, and government structural limitations might also hinder the implementation of sugar tax [18]. To clear these hurdles, the cooperation of federal and provincial level health and economic sectors is critical.

Policymakers may also face additional barriers to the implementation of sugar tax due to the critiques of the equity of sugar tax [20]. As the fifth study shows, although the sugar tax improves health equity, it would aggravate the tax burden of the low socioeconomic groups [6, 21]. Thus, eliminating financial inequity should be considered when designing policy. We recommend policymakers reinvest the revenues of taxation on the low socioeconomic groups to reduce the financial inequity of sugar tax. For example, the subsidies for some healthy foods (e.g., V&F) could relieve the tax burden, improve dietary patterns and gain more health benefits for low-income groups. It is because own price elasticity of V&F for low-income groups is higher than high-income groups. However, the absolute income impact of V&F subsidy would be slightly higher for high-income groups shown in the fifth study. Transparent communication of solutions to the equity challenges could reduce the resistance from stakeholders and facilitate the process of policymaking and implementation [18, 20, 22].

7.3 Overall strengths and limitations

The specific strengths and limitations of these five studies have been discussed in each Chapter. This chapter discourses some overall strengths and limitations of this thesis. First of all, this thesis provides detailed sugar content data and model examples for future research. This thesis shows the added and free sugar content of all foods and beverages consumed by Canadians. These sugar values help researchers better understand the sugar content of these products and conduct relevant research. Based on the previous models and most up-to-date data (e.g., GBD 2017), this thesis builds comprehensive simulation models to estimate the economic burden of excessive sugar consumption and the cost-effectiveness of the sugar tax in Canada. The model type selection procedure, model structure, parameters, and data sources used in this thesis are references for other similar economic evaluation research.

Another strength is that this thesis provides both Canadian and international evidence regarding the impact of sugar taxes for researchers and policymakers. In this thesis, the systematic review (Chapter 4) summarizes the cost-effectiveness of simulated sugar tax from various countries. The consistent conclusion of these studies (i.e., the sugar tax is cost-effective) shows the generalizability of sugar tax in the world. Meanwhile, the fifth study in this thesis (Chapter 6) simulates a series of sugar tax scenarios in Canada. The substantial health and economic benefits of taxes on all sugary products increase the feasibility of sugar tax in Canada.

In addition, using the population-level methodologies and datasets in this thesis is a significant strength. In the first and second study (Chapters 2 and 3), the National Cancer Institute (NCI) method [23] and population weights provided by the Canadian Community Health Survey (CCHS) – Nutrition were used to estimate the usual intake of sugar intake [24]. This method makes this thesis better reflect the average sugar consumption and its distribution in the whole Canadian population. Based on the population-level data (e.g., CCHS – Nutrition and Economic Burden of Illness in Canada (EBIC)) [24, 25], the second, fourth, and fifth studies (Chapter 3, 5, and 6) show the impact of excessive free sugar intake, sugar taxes, and V&F subsidy on all population. These estimates from population-level perspectives enhance the representativeness and reliability of the findings in this thesis.

One noteworthy strength is that this thesis provides comprehensive evidence and recommendations for the decision-makers. Five studies in this thesis show various evidence regarding sugar consumption, economic burden of excessive sugar, and the cost-effectiveness of sugar taxes and V&F subsidy. Although each study has separate research objectives, they all articulate recommendations to decision-makers. The decision-makers from the health and economic sectors, school boards, health promotion practitioners, communities, and the research community are significant stakeholders and knowledge users of the findings in this thesis. Catering to their needs and providing recommendations with convincing evidence is beneficial to translate the research findings into practice.

Some limitations of this thesis warrant consideration. First, some unavoidable limitations are from 24-h dietary recalls of the CCHS – Nutrition dataset used in all sugar consumption estimations. The CCHS – Nutrition dataset is the best, large sample dataset in Canada that includes many nutrition information. However, it excludes persons living on reserves and other Aboriginal settlements, full-time members of the Canadian Forces, and the institutionalized population [24]. Thus, the findings in this thesis are only applicable for a large majority of the residents (over 90%) in Canada, not including these subgroup populations. The 24-h dietary recalls are prone to error like every dietary assessment method. Because the amount of nutrients consumed by respondents in 24-h dietary recalls is not precise, the estimated added and free sugar intake in this study might have errors. Notably, the response rate (61.6%) of the 24-h dietary recalls in the CCHS - Nutrition might impact the representativity of findings [24]. In order to improve the representativeness of the findings, this thesis uses both the first and second dietary recalls data and the NCI methods to estimate the distribution of usual sugar intake. This thesis also applies the sampling weights calculated by a systematic process (including the calculation of the initial weights, the treatment of non-response and the post-stratification) in the estimations.

Second, the simulation models built in this thesis are restricted by some parameters and datasets. The Global Burden of Disease (GBD) only presents diseases risks for people aged 20 and above [26, 27]. Thus, consistent with the previous simulation model in Canada [5, 6], the proportional multi-state life table-based Markov model built in the fourth and fifth studies only simulates the impact of sugar taxes and V&F subsidy on the 2015 adult Canadian population over their lifetime. Based on methods used in the previous studies [28], the second study in this thesis assumes that the relative risks of the lowest age group could be applied to the younger group. This assumption might result in errors due to the lack of accurate diseases risks for children and adolescents. Considering the prevalence of diseases for children and adolescents are low, the impact of this age-group exclusion on the results could be negligible. In addition, the own- and cross-price elasticities used in the simulation model of the fourth and fifth studies are from New Zealand [29]. We used New Zealand price elasticities because Canada does not have comprehensive price elasticities for main food groups consumed by Canadians [30]. Applying foreign price elasticities would not significantly change the cost-effectiveness of sugar taxes.

Third, the methods used in this thesis, such as the simulation modelling method and indirect costs estimation method, face many critics. Many researchers critique the utility of simulation studies. They have argued that the forecast effects of policies in simulation studies might not drive the policy process and have policy implications because the simulated situation might not align with reality [31, 32]. To better reflect reality, this thesis considers many policy scenarios and sets the types and levels of taxes based on the existing taxes in other countries [31, 33]. This thesis also systematically summarizes and compares all economic evaluation studies of sugar taxes to improve the generalizability of the findings. Additionally, the indirect cost estimates in economic analysis are debated, and the estimated results vary substantially if using different indirect costs evaluation methods [34]. Thus, we calculated the indirect costs of excessive free sugar consumption using two methods (i.e., the modified human capital approach and friction cost method) in the second study [35].

Fourth, although other policies to control sugar consumption and diet-related CDs have been discussed, this thesis only estimated the impact of sugar taxes and V&F subsidy. Other potential interventions are not included in this thesis. For example, the health education programs, reinvestment of sugar tax revenues to disadvantaged groups, front-of-package labelling, regulation of advertising, limiting use of free sugar across the food supply chain, industry incentives for product reformulation, distribution and marketing of healthful foods, supportive environments in public institutions to serve low sugar meals, and dietetic counselling of people at higher risk. The main reasons for not including these interventions into the model of this thesis are data restrictions and simplifying the construct of the simulation model. Exploring the impacts of other interventions could provide more information to decision-makers.

7.4 Future research direction

More research could be done in the future to explore the impact of sugar taxes in the Canadian North. Based on the fact that the northern populations have a high prevalence of food insecurity and limited substitute foods [36, 37], having a sugar tax for these people might lead to a series of problems, for example, exacerbating food insecurity. Thus, it is important to explore the changes in sugary and healthy products consumption and diseases risks of the Northern populations after implementing sugar taxes.

Other potential interventions that aim to reduce free sugar intake, improve population diet, and control diet-related CDs in Canada could be further estimated. Similarly, the simulation and comparison of various policy packages could be conducted in the future, for example, school education programs and nutrition labelling. More evidence could help policymakers better understand the characteristics, strengths, and limitations of different policy choices and accordingly make informed decisions.

Future studies should conduct empirical studies to estimate the changes in food consumption due to price change in the Canadian context. This thesis borrowed the own- and cross-price elasticities from New Zealand when estimating the changes in free sugar consumption because no suitable price elasticities exist in Canada [29]. Future research estimating price elasticities of multi food categories foods in the Canadian context can better reflect the consumers' behaviors and support sugar tax and other diet-related simulation studies.

7.5 Conclusions

Diet high in added and free sugar is an unhealthy behavior that should not be ignored in both people's daily life and academic research. This thesis reveals that most Canadians did not comply with the recommended consumption level of free sugar from the WHO and Canada Food Guide. Excessive free sugar consumption resulted in substantial direct health care and indirect costs in Canada, which calls for interventions to control sugar consumption. The sugar tax is a cost-effective policy that would lead to positive health and economic outcomes.

The findings of this research could be added to the Canada Food Guide to help the public and researchers better understand free sugar consumption, its consequent health and economic burden, and potential resolutions to excessive free sugar consumption in Canada. Future actions should pay more attention to sugary foods due to their significant contribution to Canadians' diet and avoidable disease burden. In order to further control obesity, prevent diet-related CDs and improve equity, this thesis recommends a policy package that includes sugar taxes and V&F subsidies to policymakers.

