UNIVERSITY OF TECHNOLOGY SYDNEY

Can Health Taxes Save Us from Ourselves? Assessing a Sugar-Sweetened Beverage (SSB) Tax as an Anti-Obesity Policy in Thailand

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Kittiphong Thiboonboon, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Health at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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LIST OF ABBREVIATIONS

BMI: body mass index

CBA: cost-benefit analysis

CEA: cost-effectiveness analysis

CHD: coronary heart disease

CI: concentration index

CMA: cost-minimisation analysis

CUA: cost-utility analysis

DALY: disability-adjusted life year

DCEA: distributional cost-effectiveness analysis

ECEA: extended cost-effectiveness analysis

GDP: gross domestic product

GNI: gross national income

HALY: health-adjusted life year

HBS: Health Behaviour of Population Survey

ICER: incremental cost-effectiveness ratio

LMIC: low- and middle-income countries

LY: life-years

NCD: non-communicable disease

NHB: net health benefit

OECD: Organisation for Economic Co-operation and Development

OOP: out-of-pocket

PM: probit model

PSA: probabilistic sensitivity analysis

QALY: quality-adjusted life year

RCT: randomised controlled trial

MSRP: manufacturer's suggested retail price

SSB: sugar-sweetened beverage

THB: Thai Baht

TWO-PM: two-part model

USA: United States of America

USD: United States dollar

WHO: World Health Organization

WTP: willingness-to-pay

ABSTRACT

Obesity has been on the rise in Thailand for the past three decades. According to the most recent national health survey, over half of the Thai population is in a weight range defined as overweight or obese. Given the adverse consequences of obesity on health and concerns regarding its impact on health equity, policymakers have been prompted to introduce measures to counteract the rise in obesity. One significant area of concern is the country's remarkably high consumption of sugar-sweetened beverages (SSBs), which may contribute further to obesity. Consequently, Thailand is planning to increase taxation on SSBs as a policy tool to reduce obesity. The proposed tier-based tax rates applied to SSBs differ according to levels of sugar content. This thesis aims to evaluate the potential cost-effectiveness and equity impacts of an SSB tax as an anti-obesity policy in Thailand. This aim is addressed via four studies.

In the first study (Chapter 3), a systematic review was conducted to identify methodological issues in economic evaluations of SSB taxes. The review highlighted various methodological issues in current economic evaluations of SSB taxes. Specifically, these methodological concerns were associated with estimating the effect of SSBs on body weight and the impact of SSB taxes on weight outcomes. Previous evaluations have been overly focused on the effects of SSBs on body weight, neglecting the possibility that consumers compensate for changes in SSB consumption by altering their consumption of other sugary foods. Collectively, previous evaluations have overestimated the benefits of SSB taxes.

In the second study (Chapter 4), a concentration index approach and decomposition analysis were used to examine the patterns of socioeconomic inequality in obesity in Thailand and investigate the role of SSBs in influencing this inequality. The study analysed data from Thailand's 2021 Health Behaviour of Population Survey (2021 HBS), which included approximately 50,000 individuals. The results indicated that socioeconomic inequality in obesity varied by gender, with obesity more common among men of higher socioeconomic status and women of lower socioeconomic status. Individual's education, health conditions and various unhealthy behaviours played significant roles in these inequalities. While SSBs contributed to this inequality, their impact was relatively minor. Moreover, the decomposition analysis suggested that SSB consumption was concentrated in people of higher socioeconomic status, indicating that policies targeting SSB reduction might have limited impact in addressing socioeconomic-based health inequity. However, in order to gain a comprehensive understanding of the socioeconomic and other characteristics of frequent SSB consumers, a further in-depth analysis is needed, as addressed in the subsequent study.

In the third study (Chapter 5), a two-part model, logistic regression analysis, and decomposition analysis were used to investigate the characteristics of frequent SSB consumers in Thailand based on the data from the 2021 HBS survey. The findings from this study reinforced those of the second study that higher

socioeconomic status individuals consume more SSBs. Frequent SSB consumers often exhibited other unhealthy behaviours like smoking, consuming unhealthy foods, and having low leisure-time physical activity. Additionally, frequent SSB consumers often used appetitive motivations of ‘liking’ and ‘wanting’ when making food choices. People of higher socioeconomic status tended to pair SSB consumption with that of other foods regardless of whether the foods were healthy or unhealthy. Conversely, in people from lower socioeconomic backgrounds, SSB consumption was associated with behaviours like smoking, drinking, and having low leisure-time physical activity; or habits like using appetitive motivations for foods.

In the fourth study (Chapter 6), a cost-utility analysis was conducted to estimate the benefit and cost-effectiveness of the proposed SSB tax in Thailand. The study included an assessment of the impact of the tax on long-term health outcomes, economic implications, and health equity in Thailand. Using microsimulation to simulate future health and economic outcomes for the HBS 2021 population, the study suggested potential benefits to population-level health from the proposed tier-based tax. The tax was estimated to be cost-saving and offered more health benefits to lower socioeconomic groups compared to higher socioeconomic groups; overall, the proposed tax was found to be dominant (producing more health outcomes while reducing costs). However, this study also highlighted existing concerns about the regressivity of the tax in that it might impose a larger financial burden on people of lower socioeconomic status. Furthermore, the study suggested several substantial uncertainties regarding the predicted consequences of a tax on SSBs, largely due to potential adverse industry reactions, such as reducing the proportion of a tax that is reflected in the beverage price increase (i.e., tax pass-through rate).

In conclusion, this thesis shows that the proposed tax on SSBs in Thailand may offer substantial health benefits, be cost-saving and improve health equity; policymakers may wish to consider implementing the proposed tier-based tax for SSBs. The implementation of this tax should include a robust monitoring system to ensure industry compliance with the proposed tax and to observe the industry’s use of tactics to mitigate tax impacts on SSB consumption. This would allow the government to respond appropriately to any potential industry actions associated with adverse consequences. Supportive measures, such as subsidies for healthier food options, might be worth exploring to help offset the financial impact on vulnerable populations and individuals of lower socioeconomic status. Moreover, there is an urgent need for gender-specific policies addressing obesity, especially those targeting the health of women from lower socioeconomic groups. Exploration of comprehensive strategies addressing a broad range of health issues in conjunction with SSB consumption is recommended.

Chapter 1: Introduction

1.1 Research Overview

Thailand has overcome many obstacles, such as the 1997 Asian financial crisis and political instability since 2006, to achieve impressive economic growth in the last few decades[3]. Globalisation and trade liberalisation have transformed Thailand's socioeconomic landscape. In 2011, the World Bank reclassified Thailand from a lower middle-income country to an upper middle-income country, acknowledging its economic achievement[4]. However, the transformation has not been solely positive, as it has also brought challenges that the country needs to address. One challenge is the profound shift in the lifestyle of the Thai population, especially their dietary patterns, physical activity and work habits[5]. As an important sign of these changes, the 2019 national health survey indicated that over half of the Thai population is in a weight range defined as overweight or obese[6]. These conditions were estimated to cost Thailand 1.3% of its GDP in that year, with projections surging to 4.9% in 2060[7]. These statistics are critical, especially considering that discussions on obesity prevention at the national level in Thailand began as far back as two decades ago[8].

The transition towards consumption of energy-dense foods is a trend associated with economic development[9]. This shift affects the energy balance of the population by increasing energy intake beyond the optimal level, which is considered a significant factor in the obesity epidemic[10]. In parallel, economic development is also associated with a more sedentary lifestyle, as people have moved from manual jobs to more office-based service roles, leading to lower calorie needs[9]. Among energy-dense foods, sugar is one of the main reasons for overnutrition[11]. In Thailand, sugar consumption is significantly high, exceeding both the World Health Organization (WHO) recommendation[12] and the average levels of other Asian countries[13]. These elevated levels of sugar consumption in Thailand are suspected to be driven by the increasing consumption of sugar-sweetened beverages (SSBs)[14]. For example, research has suggested that as many as 70% of Thais consume SSBs on a daily basis.