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Appendix A. Detailed added and free sugar calculation steps of foods and beverages reported in the 2015 Canadian Community Health Survey-Nutrition

We took a 9-steps approach adapted from Louie et al. [1] to estimate the added and free sugar content of foods and beverages. This approach is described elsewhere [2]. Further detail of each of these 9-steps is provided below. Following the description of the 9-steps approach, we provide a table with our estimates of the added and free sugar content of all 2,784 ingredient-level foods reported by the more than 20,000 Canadian residents participating in 2015 Canadian Community Health Survey-Nutrition [2, 3]. The 2,590 recipe-level foods reported in this survey [2]. Recipes and recipe-level foods are respondent specific and therefore, due to confidentiality, subject to restricted release, but can be calculated from the ingredient-level foods.

The 9-steps approach:

***STEP 1*: Assign 0 g added and free sugar to ingredient-level foods that contain 0 g in total sugar.**

If the total sugar of ingredient-level foods in the 2015 Canadian Community Health Survey-Nutrition (CCHS 2015) was 0 g, 0 g added sugar and 0 g free sugar were assigned.

***STEP 2*: Assign 0 g added and free sugar to ingredient-level foods that are unprocessed or processed without added or free sugar.**

0 g added sugar was assigned to the following food types:

(1) Non-sweetened fruit/vegetable juice (including concentrate).

(2) Non-sweetened juice base, alcoholic beverages, soft drinks, and beverage mix, coffees and tea (including sweetened with artificial sweeteners only, without chocolate).

(3) Non-sugar-sweetened milk, buttermilk and milkshake (including sweetened with artificial sweeteners only, without chocolate).

(4) Non-sweetened dairy products (including plain yogurts and ice cream sweetened with artificial sweeteners only, without chocolate and fruits).

(5) All fats and oils.

(6) All spices and herbs.

(7) All plain cereal grains, pastas, rice, flours and oats without added sugar.

(8) Eggs and egg products (except egg-based desserts).

(9) Fresh fruit, unsweetened dried fruits, fresh vegetables (including salads without dressing and syrup pack), fresh meat, fresh seafood and tofu.

(10) Fruits, vegetables, vegetable products/fruit salad canned in water, 100% fruit juice or liquid sweetened with artificial sweeteners only.

(11) Intensely sweetened jam and beverage base (without added sugar).

(12) Legumes (fresh, dried and/or processed, except sweetened varieties).

(13) Nuts (except sweetened varieties and nut bars), coconut (and products except for sweetened varieties) and seeds.

(14) Plain breads, plain pastries, English muffin, bagels, pizza bases, naan, puff shell, Taco shell, croutons, French toast, phyllo dough, rolls, tortilla, bannock and rice cake without filling (such as chocolate, dried fruit and/or nuts).

(15) Others: vinegar, soy sauce and vanilla extract.

0 g free sugar was assigned to the following food types:

(1) 100% vegetable juice.

(2) Non-sweetened alcoholic beverages, soft drinks, and beverage mix, coffees and tea (including sweetened with artificial sweeteners only, without chocolate and juice).

(3) Non-sugar-sweetened milk, buttermilk and milkshake (including sweetened with artificial sweeteners only, without chocolate).

(4) Non-sugar-sweetened dairy products (including plain yogurts and ice cream sweetened with artificial sweeteners only, without chocolate and fruits).

(5) All fats and oils.

(6) All spices and herbs.

(7) All plain cereal grains, pastas, rice, flours and oats without added sugar.

(8) Eggs and egg products (except egg-based desserts).

(9) Fresh fruit, unsweetened dried fruits, fresh vegetables (including salads without dressing and syrup pack), fresh meat, fresh seafood and tofu.

(10) Fruits, vegetables and vegetable/fruit salad canned in water or liquid sweetened with artificial sweeteners only.

(11) Intensely sweetened jam and beverage base (without added sugar).

(12) Legumes (fresh, dried and/or processed, except sweetened varieties).

(13) Nuts (except sweetened varieties and nut bars), coconut (and products except for sweetened varieties) and seeds.

(14) Plain breads, plain pastries, English muffin, bagels, pizza bases, naan, puff shell, Taco shell, croutons, French toast, phyllo dough, rolls, tortilla, bannock and rice cake without filling (such as chocolate, dried fruit and/or nuts).

(15) Others: vinegar, soy sauce, vanilla extract, and infant formula.

***STEP 3*: Assign 100% of total sugars as added and free sugars to ingredient-level foods with very little naturally occurring sugars.**

100% of total sugars was assigned as added sugar to the following food types:

(1) Regular soft drinks, sport drinks, carbonated drinks, flavoured water and non-fruit-based energy drinks.

(2) Coffee and beverage base with no milk solids or made up with water.

(3) Soy beverages and soy yogurt without added fruits, chocolate and dairy products.

(4) Savoury biscuits, sweet biscuits, crackers, cakes and buns, donuts and batter-based products that do not contain fruit, chocolate or dairy products.

(5) Breakfast cereals and cereal bars without fruits, chocolate, dairy or milk solids.

(6) Sweetened nuts, sweetened seeds, peanut butter and other nut spreads.

(7) Crumbed/battered meat, seafood and processed meats.

(8) All confectionery except those containing fruit, chocolate and dairy products.

(9) Sugars, syrups, molasses, honey and sweetener without fruit and dairy products.

(10) Energy bar and protein bar (without fruit and dairy products).

100% of total sugars was assigned as free sugar to the following food types:

(1) 100% Fruit juice (including concentrate).

(2) Regular soft drinks, sport drinks, carbonated drinks, flavoured water, energy drinks and fruit-based alcoholic beverages.

(3) Coffee and beverage base with no milk solids, dry or made up with water.

(4) Soy beverages and soy yogurt without added chocolate and dairy products.

(5) Savoury biscuits, sweet biscuits, crackers, cakes and buns, donuts and batter-based products that do not contain fruit, chocolate or dairy products.

(6) Breakfast cereals and cereal bars without fruits, chocolate, dairy or milk solids.

(7) Sweetened nuts, sweetened seeds, peanut butter and other nut spreads.

(8) Crumbed/battered meat, seafood and processed meats.

(9) All confectionery except those containing fruit, chocolate and dairy products.

(10) Sugars, syrups, molasses, nectar, honey and sweetener without dairy products.

(11) Other: energy bar, protein bar and fruit-based sauce.

***STEP 4*: Calculate added and free sugar content by comparing the total sugar value with that of an unsweetened variety.**

Added sugar and free sugar per 100 g were calculated using the formula:

$$AS_{100g} = \frac{100 \text{ x } (TS_{us} - TS_s)}{(TS_{us} - 100)} \qquad FS_{100g} = \frac{100 \text{ x } (TS_{us} - TS_s)}{(TS_{us} - 100)}$$

Where, AS_{100g} and FS_{100g} are the added sugar and free sugar of the final product per 100g, TS_{us} is the total sugar content per 100g of the unsweetened product and TS_s is the total sugar content per 100g of the sweetened product.

***STEP 5*: Calculate added and free sugar content based on lactose and maltose content.**

Where data for lactose was available in the Canadian Nutrient File (CNF) or the United State Department of Agriculture Food and Composition Database (USDA) and the food did not contain dried fruit or malted cereal, added sugar and free sugar content of ingredient-level foods was calculated using the formula: AS=TS– lactose and FS= TS– lactose. If data for lactose and maltose was available in the CNF or the USDA and the ingredient-level food contained malted cereal and did not contain dried fruit, added sugar and free sugar was calculated using the formulae: AS = TS – lactose – maltose, and FS = TS – lactose – maltose.

STEP 6: Calculate added sugar and free sugar content using content values of similar foods of STEPs 1–5 or other nutrient databases.

For foods for which steps 1-5 had not provided estimates of added or free sugar content, similar foods for which steps 1-5 did provide these estimates or foods that were included in the Food Standards Australia and New Zealand Food Nutrient Database (AUSNUT) information on added sugar or free sugar content was used. Foods were considered to be similar if they only differed in water content, if they contained similar ingredients (such as similar vegetables in soup), or if they were calorie/energy reduced or fat reduced. Where a similar food was identified (matching), added sugar and free sugar content of the target food was estimated using the formulas: $AS_{target} = TS_{target}$ x $(AS_{matching}/TS_{matching})$, and $FS_{target} = TS_{target}$ x $(FS_{matching}/TS_{matching})$.

STEP 7: Estimate added sugar and free sugar content of ingredient-level foods subjectively based on common recipes and ingredient lists.

Where none of the ingredients of food items contain added sugar or free sugar, the added sugar and free sugar were assigned 0 g. Where there were some ingredients with added sugar or free sugar, the proportion of ingredients were estimated using common recipes. For example, the CFIA information on percentage of liquid in canned fruits or vegetables were used [4].

STEP 8: Assign 50% of total sugar as added sugar and free sugar content of all remaining ingredient-level foods.

For the ingredient-level foods for which the added sugar or free sugar content was not estimated in steps 1-7, the added sugar and free sugar content were assigned as 50% of total sugar.

***STEP 9*: *Calculate added sugar and free sugar content of recipe-level foods using respondent specific recipes and the added and free sugars content of ingredient-level foods estimated in steps 1-8*.**

All recipe-level foods in the 2015 CCHS-Nutrition are made up of ingredient-level foods for which added sugar and free sugar was calculated in steps 1-8. Due to moisture changes caused by cooking, added sugar and free sugar content of recipe-level foods were calculate using the recipes, raw weights and proportion of ingredients. To calculate the added sugar and free sugar content of recipe-level foods, the following formulas were used:

$$AS_{100g} = \frac{\sum_{i=1}^{j} RW_i \text{ x } AS_i}{\sum_{i=1}^{j} W_i} \qquad FS_{100g} = \frac{\sum_{i=1}^{j} RW_i \text{ x } FS_i}{\sum_{i=1}^{j} W_i}$$

Where, RW_i is the raw weight for the ith ingredient in the recipe, W_i is the weight of the ith ingredient after cooking in the recipe, AS_i is the added sugar content per 100g of the ith ingredient and FS_i is the free sugar content per 100g of the ith ingredient.