SSBs have been consistently criticised for their significant role in the global obesity epidemic[11,15,16]. In particular, SSBs are considered the largest source of free sugars in the diet, and these beverages are easily accessible and heavily advertised, leading to frequent overconsumption, often replacing more nutritious food in individuals' diets[17]. Globally, in light of the success of health taxes on tobacco and alcohol, there is a growing interest in applying similar taxes to other unhealth food options, such as SSBs[18]. According to WHO recommendations[16,17,19,20], SSB taxes have been continuously advocated as a critical measure to address the rise in obesity. Consequently, SSB taxes have been implemented in various countries.

Similarly, Thailand is planning to implement taxation on SSBs as a policy tool to reduce obesity[8]. The proposed tax on SSBs in Thailand is unique in many ways compared to similar taxes implemented in other countries. Specifically, it combines both ad valorem and specific tax approaches[i]. Additionally, its structure is intended to incentivise the beverage industry to reformulate products and reduce sugar content. This implies that the tax aims not to limit choice but to force the industry to offer more healthy alternatives. However, the potential impacts of this taxation on obesity and broader public health consequences remain largely unexplored.

Examining Existing Economic Evaluations of SSB Taxes

A public health intervention such as a tax on SSBs needs to be evaluated for its effectiveness and cost-effectiveness[21]. However, evaluating SSB taxes can be challenging for many reasons. Specifically, there has been a concern raised about economic evaluations of public health interventions that often face more methodological challenges than medical technologies[22,23]. Public health interventions are complex in nature. For instance, public health interventions often have spillover effects to non-health consequences like improving education or reducing crime that generally are more difficult to capture in a conventional economic evaluation framework[21]. Until recently, little has been known about potential methodological issues in economic evaluations of SSB taxes. Since several economic evaluations have been conducted to assess the cost-effectiveness of SSB taxes in different countries[2,24-27], understanding the experience of these studies can provide useful insights for conducting similar analyses for Thailand.

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[i] SSB taxes can be broadly categorised into two groups: ad valorem and specific taxes. An ad valorem tax is levied as a percentage of a beverage's value, and a specific tax is levied as a monetary value per quantity (refer to Section 2.4 for further details).

Therefore, the first study of the thesis aims to conduct a literature review to examine the characteristics of existing economic evaluations of SSB taxes as well as identify their methodological issues.

Measuring Socioeconomic Inequality in Obesity

In addition to evaluating the efficiency of public health interventions in terms of their cost-effectiveness, their impacts on equity also need to be assessed[28]. This typically requires knowledge about health inequality in the population[29,ii]. Obesity is one area where socioeconomic factors play a key role in creating unequal health outcomes[30]. Several studies have used a specific approach to measure and compare socioeconomic inequality in obesity across different contexts[31-34]. These studies also revealed that there could be other factors that interact with socioeconomic status and worsen obesity inequality. Understanding the magnitude and direction of these factors can help design better interventions to reduce obesity inequality. In Thailand, some studies have explored the link between socioeconomic status and obesity, but none have focused on measuring socioeconomic inequality in obesity[35-41]. The second study of this thesis aims to address this knowledge gap.

Understanding the characteristics of SSB consumers

A situational analysis to gain a thorough understanding of the target population's characteristics is a crucial step for evidence-based health policy planning[17,iii]. However, in Thailand, this essential step remains inadequately addressed. More insight regarding the characteristics of SSB consumers can help identify the opportunities and challenges or risks that may arise during the implementation of the proposed SSB tax policy[17]. For instance, understanding the socioeconomic profile of SSB consumers can help evaluate the potential distribution of the tax burden among different social classes of consumers[42]. In addition to the socioeconomic domain, other factors that influence SSB consumption have been reported in previous studies in other countries[42-48]. For example, due to the palatability of SSB, research also indicates that certain individuals might struggle to reduce their SSB intake, citing a

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[ii] Health inequity is defined as the unjust differences in health between individuals and is typically difficult to measure precisely. Health inequality refers to observable differences in health between individuals, which can be measured. It often serves as an indirect means of evaluating the presence of health inequity (refer to Section 2.5 for further details).