Note 1: Some food items reported in the 2015 CCHS-Nutrition had missing information on total sugar. For these food items the CNF, the USDA, common grocery stores in Canada, or the AUSNUT were searched for similar food items. Where a similar food item was identified, total sugar for the 2015 CCHS-Nutrition food item was calculated whereby considering the total sugar/ energy ratio. Where more than one similar food item was identified, the average was used in this calculation.

Note 2: The above described 9-steps approach was adapted from Louie et al. [3] who applied their 10 steps-approach to Australian data. One of their 10 steps (step #4) was omitted in the above described 9-steps approach because some recipe-level foods reported.

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Appendix B. Search Algorithm

Search strategy of MEDLINE and EMBASE by Ovid

1. exp Taxes/
2. (tax* or price* or pricing or finance* or financial).mp.
3. exp Government/ or exp Government Programs/ or exp Policy/ or Government Regulation/
4. ordinance* or policy or policies or govern* or regulations or intervention*.mp.
5. Exp Sugars/
6. (sugar* or sweetened or unhealth* or junk).mp.
7. (food* or product* or good*).mp.
8. ((sugar* or sweetened or carbonated or soft) adj3 (drink* or beverage*)) or pop or soda.mp.
9. exp "Quality of Life"/
10. (QOL or QALY or DALY or HALY or LY).mp.
11. (quality of life or life year*).mp.
12. Cost* or cost-effective* or cost-utility
13. ICER* or ICUR*
14. 1 or 2 or 3 or 4
15. 6 and 7
16. 5 or 8 or 15
17. 14 and 16
18. 9 or 10 or 11
19. 17 and 18
20. 12 or 13
21. 19 and 20
22. limit 21 to (english language and humans)

Search strategy of Web of science

1. ALL= (tax* or price* or pricing or finance* or financial)
2. ALL= (program* or ordinance* or policy or policies or govern* or regulations or intervention*)
3. #1 OR #2
4. ALL= (sugar* or sweetened or unhealth* or junk)
5. ALL= (food* or product* or good*)
6. #4 AND #5
7. TS= ((sugar* or sweetened or carbonated or soft) NEAR/3 (drink* or beverage*))
8. All = (pop or soda)
9. #6 OR #7 OR #8
10. #3 AND #9
11. ALL= (QOL or QALY or DALY or HALY or LY)
12. ALL = (quality of life or life year*)
13. #11 OR #12
14. ALL = (Cost* or cost-effective* or cost-utility)
15. ALL = (ICER* or ICUR*)
16. #14 OR #15
17. #10 AND #13 AND #16
18. (#17) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article)

Search strategy of the Cochrane Library

(tax* or price* or pricing or finance* or financial) OR (program* or ordinance* or policy or policies or govern* or regulations or intervention*) in All Text AND ((sugar* or sweetened or unhealth* or junk) AND (food* or product* or good*)) OR ((sugar* or sweetened or carbonated or soft) NEAR/3 (drink* or beverage*)) OR (pop or soda) in All Text AND (QOL or QALY or

DALY or HALY or LY) OR (quality of life or life year*) in All Text AND (Cost* or cost-effective* or cost-utility) OR (ICER* or ICUR*) in All Text - in Trials (Word variations have been searched)

Search strategy of the EconLit

TX (tax* or price* or pricing or finance* or financial) and (program* or policy or policies or intervention*) AND TX ((sugar* and food*)) OR ((sugar* or sweetened or carbonated or soft) N3 (drink* or beverage*)) AND TX (QOL or QALY or DALY or HALY or LY) OR (quality of life or life year*) AND TX (Cost* and (cost-effective* or cost-utility or ICER* or ICUR*)) AND LA english

Appendix C. Quality assessment of included studies

Table C1 Quality of included studies using the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) checklist

Item	Item No.	Included studies references [22]	[23]	[30]	[31]	[32]	[33]	[34]	[35]	[36]	[37]	[38]	[39]	[40]	[41]	[42]
Title and abstract																
Title	1	Yes	Yes	Yes	Yes	Yes	Yes	Part	Yes	Yes	Part	Part	Part	Part	Part	Yes
Abstract	2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Introduction																
Background and objectives	3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Methods																
Target population and subgroups	4	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Setting and location	5	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Study perspective	6	Yes	Yes	Yes	Yes	No	Yes	Part	Yes	Yes	No	No	No	Yes	Yes	No
Comparators	7	Yes	Yes	Yes	Yes	Part	Yes	Yes	Yes	Yes	Part	Part	Part	Part	Yes	Yes
Time horizon	8	Part	Yes	Yes	Part	Part	Part	Part	Yes	Part	Part	Part	Part	Part	Part	Part
Discount rate	9	Yes	Part	Part	Part	Yes	Part	Yes	Part	Yes	Part	Part	No	Part	Yes	Yes
Choice of health outcomes	10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Measurement of effectiveness	11a	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Part	Part	Part	Yes	Yes	Yes
	11b	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Measurement and valuation of preference-based outcomes	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Estimating resources and costs	13a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	13b	Part	Part	Part	Yes	Part	Yes	Yes	Yes	Yes	Part	Part	Part	Part	Part	Part
Currency, price date, and conversion	14	Yes	Yes	Yes	Yes	Yes	Yes	Part	Yes	Yes	Part	Part	Part	Yes	Yes	Yes

Choice of model	15	Part	Part	Yes	Part	Yes	Yes	Yes	Yes	Yes	Part	Yes	Yes	Yes	Yes	Part
Assumptions	16	Yes	Yes	Part	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Analytical methods	17	Part	Part	Part	Yes	Yes	Yes	Yes	Yes	Part	Yes	Yes	Yes	Yes	Yes	Yes
Results																
Study parameters	18	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Incremental costs and outcomes	19	Part	Part	Part	Yes	Part	Yes	Part	Part	Yes	Part	Part	Part	Part	Part	Part
Characterizing uncertainty	20a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	20b	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Characterizing heterogeneity	21	Part	Part	Yes	Yes	Yes	Yes	Yes	Yes	Part	Yes	Yes	Yes	Yes	Yes	Yes
Discussion																
Study findings, limitations, generalizability, and current knowledge	22	Part	Yes	Part	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Part
Other																
Source of funding	23	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Conflicts of interest	24	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Total score		17.5	20	20	20.5	20	22	19.5	22	21.5	17.5	17.5	17.5	20	21	18.5

Appendix D. Data input and sources of simulation models

Table D1 The Consolidated Health Economic Evaluation Reporting Standards (CHEERS) Checklist for the sugar tax model

Item	Item No.	Recommendation	Reported on page No/ line No
Title and abstract			
Title	1	Identify the study as an economic evaluation or use more specific terms such as "cost-effectiveness analysis", and describe the interventions compared.	Chapter 5 Title
Abstract	2	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base case and uncertainty analyses), and conclusions.	5.1 Abstract
Introduction			
Background and objectives	3	Provide an explicit statement of the broader context for the study. Present the study question and its relevance for health policy or practice decisions.	5.2 Introduction
Methods			
Target population and subgroups	4	Describe characteristics of the base case population and subgroups analyzed, including why they were chosen.	5.3.1 para 2
Setting and location	5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made.	5.3.1 para 1
Study perspective	6	Describe the perspective of the study and relate this to the costs being evaluated.	5.3.1 para 1
Comparators	7	Describe the interventions or strategies being compared and state why they were chosen.	5.3.1 para 1, 5.3.2
Time horizon	8	State the time horizon(s) over which costs and consequences are being evaluated and say why appropriate.	5.3.1 para 1
Discount rate	9	Report the choice of discount rate(s) used for costs and outcomes and say why appropriate.	5.3.1 para 1
Choice of health outcomes	10	Describe what outcomes were used as the measure(s) of benefit in the evaluation and their relevance for the type of analysis performed.	5.3.1 para 1
Measurement of effectiveness	11a	Single study-based estimates: Describe fully the design features of the single effectiveness study and why the single study was a sufficient source of clinical effectiveness data.	5.3.1 para 3

	11b	Synthesis-based estimates: Describe fully the methods used for identification of included studies and synthesis of clinical effectiveness data.	N/A
Measurement and valuation of preference-based outcomes	12	If applicable, describe the population and methods used to elicit preferences for outcomes.	5.3.7 para 4, 5.3.8 para 1
Estimating resources and costs	13a	Single study-based economic evaluation: Describe approaches used to estimate resource use associated with the alternative interventions. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	N/A
	13b	Model-based economic evaluation: Describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	5.3.7, 5.3.8
Currency, price date, and conversion	14	Report the dates of the estimated resource quantities and unit costs. Describe methods for adjusting estimated unit costs to the year of reported costs if necessary. Describe methods for converting costs into a common currency base and the exchange rate.	5.3.8 para 2, 3
Choice of model	15	Describe and give reasons for the specific type of decision analytical model used. Providing a figure to show model structure is strongly recommended.	5.3.3
Assumptions	16	Describe all structural or other assumptions underpinning the decision-analytical model.	5.3.4, 5.3.5, 5.3.6
Analytical methods	17	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing, or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments (such as half cycle corrections) to a model; and methods for handling population heterogeneity and uncertainty.	5.3.1 para 2, 5.3.9
Results			
Study parameters	18	Report the values, ranges, references, and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table to show the input values is strongly recommended.	5.3.5, 5.3.6, 5.3.7

Incremental costs and outcomes	19	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as well as mean differences between the comparator groups. If applicable, report incremental cost-effectiveness ratios.	5.4.1, 5.4.2, 5.4.3
Characterizing uncertainty	20a	Single study-based economic evaluation: Describe the effects of sampling uncertainty for the estimated incremental cost and incremental effectiveness parameters, together with the impact of methodological assumptions (such as discount rate, study perspective).	N/A
	20b	Model-based economic evaluation: Describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions.	5.4.4
Characterizing heterogeneity	21	If applicable, report differences in costs, outcomes, or cost-effectiveness that can be explained by variations between subgroups of patients with different baseline characteristics or other observed variability in effects that are not reducible by more information.	5.4.1, 5.4.2
Discussion			
Study findings, limitations, generalizability, and current knowledge	22	Summarize key study findings and describe how they support the conclusions reached. Discuss limitations and the generalizability of the findings and how the findings fit with current knowledge.	5.5 para 1, 6, 7
Other			
Source of funding	23	Describe how the study was funded and the role of the funder in the identification, design, conduct, and reporting of the analysis. Describe other non-monetary sources of support.	Preface
Conflicts of interest	24	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors comply with International Committee of Medical Journal Editors recommendations.	Preface

Adapted from Husereau et al. [1].

Table D2 Own- and cross-price food elasticities values (Means and Standard Errors (SE))

	Cake and buscuits	Bread and breakfast cereals	Chocolate, confectionary	Non-alcholic beverages	Prepared, preserved and	Sauces, sugar and condiments	Other grocery food	Pasta, grains and flours	Magrine and edible oil	Poultry	Pork	Beef, lamb, and hogget	Fish and seafood	Vegetables	Cheese and cream	Milk, yougurt and eggs	Fruits	Pastry cook products
Non-alcholic beverages	-0.05	0.03	-0.08	**-1.15**	0.02	-0.03	-0.08	0.01	0.01	0.06	0.05	0.05	0.03	0.01	0.05	0.09	-0.01	-0.02
	(0.02)	(0.02)	(0.02)	**(0.02)**	(0.02)	(0.01)	(0.05)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)
Bread and breakfast	-0.05	**-0.80**	-0.01	0.00	-0.08	-0.04	-0.26	0.00	-0.12	-0.05	-0.04	-0.11	0.02	-0.09	0.01	0.20	-0.03	-0.10
cereals	(0.04)	**(0.05)**	(0.03)	(0.01)	(0.03)	(0.01)	(0.03)	(0.02)	(0.02)	(0.04)	(0.02)	(0.04)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)
Chocolate, confectionary	0.07	0.19	**-1.15**	-0.07	-0.01	-0.06	-0.05	0.01	-0.03	0.00	0.12	-0.03	-0.03	0.03	-0.06	0.06	0.07	0.01
and snacks	(0.02)	(0.04)	**(0.03)**	(0.01)	(0.02)	(0.01)	(0.04)	(0.01)	(0.01)	(0.02)	(0.02)	(0.04)	(0.02)	(0.03)	(0.02)	(0.03)	(0.03)	(0.01)
Cake and buscuits	**-1.08**	0.06	-0.10	0.00	-0.03	-0.04	-0.09	-0.02	-0.17	0.19	0.17	-0.15	0.05	-0.24	-0.06	-0.03	-0.17	-0.07
	(0.11)	(0.06)	(0.03)	(0.01)	(0.04)	(0.02)	(0.05)	(0.02)	(0.03)	(0.06)	(0.06)	(0.06)	(0.03)	(0.04)	(0.03)	(0.04)	(0.05)	(0.05)
Prepared, preserved and	-0.11	-0.10	-0.18	0.00	**-1.04**	-0.08	-0.24	0.08	-0.12	0.20	0.09	-0.06	0.01	-0.11	0.02	-0.08	-0.13	-0.02
processed meat	(0.03)	(0.03)	(0.03)	(0.01)	**(0.04)**	(0.01)	(0.04)	(0.02)	(0.02)	(0.03)	(0.02)	(0.05)	(0.02)	(0.04)	(0.02)	(0.03)	(0.03)	(0.02)
Sauces, sugar and	-0.03	-0.03	-0.14	0.01	-0.03	**-1.24**	-0.16	-0.05	-0.02	0.07	0.00	-0.08	0.03	0.12	-0.09	0.07	0.06	0.01
condiments	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	**(0.02)**	(0.05)	(0.02)	(0.01)	(0.03)	(0.01)	(0.04)	(0.02)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)
Other grocery food	-0.01	-0.04	0.02	0.00	-0.03	-0.01	**-0.22**	0.02	-0.04	0.01	0.00	-0.16	-0.03	-0.06	-0.05	-0.04	-0.08	0.08
	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	**(0.05)**	(0.01)	(0.01)	(0.02)	(0.01)	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)
Vegetables	-0.24	0.01	-0.06	0.02	-0.03	0.04	-0.30	0.02	-0.04	0.01	-0.01	-0.09	0.03	**-0.91**	-0.02	-0.01	0.01	-0.02
	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	(0.04)	(0.01)	(0.01)	(0.02)	(0.02)	(0.03)	(0.02)	**(0.04)**	(0.01)	(0.02)	(0.02)	(0.01)
Fruits	-0.32	0.16	-0.07	-0.01	-0.07	-0.01	-0.33	-0.05	-0.07	0.03	0.05	-0.11	0.00	0.03	0.08	0.03	**-0.65**	0.08
	(0.04)	(0.03)	(0.03)	(0.01)	(0.03)	(0.03)	(0.04)	(0.01)	(0.02)	(0.03)	(0.02)	(0.04)	(0.02)	(0.03)	(0.02)	(0.03)	**(0.05)**	(0.02)

From Ni Mhurchu et al. [2]

Table D3 Trend in body mass index

Age	**Females** (kg/m^2 per year)	**Males** (kg/m^2 per year)
20~24	0.010	0.017
25~29	0.018	0.027
30~34	0.026	0.036
35~39	0.033	0.044
40~44	0.039	0.051
45~49	0.044	0.057
50~54	0.049	0.063
55~59	0.054	0.068
60~64	0.057	0.072
65~69	0.060	0.075
70~74	0.063	0.078
75~79	0.065	0.080
80+	0.066	0.082

From Lau et al. [3].

Table D4 Disease data sources and processing notes for sugar tax model

Disease	Data Source	Notes
Oesophageal cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Colon and rectum cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Liver cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Gallbladder and biliary tract cancer	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence rates from Statistic Canada are not available for biliary cancer; Prevalence rates from Statistic Canada are not available for 5-age group
Pancreatic cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Breast cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Uterine cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Ovarian cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Kidney cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Thyroid cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Non-Hodgkin's lymphoma	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group

Multiple myeloma	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Leukaemia	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Ischemic heart disease	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0147-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence rates from Statistic Canada are not available for people aged <20 and 5-age group
Ischemic stroke	Incidence cases from GBD Result Tool (2015); Death cases from GBD Result Tool (2015); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence rates from Statistic Canada are not available for people aged <20 years old and 5-age group; Death cases from Statistic Canada are not available for ischemic stroke
Hemorrhagic stroke	Incidence cases from GBD Result Tool (2015); Death cases from GBD Result Tool (2015); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence rates from Statistic Canada are not available for people aged <20 years old and 5-age group; Death cases from Statistic Canada are not available for ischemic stroke
Hypertensive heart disease	Death cases from GBD Result Tool (2015); Prevalence cases from GBD Result Tool (2015)	Incidence rates are not available from Statistic Canada and the GBD Result Tool
Atrial fibrilliation and flutter	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0147-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence rates from Statistic Canada are not available for people aged <20 and 5-age group
Asthma	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0782-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available 5-age group
Gallbladder and biliary disease	Incidence cases from GBD Result Tool (2015); Death cases from GBD Result Tool (2015); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available 5-age group; Death cases from Statistic Canada are not available for asthma
Alzheimer's disease and other dementias	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0145-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available 5-age group
Diabetes mellitus type 2	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0144-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available

Chronic kidney disease due to diabetes	Incidence cases from GBD Result Tool (2015); Death cases from GBD Result Tool (2015); Prevalence cases from GBD Result Tool (2015)	Incidence, death and prevalence cases from Statistic Canada are not available
Chronic kidney disease due to hypertension	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0147-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available
Chronic kidney disease due to glomerulonephritis	Incidence cases from GBD Result Tool (2015); Death cases from GBD Result Tool (2015); Prevalence cases from GBD Result Tool (2015)	Incidence, death and prevalence cases from Statistic Canada are not available
Chronic kidney disease due to other causes	Incidence cases from GBD Result Tool (2015); Death cases from GBD Result Tool (2015); Prevalence cases from GBD Result Tool (2015)	Incidence, death and prevalence cases from Statistic Canada are not available
Cataract	Death cases were inputted as 0; Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available
Low back pain	Incidence cases from GBD Result Tool (2015); Death cases were inputted as 0; Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available
Gout	Incidence cases from GBD Result Tool (2015); Death cases were inputted as 0; Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available
Osteoarthritis of the hip	Incidence cases from GBD Result Tool (2015); Death cases were inputted as 0; Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available
Osteoarthritis of the knee	Incidence cases from GBD Result Tool (2015); Death cases were inputted as 0; Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available