[iii] A situational analysis refers to a systematic collection and analysis of health, social, demographic, economic and political information in order to gain a comprehensive understanding of the context in which a policy would be implemented.

brain reaction to SSBs or sugar that is similar to addiction[49,50]. This characteristic is of concern as it could hinder the effectiveness of the tax. Another risk highlighted in a study from the USA suggests that a tax burden from SSBs could compound financial stress for individuals already facing health taxes on tobacco and alcohol, given that they are often the same consumers[51]. This risk should be examined in Thailand. Therefore, the third study of the thesis aims to gain in-depth knowledge of the characteristics of frequent SSB consumers in Thailand.

Decision analytic modelling of an SSB tax's impacts in Thailand

Ideally, policymakers would prefer a health intervention like a tax on SSB to reduce SSB consumption effectively, thereby delivering better health to the population. Nevertheless, various challenges arise in reality[52]. For example, the beverage industry might choose to absorb most of the tax and keep the prices low[52]. Furthermore, the success of the tax is dependent on consumers' price elasticity of demand[53,iv] for SSBs. This is a concern when SSB consumers are less responsive than anticipated to the price increase from the tax[54]. Such factors can substantially reduce the impact on consumption of an SSB tax. As a result, there is a need for a comprehensive systematic approach to provide a comparative assessment of the potential effects of different approaches to implementing SSB taxes[55]. Decision analytic modelling assists by offering a systematic approach to formulating such a comparison in a manner that allows uncertainty to be addressed, which helps identify the possible long-term consequences that would occur from a set of options being assessed[56]. Yet, this has never been done in Thailand. Therefore, the final study of the thesis aims to conduct a decision model to estimate the health benefits, cost-effectiveness, tax burden, economic impact, and equity implications of the proposed tax on SSBs in Thailand.

1.2 Objectives of the Research

The primary research question addressed in the thesis is:

[iv] Price elasticity of demand is a term in economics that refers to price responsiveness. It is calculated as the percentage change in quantity (of goods) divided by the percentage change in price (of goods).

Krugman P, Wells R. Microeconomics. Macmillan; 2008.

What are the cost-effectiveness and equity impacts of the taxation of SSBs as an anti-obesity policy in Thailand?

Specifically, this thesis aims to:

- Identify methodological issues in economic evaluations of SSB taxes. A systematic review of the literature was conducted. Criteria for assessing study methods were developed to align with previously identified methodological issues in economic evaluations of public health interventions and key issues in the evidence for SSB taxes.
- Examine the patterns of socioeconomic inequality in obesity in Thailand and determine the role of SSBs in influencing this inequality. A concentration index approach was applied to assess inequality in obesity according to socioeconomic status. Decomposition analysis was applied to study how various demographic, behavioural and health factors, interacting with socioeconomic status, affect inequality. The study analyses data from Thailand's 2021 Health Behaviour of Population Survey (2021 HBS), which included approximately 50,000 individuals. This nationally representative survey was conducted by the National Statistical Office of Thailand[57] from February to May 2021. The survey included various information on demographics, socioeconomics, health behaviours and habits, and the health of the Thai population.
- Investigate the characteristics of frequent SSB consumers in Thailand. A two-part model and logistic regression analysis were used to examine how SSB consumption was influenced by underlying demographic, socioeconomic, behavioural, habitual and health factors. Decomposition analysis was used to examine how the impact of these factors affecting SSB consumption varied across socioeconomic groups. The analysis examines data from the 2021 HBS.
- Estimate the potential long-term effects of the proposed SSB tax on health outcomes, its economic implications, and its impact on health equity in Thailand. A cost-utility analysis was conducted to evaluate the proposed SSB tax in Thailand. This took the form of a

microsimulation model to examine the effects of the proposed SSB tax structure (relative to status quo) for a cohort of the 2021 HBS population.

1.3 Thesis Structure

This is a thesis by compilation of four studies. The thesis has seven chapters.

Chapter 1 provides the statement of the problem, the objective of the four studies, and a summary of the methods used in each study.

Chapter 2 presents the detailed background for the thesis. This includes background information about obesity and its prevalence in Thailand, a review of evidence linking SSB consumption to obesity, the rationale for an SSB tax, the design of an SSB tax, frameworks in economics studying health behaviours and health equity, and economic evaluations of public health interventions.

Chapter 3 presents the first study in this thesis – A Systematic Review of Economic Evaluations of SSB Taxes. It is presented as a manuscript titled "Economic evaluations of obesity-targeted sugar-sweetened beverage (SSB) taxes – A review to identify methodological issues". The review highlights various concerns regarding existing economic evaluations of SSB taxes. The manuscript was published in *Health Policy* on 22nd April 2024.

Chapter 4 presents the second study of this thesis – Socioeconomic Inequality in Obesity in Thailand. It is presented as a manuscript titled "Exploring socioeconomic inequality in obesity in Thailand: A decomposition analysis". The study suggests the existence of socioeconomic inequality in Thailand, as well as various factors that, along with socioeconomic status, contribute to this inequality. The manuscript is currently under review at *International Journal of Obesity*.

Chapter 5 presents the third study of this thesis – Characteristics of Frequent SSB Consumers in Thailand. It is presented as a manuscript titled "Sugar-sweetened beverage consumption in Thailand: Determinants and variation across socioeconomic status". The study suggests that various factors, specifically unhealthy behaviours, are associated with frequent SSB consumption. The manuscript is currently under review at *Public Health*.

Chapter 6 presents the fourth study in this thesis – Cost-Effectiveness of a Tax on SSBs to Reduce Obesity in Thailand. It is presented as a manuscript titled "Assessing Cost-Effectiveness and Equity of Content vs Value-Based Tax for Sugar-Sweetened Beverages in Thailand". The study reveals the potential cost-effectiveness of the proposed SSB tax but also highlights various uncertainties that might hinder the tax's effectiveness. The manuscript is currently under review at *Health Economics*.

Chapter 7 concludes the thesis by summarising key findings from each of the four studies and deriving policy implications and recommendations. It includes a discussion of the limitations and uncertainties of this research and makes recommendations for future research.

Chapter 2: Background

2.1 Obesity

The World Health Organization (WHO) defines obesity as a medical condition characterised by excessive adiposity to the extent that it can impair health[58]. A body mass index (BMI), calculated as weight in kilograms (kg) divided by height in metres squared (m^2), is a surrogate marker of adiposity often used in clinical practice and research due to its ease of collection[59]. The WHO has established BMI-based criteria to classify weight and contends that these classifications are appropriate for all ethnic groups, including Asian populations[60]. According to the WHO BMI classifications, overweight is a BMI of greater than or equal to 25 kg/m^2 and obesity is a BMI greater than or equal to 30 kg/m^2. In some contexts, the term 'excess weight' is a neutral alternative to 'obesity' describing the extra weight an individual carries beyond established benchmarks for good health[61].

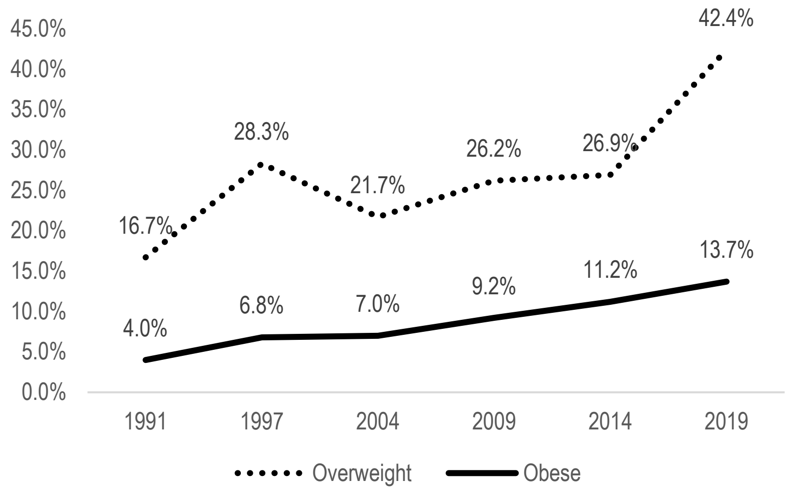
Obesity results from an imbalance between energy consumed and energy expended[62]. Globally, there has been a shift in food consumption patterns whereby individuals are consuming more energy-dense foods such as those high in sugars and fats; at the same time, individuals are engaging in significantly less physical activity[9,10,63]. Obesity, often referred to as a global epidemic, is a significant public health threat, affecting millions of people worldwide. Obesity rates have more than tripled since the 1970s, and rates continue to rise. In 2016, according to the WHO, more than 1.9 billion adults had excess weight, with 650 million of them living with obesity[58]. Additionally, it was estimated that over 70% of individuals with excess weight lived in low- and middle-income countries (LMICs), dispelling the perception that the problem exists in high-income countries alone[64].