Table D5 Direct health care costs inputs for sugar tax model (2015 CAD$)

Sex	Age	Esophagus cancer $/prevalent case	Colorectal cancer $/prevalent case	Liver cancer $/prevalent case	Gallbladder and billiary track cancer $/prevalent case	Pancreas cancer $/prevalent case	Breast cancer $/prevalent case	Uterus cancer $/prevalent case
Females	<55	13,101	12,196	13,495	312,114	48,705	3,296	7,414
	55-64	14,099	8,689	11,541	241,301	32,413	2,084	3,156
	65-74	14,675	7,633	12,284	189,180	30,052	1,535	2,338
	75+	13,645	8,311	10,052	53,740	16,678	1,396	4,391
Males	<55	22,689	12,042	24,917	152,411	51,650	-	-
	55-64	23,614	9,447	17,449	75,624	34,734	-	-
	65-74	26,570	7,644	15,230	99,707	34,130	-	-
	75+	26,872	9,229	19,062	52,811	16,532	-	-

Sex	Age	Ovary cancer $/prevalent case	Kidney cancer $/prevalent case	Thyroid cancer $/prevalent case	Non-Hodgkin lymphoma $/prevalent case	Multiple myeloma $/prevalent case	Leukemia $/prevalent case	Ischemic heart disease $/prevalent case
Females	<55	4,989	9,541	15,640	21,278	19,321	48,775	5,727
	55-64	2,481	7,236	5,852	11,332	34,524	8,031	5,759
	65-74	1,589	7,586	7,081	7,136	23,232	4,199	4,554
	75+	4,547	12,381	14,721	4,251	16,194	9,795	4,260
Males	<55	-	4,661	17,894	21,887	28,602	18,955	12,816
	55-64	-	4,400	5,137	9,126	36,169	9,287	8,959
	65-74	-	3,959	6,782	4,962	13,702	4,913	5,834
	75+	-	6,579	10,355	3,988	12,305	4,843	5,098

Sex	Age	Ischemic stroke $/prevalent case	Hemorrhagic stroke $/prevalent case	Hypertensive heart disease $/prevalent case	Atrial fibrilliation and flutter $/prevalent case	Asthma $/prevalent case	Gallbladder and biliary tract $/prevalent case	Alzheimer's disease $/prevalent case
Females	<55	2,084	4,759	88,473	344	1,906	689	554
	55-64	2,274	3,978	124,217	244	1,638	592	1,513
	65-74	2,753	5,428	60,866	294	1,537	640	1,514
	75+	5,234	14,373	6,888	572	1,467	896	1,395
Males	<55	3,243	6,887	134,425	213	2,062	1,434	443

	55-64	3,995	8,063	204,777	265	2,157	1,113	1,047
	65-74	3,525	13,068	83,029	232	1,841	925	1,367
	75+	5,876	25,127	9,620	451	2,087	1,125	2,329
Sex	**Age**	**Diabetes** $/prevalent case	**Chronic kidney disease** $/prevalent case	**Cataract** $/prevalent case	**Low back pain** $/prevalent case	**Gout** $/prevalent case	**Arthrosis of hip** $/prevalent case	**Arthrosis of knee** $/prevalent case
Females	<55	7,446	626	11,269	782	47	1,657	470
	55-64	5,712	375	19,107	602	34	1,992	765
	65-74	4,500	318	20,645	544	48	2,172	817
	75+	3,931	280	6,812	732	124	2,314	718
Males	<55	7,205	698	12,638	1,124	43	2,055	417
	55-64	7,134	529	19,904	966	36	2,248	739
	65-74	5,206	514	22,019	702	47	2,169	871
	75+	4,245	391	10,540	810	107	2,110	849

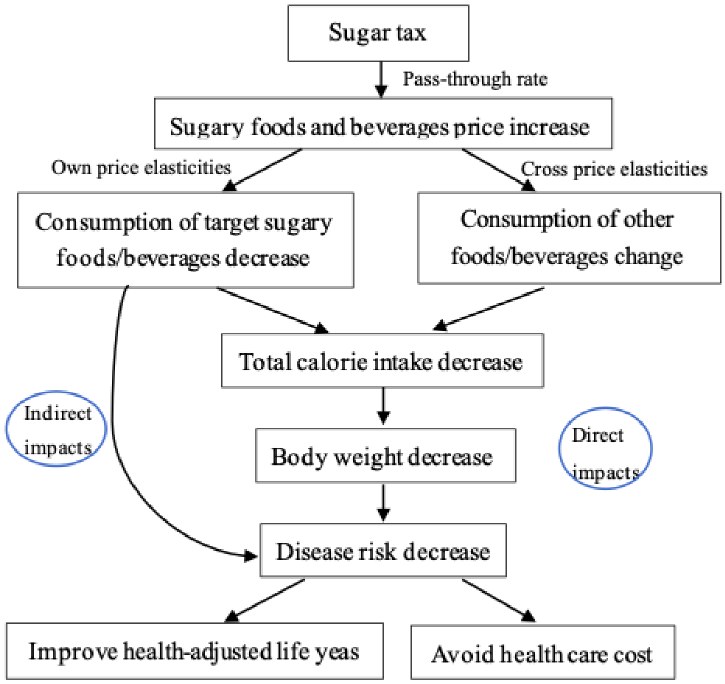

Figure D1 The model diagram of a simulated sugar tax for the intervention population

Table D6 The average free sugar content and pre- and post-tax price for a CAD$0.75/100g tax on free sugar content of sugary foods and beverages by food categories in Canada in 2015

Food group	**Average free sugar content** (g/100g)	**Pre-tax price** (CAD$/100g)	**Post-tax price** (CAD$/100g)
Non-alcholic beverages	8.04	0.35	0.37
Cake and buscuits	21.76	1.17	1.36
Chocolate, confectionary and snacks	31.79	1.96	2.43
Bread and breakfast cereals	15.94	0.83	0.92
Prepared, preserved and processed meat	1.36	1.84	1.85
Sauces, sugar and condiments	22.80	0.84	0.99
Other grocery food	9.66	1.44	1.55

Average free sugar content from Liu et al. [4]; Pre-tax price from Walmart websites [5].

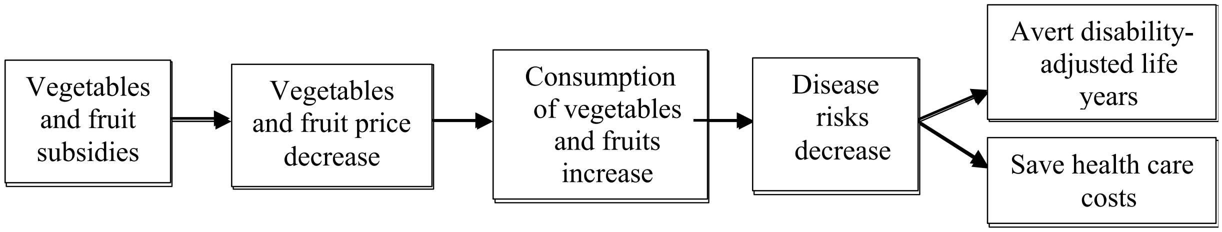

Figure D2 The model diagram of a simulated vegetables and fruit subsidies for the intervention population

Table D7 Own-price food elasticities values by income quintile (Means and Standard Errors (SE))

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Non-alcholic beverages	-1.08 (0.06)	-1.20 (0.03)	-1.24 (0.03)	-1.17 (0.03)	-1.08 (0.03)
Bread and breakfast cereals	-1.15 (0.15)	-0.71 (0.10)	-0.70 (0.09)	-0.69 (0.10)	-0.48 (0.14)
Chocolate, confectionary and snacks	-1.30 (0.09)	-1.18 (0.10)	-1.14 (0.07)	-1.13 (0.07)	-1.17 (0.06)
Cake and buscuits	-1.30 (0.29)	-1.16 (0.24)	-1.09 (0.23)	-0.69 (0.20)	-1.31 (0.24)
Prepared, preserved and processed meat	-1.01 (0.13)	-1.21 (0.10)	-1.01 (0.07)	-1.01 (0.08)	-0.87 (0.10)
Sauces, sugar and condiments	-1.37 (0.06)	-1.30 (0.06)	-1.20 (0.04)	-1.17 (0.03)	-1.13 (0.03)
Other grocery foods	-0.55 (0.16)	-0.10 (0.12)	-0.09 (0.11)	-0.24 (0.12)	-0.22 (0.05)
Vegetables	-1.09 (0.10)	-1.04 (0.08)	-0.80 (0.08)	-0.82 (0.06)	-0.64 (0.08)
Fruits	-0.78 (0.17)	-0.70 (0.10)	-0.51 (0.12)	-0.65 (0.15)	-0.66 (0.11)

From Ni Mhurchu et al. [2]

Table D8 Disease data sources and processing notes for vegetables and fruit subsidies model