Obesity leads to numerous life-threatening health consequences. It increases the risk of chronic diseases such as type 2 diabetes, cardiovascular disease, stroke and certain types of cancer[65]. Obesity is associated with a 1.3 times higher risk of premature death compared to normal weight[66] , for example, individuals with obesity have a four times higher risk of developing severe COVID-19[67]. It was estimated that 8% of all deaths worldwide in 2017 were attributed to obesity, a total of 4.7 million deaths globally[68]. In addition to the health burden, obesity also has substantial economic consequences, with obesity-related healthcare costs estimated to be as high as 2.19% of global gross domestic product (GDP) in 2019[69].

2.2 Obesity in Thailand

The growth of obesity is highly correlated with a country's income[70]. As such, literature usually considers countries' income in studying national obesity levels[29]. This appears to be the case in Thailand. As the economic transition continues, Thailand was re-classified from a lower middle-income country to an upper middle-income country in 2011, and like many other countries, has been experiencing a significant increase in its obesity rate[4] (Figure 2.1). Historically, the earliest Thai study on the epidemiology of obesity at the national level was carried out as part of the first National Health Examination Survey in 1991[71], 20 years before Thailand was re-classified as an upper-middle income country. Based on the WHO BMI classification, the study reported that the prevalence of excess weight in the population aged 15 years and older was 20.7%, with 16.7% of individuals living with overweight and 4.0% living with obesity, a proportion comparable to other lower-middle income countries[68]. In the most recent survey collected in 2019[6], the prevalence of excess weight in the Thai population had nearly tripled since 1991, reaching 56.1%, with 42.4% of individuals living with overweight and 13.7% living with obesity. This prevalence is similar to rates found in other countries of similar income level[68]. In the Southeast Asian region, Thailand has the highest prevalence of people with overweight, second only to Malaysia in 2019[68].

Figure 2.1: Prevalence of overweight and obesity in the population aged 15 years and older in Thailand from 1991 to 2019



Source: Compiled using data from the National Health Examination Survey (1991, 1997, 2004, 2009, 2014, 2019)[6,36]

Alongside the growing rate of obesity, the country has also seen changes in dietary habits[5]. While traditional Thai diets once focused on rice and fish and rarely included other meats, modern Thai diets have become more varied and calorie-rich[1,5,72-75]. The Thai population also consumes more compared with the past. According to the Food Balance Sheet, per capita daily caloric intake in Thailand increased by 25% over the past 30 years, reaching 2,788.07 kcal in 2020[76] (Table 2.1). Specifically, fat consumption per capita has increased by 44% since 1990, outpacing the overall 25% increase in caloric intake[76].

Table 2.1: Change in food consumption in Thailand between 1990 and 2020 (kcal per capita per day)

	1990 kcal/capita/day	Proportion of total intake	2020 kcal/capita/day	Proportion of total intake	% change
Fat	420.00	19%	606.35	22%	44%
Carbohydrate	1611.71	72%	1930.74	69%	20%
Sugar-contributed	210.14	13% [a]	426.29	22% [a]	69%
Protein – plant	123.97	6%	147.89	5%	19%
Protein – animal	77.78	3%	103.09	4%	33%
Total	2233.46	100%	2788.07	100%	25%

Source: Food Balance Sheet (FAO: Food and Agriculture Organization)[76]
[a] as a proportion of carbohydrate.
Note: The general recommendation for energy intake for moderately active adults is 2,200 kcal for women and 2,900 kcal for men[77].

The rising prevalence of obesity has significant health implications for Thailand, as the rate of obesity-related morbidity and mortality among its population. For instance, the prevalence of type 2 diabetes in the adult population increased from less than 3.0% in 1991[78] to 9.5% in 2019[79]. Over the same period, hypertension has increased from less than 6%[78] to 25.4% of the population[79]. Obesity was estimated to be related to 20% of osteoarthritis cases and 30% of ischemic heart disease cases, respectively[80]. The increase in obesity rates has led to a significant rise in mortality in Thailand. According to the 2020 Global Burden of Disease Study, excess weight was responsible for 43.8 deaths per 100,000 individuals in 2017 in the country, marking a 66.70% increase from 1990[81]. Using disability-adjusted life years (DALYs)[i] as a measure that represents morbidity and mortality, excess weight contributed to 1,634.6

[i] Disability-adjusted life years (DALYs) is a measure used to assess the overall disease burden. It combines both years of life lost due to premature mortality and years lived with disability, thus representing the total years of "healthy" life lost.
Murray CJ. Quantifying the burden of disease: the technical basis for disability-adjusted life years. Bulletin of the World health Organization. 1994;72(3):429.

DALYs lost per 100,000 individuals in 2017[81]. This represents an 85.2% increase from 1990, which far exceeds the 56.7% increase seen in countries with similar income levels[81].

The increased prevalence of obesity also has economic implications in Thailand. Health expenditure for obesity and its associated diseases has become a significant concern in the country[82]. In a country with a publicly funded healthcare system like Thailand, some of these costs could be considered external costs, as they are not entirely covered by individuals with obesity related disease but are partially paid for by the general taxpayer population[62]. From an economics viewpoint, this situation where sick individuals do not bear the full cost of treatment but the cost extends to third parties not directly involved, creates a form of market failure known as negative externalities[62]. In Thailand, specific research examining these external costs of obesity is lacking. However, multiple international studies suggest that such externalities could be substantial[83-88], with one study suggesting that it could represent up to 85% of obesity-related healthcare costs[83]. Cost-of-illness studies have begun to shed light on the public health spending allocated to obesity in Thailand, highlighting the substantial economic burden it imposes[7,80]. One study estimated that the annual direct medical costs of obesity-related diseases in Thailand were USD 162 million (THB 5,584 million) in 2009, accounting for 1.5% of national health expenditure. Additionally, the study suggested that indirect costs, such as productivity loss due to hospital-related absenteeism (absence from work due to illnesses), presenteeism (the act of attending work while not at full productive capacity) and premature death, are also significant. In the same study, the total indirect costs of obesity in Thailand were estimated at USD 191 million (THB 6,558 million) in 2009. The combined direct and indirect costs of obesity in Thailand are approximately 0.13% of the national gross domestic product (GDP). A subsequent study in 2019 reassessed the economic impact of obesity in Thailand and found the direct medical costs of obesity-related diseases to be USD 1,340 million, while the indirect costs increased to USD 5,220 million[7]. In total, these costs represented 2.25% of national GDP in 2019, a significant increase from the 0.13% estimated in 2009. Furthermore, the study projected the costs associated with obesity would rise to 4.88% of national GDP by 2060.

2.3 Sugar-Sweetened Beverages and Obesity

There is no one standard definition of sugar-sweetened beverages (SSBs)[17,89,90]. The WHO provides a comprehensive definition, describing SSBs as "all types of beverages containing free sugars, such as carbonated or non-carbonated soft drinks, fruit and vegetable juices, concentrates, flavoured water, energy and sports drinks, ready-to-drink teas and coffees, and flavoured milk drinks"[17]. According to the WHO, 'free sugars' are "monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook, or consumer, as well as sugars naturally present in honey, syrups, fruit juices, and fruit juice concentrates"[17]. In Thailand, while a universally accepted definition for SSBs has not been established, SSBs are generally described in research as non-alcoholic beverages that contain sugar[8,91-94].

The role of sugar in SSBs has gained significant attention as a key contributor to the growing obesity epidemic[11]. The focus on sugar and its impact on obesity was initially hypothesised in a landmark 2004 study by Bray, Nielsen and Popkin that observed a correlation between soaring obesity rates and higher SSB consumption in the United States[15]. According to their hypothesis, high-fructose corn syrup (HFCS), a prevalent sugar in SSBs, undergoes different digestive, absorptive and metabolic processes compared to glucose. This difference could lead to increased energy intake and weight gain. They further proposed that fructose contained in SSBs could contribute to excessive caloric consumption, thereby exacerbating obesity. Subsequent research, however, has shifted its focus from these specific mechanisms to the overarching issue of SSB consumption. For example, the rationale provided by the WHO for endorsing anti-SSB consumption policies is that SSBs are the largest source of free sugars in the diet, and these beverages are easily accessible and heavily advertised, leading to frequent overconsumption, often replacing more nutritious food options in people's diets[17]. For instance, considering that a single can of carbonated soft drink contains roughly 40 grams of free sugars, when combined with sugars from other dietary sources, it can easily lead one to exceed the WHO's recommended daily limit of 50 grams of sugar[12].