Disease	Data Source	Notes
Oesophageal cancer	Incidence rates from the Statistics Canada (Table 13-10-0111-01 (2015)); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Prevalence rates from Statistic Canada are not available for 5-age group
Lip and oral cavity cancer	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence rates from Statistic Canada are not available for Lip and oral cavity cancer; Prevalence rates from Statistic Canada are not available for 5-age group
Nasopharynx cancer	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence rates from Statistic Canada are not available for Nasopharynx cancer; Prevalence rates from Statistic Canada are not available for 5-age group
Other pharynx cancer	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence rates from Statistic Canada are not available for Other pharynx cancer; Prevalence rates from Statistic Canada are not available for 5-age group
Larynx cancer	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence rates from Statistic Canada are not available for Larynx cancer; Prevalence rates from Statistic Canada are not available for 5-age group
Tracheal, bronclus, and lung cancer	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0142-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence rates from Statistic Canada are not available for Tracheal, bronclus, and lung cancer; Prevalence rates from Statistic Canada are not available for 5-age group
Ischemic heart disease	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0147-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence rates from Statistic Canada are not available for people aged <20 and 5-age group
Ischemic stroke	Incidence cases from GBD Result Tool (2015); Death cases from GBD Result Tool (2015); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence rates from Statistic Canada are not available for people aged <20 years old and 5-age group; Death cases from Statistic Canada are not available for ischemic stroke
Intracerebral hemorrhage	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0147-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence rates from Statistic Canada are not available for Intracerebral hemorrhage; Prevalence rates from Statistic Canada are not available for 5-age group
Subarachnoid hemorrhage	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0147-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence rates from Statistic Canada are not available for Subarachnoid hemorrhage; Prevalence rates from Statistic Canada are not available for 5-age group
Diabetes mellitus type 2	Incidence cases from GBD Result Tool (2015); Death cases from Statistic Canada (Table: 13-10-0144-01 (2015)); Prevalence cases from GBD Result Tool (2015)	Incidence and prevalence cases from Statistic Canada are not available

Table D9 Direct health care costs inputs for vegetables and fruit subsidies model (2015 CAD$)

Sex	**Age**	**Esophagus cancer** $/prevalent case	**Lip and oral cavity cancer** $/prevalent case	**Nasopharynx cancer** $/prevalent case	**Other pharynx cancer** $/prevalent case	**Larynx cancer** $/prevalent case	**Tracheal, bronclus, and lung cancer** $/prevalent case
Females	<55	13,101	9,909	9,909	9,909	4,598	25,249
	55-64	14,099	10,230	10,230	10,230	3,884	14,276
	65-74	14,675	13,655	13,655	13,655	7,979	14,091
	75+	13,645	18,048	18,048	18,048	10,294	19,220
Males	<55	22,689	10,726	10,726	10,726	9,149	29,492
	55-64	23,614	12,675	12,675	12,675	9,569	17,187
	65-74	26,570	12,229	12,229	12,229	7,157	16,961
	75+	26,872	17,130	17,130	17,130	9,824	22,545
Sex	**Age**	**Ischemic heart disease** $/prevalent case	**Ischemic stroke** $/prevalent case	**Intracerebral hemorrhage** $/prevalent case	**Subarachnoid hemorrhage** $/prevalent case	**Diabetes mellitus type 2** $/prevalent case	**Cost unrelated disease** $/person
Females	<55	5,727	2,084	3,846	5,871	7,446	1,142
	55-64	5,759	2,274	5,732	3,275	5,712	1,541
	65-74	4,554	2,753	10,003	2,932	4,500	1,877
	75+	4,260	5,234	21,557	4,271	3,931	3,251
Males	<55	12,816	3,243	7,401	7,275	7,205	862
	55-64	8,959	3,995	11,126	5,500	7,134	1,594
	65-74	5,834	3,525	20,167	3,838	5,206	2,047
	75+	5,098	5,876	39,196	2,645	4,245	3,631

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Appendix E: Additional results of sugar tax and vegetables and fruit subsidy models

Table E1 Mean change in energy intake from sugar sweetened beverages (SSBs) and total energy intake (TEI) due to a CAD$0.015/oz SSB tax, by age and gender

	Changes in energy intake from SSBs (per person, per day; kcal)				Changes in TEI (per person, per day; kcal)			
Age	**Females**		**Males**		**Females**		**Males**	
group[2]	Mean	95%UI[1]	Mean	95%UI	Mean	95%UI	Mean	95%UI
1~9	-16.11	(-16.87, -15.33)	-18.39	(-19.27, -17.50)	-14.11	(-14.86, -13.33)	-16.08	(-16.95, -15.21)
10~19	-20.73	(-11.71, -19.71)	-33.01	(-34.31, -31.64)	-19.56	(-20.53, -18.56)	-30.50	(-31.92, -29.21)
20~29	-16.19	(-17.62, -14.73)	-28.68	(-30.99, -26.39)	-15.23	(-16.72, -13.73)	-28.24	(-30.83, -25.52)
30~39	-13.36	(-14.36, -12.33)	-23.76	(-25.64, -21.93)	-12.79	(-13.84, -11.71)	-22.51	(-24.47, -20.56)
40~49	-9.98	(-10.91, -9.09)	-17.48	(-19.05, -15.87)	-9.34	(-10.33, -8.37)	-17.45	(-19.09, -15.89)
50~59	-9.06	(-9.97, -8.12)	-14.71	(-15.80, -13.60)	-10.35	(-11.39, -9.35)	-14.31	(-15.56, -13.13)
60~69	-13.53	(-14.89, -12.17)	-9.27	(-10.11, -8.40)	-8.90	(-9.82, -7.95)	-13.12	(-14.54, -11.68)
70~79	-9.33	(-10.19, -8.84)	-11.46	(-12.44, -10.50)	-8.92	(-9.83, -8.05)	-10.35	(-11.37, -9.34)
80~89	-11.78	(-13.09, -10.46)	-14.75	(-17.07, -12.40)	-11.46	(-12.84, -10.13)	-14.03	(-16.37, -11.64)
90+	-13.16	(-16.07, -10.27)	-17.78	(-24.09, -11.88)	-10.65	(-13.71, -7.62)	-16.07	(-22.84, -9.46)
Total	-12.83	(-13.17, -12.52)	-20.27	(-20.77, -19.77)	-12.27	(-12.61, -11.91)	-19.25	(-19.77, -18.71)

[1] 95%UI, 95% uncertainty interval; [2] 1~19 age groups were not included in cost-effectiveness modeling.

Table E2 Mean change in body mass index due to a CAD$0.015/oz SSB tax, by age and gender

Age group[2]	Females		Males	
	Mean (kg/m^2)	95%UI[1]	Mean (kg/m^2)	95%UI
1~9	-0.07	(-0.08, -0.07)	-0.08	(-0.08, -0.08)
10~19	-0.12	(-0.12, -0.11)	-0.14	(-0.15, -0.13)
20~29	-0.16	(-0.17, -0.14)	-0.22	(-0.24, -0.20)
30~39	-0.15	(-0.16, -0.13)	-0.20	(-0.22, -0.19)
40~49	-0.11	(-0.13, -0.10)	-0.16	(-0.18, -0.15)
50~59	-0.13	(-0.14, -0.12)	-0.14	(-0.15, -0.13)
60~69	-0.12	(-0.13, -0.10)	-0.14	(-0.15, -0.12)
70~79	-0.13	(-0.14, -0.11)	-0.12	(-0.13, -0.10)
80~89	-0.15	(-0.17, -0.14)	-0.15	(-0.17, -0.13)
90+	-0.13	(-0.17, -0.09)	-0.17	(-0.24, -0.10)
Total	-0.14	(-0.15, -0.14)	-0.18	(-0.19, -0.18)

[1] 95%UI, 95% uncertainty interval; [2] 1~19 age groups were not included in cost-effectiveness modeling.

Table E3 Prevented disease incident cases, prevalent cases, and deaths due to a CAD$0.015/oz SSB tax in Canada

	Incident cases (2016-2041)		**Prevalent cases (2041)**		**Deaths (2016-2041)**	
	Mean	95%UI[1]	Mean	95%UI	Mean	95%UI
Diabetes mellitus type 2	72,673	(69,866, 74,923)	69,180	(66,505, 71,327)	81	(78, 84)
Cancer						
Esophageal cancer	32	(26, 39)	11	(9, 13)	21	(17, 25)
Colon and rectum cancer	233	(223, 243)	174	(166, 181)	50	(47, 52)
Liver cancers	32	(28, 36)	6	(5, 7)	26	(22, 29)
Gallbladder and biliary tract cancer	7	(7, 8)	5	(4, 5)	2	(2, 2)
Pancreatic cancer	13	(11, 15)	3	(3, 4)	9	(8, 11)
Breast cancer (premenopausal)[2]	1,451	(1,186, 1,708)	555	(336, 765)	132	(102, 161)
Uterine cancer[2]	253	(246, 260)	222	(216, 229)	20	(20, 21)
Ovarian cancer[2]	16	(12, 19)	12	(10, 15)	2	(2, 3)
Kidney cancer	204	(193, 215)	186	(175, 196)	8	(7, 8)
Thyroid cancer	522	(477, 567)	499	(455, 541)	1	(1, 1)
Non-Hodgkin's lymphoma	87	(73, 101)	72	(60, 84)	11	(10, 13)
Multiple myeloma, leukemia	11	(9, 13)	9	(8, 11)	1	(1, 2)
Cardiovascular disease						
Ischaemic heart disease	27,972	(23,767, 31,289)	25,292	(21,389, 28,307)	1,535	(1,274, 1,730)
Ischaemic stroke	1,526	(1,448, 1,603)	1,455	(1,379, 1,529)	9	(9, 10)

Hemorrhagic stroke	1,785	(1,716, 1,845)	1,538	(1,489, 1,589)	189	(181, 196)
Hypertensive heart disease	113	(107, 119)	38	(36, 40)	74	(70, 78)
Atrial fibrillation and flutter	1,020	(936, 1,099)	956	(878, 1,031)	0	(0, 0)
Other conditions						
Chronic kidney disease due to diabetes mellitus	72	(62, 82)	62	(54, 71)	4	(3, 5)
Chronic kidney disease due to hypertension	106	(91, 120)	98	(84, 111)	0	(0, 0)
Chronic kidney disease due to glomerulonephritis	155	(130, 178)	140	(117, 162)	2	(1, 2)
Chronic kidney disease due to other causes	1,428	(1,222, 1,621)	1,318	(1,127, 1,498)	3	(2, 3)
Asthma	9,289	(8,654, 9,982)	8,425	(7,790, 9,093)	4	(4, 4)
Gallbladder and biliary diseases	42,055	(39,687, 44,513)	40,887	(38,587, 43,280)	5	(5, 6)
Alzheimer's disease and other dementias	64	(51, 77)	200	159, 239)	0	(0, 1)
Cataract	119	(105, 135)	116	(102, 131)	-	-
low back pain	19,679	(18,739, 20,606)	18,610	(17,697, 19,518)	-	-
Gout	19,396	(17,510, 21,420)	18,693	(16,797, 20,549)	-	-
Osteoarthritis of hip	387	(352, 420)	362	(330, 394)	-	-
Osteoarthritis of knee	9,842	(9,061, 10,613)	9,292	(8,551, 10,024)	-	-

[1] 95%UI: 95% uncertainty interval, [2] Only for females.

Table E4 Mean change in free sugar intake and consumption of vegetables and fruit due to a CAD$0.75 tax on sugar content of products and a 20% subsides for vegetables and fruit, by age and gender

	Changes in free sugar intake due to tax on sugary beverages (g/per day)				**Changes in free sugar intake due to tax on sugary foods** (g/per day)				**Changes in consumption of vegetables and fruits due to subsidies** (g/per day)			
Age	**Females**		**Males**		**Females**		**Males**		**Females**		**Males**	
group[3]	Mean	95%UI[1]	Mean	95%UI	Mean	95%UI	Mean	95%UI	Mean	95%UI	Mean	95%UI
1~9	-1.15	(-1.20, -1.09)	-1.34	(-1.40, -1.27)	-6.37	(-6.66, -6.09)	-6.56	(-6.86, -6.27)	39.83	(38.84, 41.12)	39.42	(38.12, 40.99)
10~19	-1.56	(-1.63, -1.48)	-2.57	(-2.67, -2.46)	-7.60	(-7.95, -7.23)	-7.64	(-8.02, -7.26)	40.95	(40.28, 41.72)	41.27	(40.20, 43.03)
20~29	-1.31	(-1.43, -1.20)	-2.31	(-2.50, -2.11)	-5.94	(-6.29, -5.58)	-6.80	(-7.22, -6.39)	48.06	(46.17, 50.17)	47.84	(45.72, 49.69)
30~39	-1.06	(-1.14, -0.98)	-1.97	(-2.15, -1.81)	-5.30	(-5.59, -5.01)	-6.33	(-6.69, -5.95)	54.36	(52.98, 55.63)	53.09	(49.85, 54.80)
40~49	-0.76	(-0.84, -0.69)	-1.40	(-1.52, -1.27)	-4.91	(-5.19, -4.63)	-7.10	(-7.72, -6.42)	55.60	(53.11, 57.73)	57.96	(56.39, 59.77)
50~59	-0.73	(-0.81, -0.65)	-1.17	(-1.26, -1.08)	-6.20	(-6.53, -5.87)	-6.30	(-6.66, -5.89)	56.55	(54.99, 58.20)	60.31	(58.53, 62.46)
60~69	-0.71	(-0.78, -0.64)	-1.08	(-1.20, -0.96)	-5.36	(-5.73, -5.00)	-6.34	(-6.72, -5.99)	56.72	(54.38, 58.42)	57.51	(54.26, 60.47)
70~79	-0.71	(-0.78, -0.64)	-0.86	(-0.93, -0.78)	-5.28	(-5.60, -4.96)	-6.58	(-6.95, -6.21)	49.29	(46.65, 50.63)	52.51	(50.71, 54.19)
80~89	-0.82	(-0.91, -0.73)	-1.08	(-1.26, -0.89)	-4.99	(-5.33, -4.62)	-7.17	(-7.77, -6.56)	42.43	(40.87, 46.13)	58.57	(54.04, 62.66)
90+	-0.90	(-1.09, -0.69)	-1.31	(-1.80, -0.83)	-5.34	(-6.18, -4.50)	-6.05	(-8.07, -3.99)	47.81	(40.75, 54.61)	46.24	(36.41, 58.99)
Total	-0.98	(-1.01, -0.96)	-1.60	(-1.64, -1.56)	-5.81	(-5.92, -5.71)	-6.73	(-6.87, -6.58)	50.37	(50.08, 50.80)	51.64	(51.20, 52.23)

[1] 95%UI, 95% uncertainty interval, [2] TEI: total energy intake, [3] 1~19 age groups were not included in cost-effectiveness modeling.

Table E5 Mean change in body mass index (BMI) due to a CAD$0.75 tax on sugar content of products, by age and gender

Age group[2]	Tax on sugary drinks				Tax on sugary foods			
	Females		Males		Females		Males	
	Mean	95%UI[1]	Mean	95%UI	Mean	95%UI	Mean	95%UI
1~9	-0.03	(-0.03, -0.03)	-0.03	(-0.03, -0.03)	-0.51	(-0.52, -0.50)	-0.52	(-0.53, -0.51)
10~19	-0.05	(-0.05, -0.04)	-0.06	(-0.06, -0.05)	-0.70	(-0.72, -0.69)	-0.64	(-0.66, -0.63)
20~29	-0.06	(-0.07, -0.06)	-0.09	(-0.10, -0.08)	-1.08	(-1.11, -1.04)	-1.04	(-1.08, -1.00)
30~39	-0.06	(-0.06, -0.05)	-0.08	(-0.09, -0.07)	-1.09	(-1.13, -1.06)	-1.10	(-1.13, -1.07)
40~49	-0.05	(-0.05, -0.04)	-0.06	(-0.07, -0.06)	-1.15	(-1.19, -1.12)	-1.26	(-1.30, -1.22)
50~59	-0.05	(-0.06, -0.05)	-0.06	(-0.06, -0.05)	-1.30	(-1.33, -1.26)	-1.18	(-1.21, -1.14)
60~69	-0.05	(-0.05, -0.04)	-0.05	(-0.06, -0.05)	-1.25	(-1.29, -1.22)	-1.27	(-1.31, -1.23)
70~79	-0.05	(-0.05, -0.04)	-0.05	(-0.05, -0.04)	-1.26	(-1.30, -1.22)	-1.20	(-1.23, -1.17)
80~89	-0.06	(-0.07, -0.05)	-0.06	(-0.07, -0.05)	-1.16	(-1.22, -1.11)	-1.15	(-1.19, -1.10)
90+	-0.05	(-0.07, -0.04)	-0.07	(-0.10, -0.04)	-1.10	(-1.20, -0.99)	-0.99	(-1.16, -0.82)
Total	-0.06	(-0.06, -0.06)	-0.07	(-0.07, -0.07)	-1.17	(-1.18, -1.16)	-1.16	(-1.17, -1.15)

[1] 95%UI, 95% uncertainty interval, [2] 1~19 age groups were not included in cost-effectiveness modeling.

Table E6 Prevented disease incident cases, prevalent cases, and deaths due to a CAD$0.75 tax on free sugar content of products and a 20% subsidy for vegetables and fruit

Tax on sugary beverages

	Incident cases (2016-2041)		**Prevalent cases (2041)**		**Deaths (2016-2041)**	
	Mean	95%UI[1]	Mean	95%UI	Mean	95%UI
Diabetes mellitus type 2	28,921	(27,775, 29,876)	27,531	(26,442, 28,440)	32	(31, 33)
Cancer						
Esophageal cancer	13	(10, 15)	4	(3, 5)	8	(7, 10)
Colon and rectum cancer	93	(89, 97)	69	(66, 72)	20	(19, 21)
Liver cancers	13	(11, 14)	2	(2, 3)	10	(9,12)
Gallbladder and biliary tract cancer	3	(3, 3)	2	(2, 2)	1	(1, 1)
Pancreatic cancer	5	(4, 6)	1	(1, 1)	4	(3, 4)
Breast cancer (premenopausal)[2]	581	(476, 688)	224	(139, 316)	53	(41, 65)
Uterine cancer[2]	101	(99, 104)	89	(87, 91)	8	(8, 8)
Ovarian cancer[2]	6	(5, 8)	5	(4, 6)	1	(1, 1)
Kidney cancer	81	(77, 86)	74	(70, 78)	3	(3, 3)
Thyroid cancer	208	(190, 226)	199	(181, 216)	0	(0, 1)
Non-Hodgkin's lymphoma	35	(29, 40)	29	(25, 34)	5	(4, 5)
Multiple myeloma, leukemia	5	(4, 5)	4	(3, 4)	1	(0, 1)
Cardiovascular disease						

Ischaemic heart disease	11,132	(9,559, 12,426)	10,066	(8,643, 11,231)	612	(513, 691)
Ischaemic stroke	612	(579, 642)	583	(551, 612)	4	(3, 4)
Hemorrhagic stroke	717	(688, 740)	617	(593, 638)	76	(73, 79)
Hypertensive heart disease	46	(43, 48)	15	(15, 16)	30	(28, 31)
Atrial fibrillation and flutter	407	(373, 442)	382	(350, 414)	0	(0, 0)
Other conditions						
Chronic kidney disease due to diabetes mellitus	29	(25, 33)	25	(21, 29)	2	(1, 2)
Chronic kidney disease due to hypertension	42	(37, 48)	39	(34, 45)	0	(0, 0)
Chronic kidney disease due to glomerulonephritis	62	(52, 72)	56	(47, 65)	1	(1, 1)
Chronic kidney disease due to other causes	573	(492, 654)	529	(454, 605)	1	(1, 1)
Asthma	3,711	(3,430, 3,998)	3,366	(3,096, 3,640)	2	(1, 2)
Gallbladder and biliary diseases	16,815	(15,863, 17,745)	16,348	(15,417, 17,251)	2	(2, 2)
Alzheimer's disease and other dementias	25	(21, 31)	80	(64, 96)	0	(0, 0)
Cataract	48	(42, 54)	46	(41, 52)	-	-
low back pain	7,840	(7,447, 8,208)	7,414	(7,033, 7,775)	-	-
Gout	7,818	(7,008, 8,620)	7,496	(6,714, 8,266)	-	-
Osteoarthritis of hip	154	(141, 167)	144	(132, 156)	-	-
Osteoarthritis of knee	3,937	(3,610, 4,257)	3,717	(3,409, 4,021)	-	-

[1] 95%UI: 95% uncertainty interval, [2] Only for females.

Tax on sugary foods

	Incident cases (2016-2041)		Prevalent cases (2041)		Deaths (2016-2041)	
	Mean	95%UI[1]	Mean	95%UI	Mean	95%UI
Diabetes mellitus type 2						
Diabetes mellitus type 2	233,427	(228,557, 237,777)	220,604	(215,970, 224,705)	232	(227, 236)
Cancer						
Esophageal cancer	207	(164, 248)	79	(63, 96)	124	(99, 149)
Colon and rectum cancer	1,516	(1,454, 1,579)	1,161	(1,114, 1,210)	285	(274, 297)
Liver cancers	198	(174, 223)	47	(41, 54)	150	(130,170)
Gallbladder and biliary tract cancer	54	(50, 59)	37	(33, 40)	16	(15, 17)
Pancreatic cancer	91	(77, 105)	27	(23, 31)	63	(53, 73)
Breast cancer (premenopausal)[2]	16,627	(14,122, 19,229)	9,750	(7,799, 11,779)	1,691	(1,415, 1,978)
Uterine cancer[2]	2,064	(2,019, 2,111)	1,815	(1,776, 1,857)	147	(144, 151)
Ovarian cancer[2]	137	(110, 167)	112	(89, 136)	18	(15, 22)
Kidney cancer	1,367	(1,300, 1,434)	1,244	(1,183, 1,305)	46	(44, 48)
Thyroid cancer	3,657	(3,383, 3,931)	3,483	(3,221, 3,744)	8	(8, 9)
Non-Hodgkin's lymphoma	529	(445, 613)	445	(374, 517)	65	(54, 75)
Multiple myeloma, leukemia	84	(70, 97)	71	(59, 82)	9	(7, 10)
Cardiovascular disease						
Ischaemic heart disease	82,547	(75,303, 88,913)	74,632	(68,014, 80,418)	4,108	(3,692, 4,454)

Ischaemic stroke	10,007	(9,529, 10,451)	9,492	(9,032, 9,918)	54	(51, 56)
Hemorrhagic stroke	11,324	(10,943, 11,662)	9,816	(9,487, 10,107)	1,072	(1,030, 1,107)
Hypertensive heart disease	681	(648, 710)	260	(246, 268)	417	(396, 436)
Atrial fibrillation and flutter	6,998	(6,422, 7,569)	6,526	(5,990, 7,059)	0	(0, 0)
Other conditions						
Chronic kidney disease due to diabetes mellitus	551	(475, 621)	478	(412, 539)	27	(23, 31)
Chronic kidney disease due to hypertension	791	(686, 890)	726	(630, 817)	2	(2, 3)
Chronic kidney disease due to glomerulonephritis	1,077	(919, 1,235)	981	(835, 1,127)	11	(9, 13)
Chronic kidney disease due to other causes	10,912	(9,379, 12,374)	10,047	(8,630, 11,403)	20	(17, 23)
Asthma	62,367	(57,945, 67,047)	58,423	(54,130, 62,973)	21	(20, 23)
Gallbladder and biliary diseases	284,639	(269,394, 299,543)	275,562	(261,379, 290,038)	31	(29, 33)
Alzheimer's disease and other dementias	537	(435, 634)	1,314	(1,062, 1,552)	4	(4, 5)
Cataract	796	(699, 895)	780	(684, 878)	-	-
low back pain	126,944	(121,137, 132,667)	121,339	(115,706, 126,888)	-	-
Gout	114,399	(103,374, 125,905)	109,049	(98,517, 120,059)	-	-
Osteoarthritis of hip	2,762	(2,550, 2,980)	2,583	(2,384, 2,788)	-	-
Osteoarthritis of knee	71,438	(65,887, 76,739)	67,048	(61,816, 72,040)	-	-

[1] 95%UI: 95% uncertainty interval, [2] Only for females

Subsidy for vegetables and fruit

	Incident cases (2016-2041)		Prevalent cases (2041)		Deaths (2016-2041)	
	Mean	95%UI[1]	Mean	95%UI	Mean	95%UI
Diabetes mellitus type 2	551	(505, 575)	528	(484,550)	1	(1,1)
Cancer						
Oesophageal cancer	3	(2, 3)	1	(1, 1)	2	(2, 2)
Lip and oral cavity cancer	5	(4, 5)	3	(3, 4)	1	(1, 1)
Nasopharynx cancer	4	(4, 5)	4	(4, 4)	0	(0,0)
Other pharynx cancer	1	(1, 1)	1	(1, 1)	0	(0, 0)
Larynx cancer	1	(1, 1)	1	(1, 1)	0	(0, 0)
Tracheal, bronclus, and lung cancer	6	(5, 6)	2	(2, 2)	3	(3, 4)
Cardiovascular disease						
Ischemic heart disease	513	(486, 544)	463	(438, 490)	32	(31, 34)
Ischemic stroke	131	(123, 141)	125	(118, 134)	1	(1, 1)
Intracerebral hemorrhage	37	(33, 39)	34	(31, 36)	2	(2, 2)
Subarachnoid hemorrhage	60	(56, 65)	53	(49, 57)	5	(5, 5)

[1] 95%UI: 95% uncertainty interval

Table E7 Sensitivity analyses for CAD$0.75/100g free sugar content taxes in Canada in the lifetime period

	Lifetime DALYs averted		Lifetime QALYs gained		Health care cost offsets (CAD$ million)		Tax revenue and intervention costs (CAD$ million)	
Tax on sugary beverages - base case	752,353		534,779		12,942		48,781	
1) CAD$0.5/100g free sugar content tax	477,444	-36.5%	355,959	-33.4%	8,629	-33.3%	33,297	-31.7%
2) CAD$1/100g free sugar content tax	1,026,203	36.4%	713,175	33.4%	17,274	33.5%	63,377	29.9%
3) BMI remain at 2015 levels	748,935	-0.5%	533,445	-0.2%	12,913	-0.2%	48,748	-0.1%
4) Tax pass-on 80%	589,230	-21.7%	428,596	-19.9%	10,357	-20.0%	39,580	-18.9%
5) Tax pass-on 120%	916,623	21.8%	641,986	20.0%	15,540	20.1%	57,637	18.2%
6) Health gains and costs discounted by 3%	368,749	-51.0%	274,143	-48.7%	7,970	-38.4%	27,944	-42.7%
7) Price elasticities from the US	589,796	-21.6%	425,419	-20.4%	10,840	-16.2%	49,109	0.7%
Tax on sugary foods – base case	11,414,760		7,679,163		136,985		82,047	
1) CAD$0.5/100g free sugar content tax	7,657,003	-32.9%	5,185,493	-32.5%	92,533	-32.5%	58,807	-28.3%
2) CAD$1/100g free sugar content tax	15,085,057	32.2%	10,102,018	31.6%	180,296	31.6%	101,210	23.4%
3) BMI remain at 2015 levels	11,369,512	-0.4%	7,666,089	-0.2%	136,557	-0.3%	82,059	0.0%
4) Tax pass-on 80%	9,176,162	-19.6%	6,193,315	-19.3%	110,519	-19.3%	68,584	-16.4%
5) Tax pass-on 120%	13,638,843	19.5%	9,144,330	19.1%	163,104	19.1%	94,067	14.7%
6) Health gains and costs discounted by 3%	5,506,006	-51.8%	4,005,637	-47.8%	82,728	-39.6%	47,528	-42.1%
7) Price elasticities from the US	15,793,300	38.4%	10,590,504	37.9%	186,207	35.9%	77,033	-6.1%