There are four systematic reviews of randomised controlled trials (RCTs) that examined the relationship between sugary drink consumption and obesity risk[95-98] (Table 2.2). These reviews included a total of eight RCTs[17,99-106], with the first RCT published in 1988[99] and the latest in 2012[106]. Two RCTs appeared in all the systematic reviews: one by Tordoff and Alleva in 1990[99], and another by Reid et al. in 2007[102]. Across the eight studies, the timeframe used to investigate links between sugar consumption and obesity risk typically ranged from three to four weeks[99,100,102-104], although one lasted as long as 52 weeks[101]. The daily sugar dose given to participants in these studies varied widely, from 50 grams[99] to 133 grams[100], with the most common range being 91 to 110 grams[102,103,105,106]. The individual RCTs reported a wide range of mean differences in weight gain outcomes, from as little as 0.09 kg[99] to as much as 1.37 kg[102].

The pool of these outcomes (i.e., meta-analysis) across the RCTs indicates a statistically significant association between SSB consumption and weight gain in all systematic reviews[95-98]. The pooled estimate ranged from 0.34 kg[97] to 0.85 kg[98] for the mean difference in weight gain. Among the four meta-analyses, three explicitly stated that SSBs contribute to weight gain[95,96,98], while the fourth deemed the evidence inconclusive[97]. Some criticisms of these RCTs focus on the unusually high doses of SSBs (sugar) administered[107] and the lower-than-expected weight gain given the caloric intake from these SSBs[97]. This lower-than-expected weight gain is often attributed to the possibility that SSBs might be offsetting the consumption of other foods[102,108,109].

Table 2.2: A summary of results from the included systematic reviews

RCTs \ Systematic reviews		Mattes et al., 2011[95]	Te Morenga et al., 2013[a 110]	Kaiser et al., 2013[97]	Malik et al., 2013[98]
Trial	**Participant, dose of intervention vs control, and duration**	**Mean difference in weight gain in kg (95% CI)**			
Addington, 1988[99]	70 adult women, 50 g/d vs 0 g/d, 3 w	0.09 (-0.62, 0.80)	NA	0.09 (-0.61, 0.44)	NA
Tordoff and Alleva, 1990[100]	30 normal weight adults, 133 g/d vs 0 g/d, 3 w	Women: 0.72 (-0.02. 1.46) Men: 0.99 (0.36, 1.62)	0.91 (0.47, 1.35)	1.05 (0.61, 1.59)	Women: 0.72 (0.14, 1.30) Men: 0.99 (0.41, 1.57)
Haub et al., 2005[101]	41 adult women, 0.6 L/d vs free living, 52 w	0.50 (-1.52, 2.52)	NA	0.16 (-0.49, 0.81)	NA
Reid et al., 2007[102]	133 normal weight adult women, 105 g/d vs 0 g/d, 4 w	0.53 (0.08, 0.98)	0.30 (-1.07, 1.67)	0.41 (0.06, 075)	1.37 (0.38, 2.36)
Reid et al., 2010[103]	53 overweight adult women, 105 g/d vs 0 g/d, 4 w	NA	0.36 (-0.07, 0.79)	NA	0.43 (-0.84, 1.75)
Aeberli et al., 2011[104]	29 normal weight adults, 80 g/d vs 40 g/d, 3 w	NA	-0.17 (-0.42, 0.08)	NA	0.30 (-1.12, 1.72)
Njike et al., 2011[105]	44 overweight adults, 91/110 g/d vs 0 g/d, 6 w	NA	NA	0.21 (-0.18, 0.60)	NA
Maersk et al., 2012[106]	47 overweight adults, 106 g/d vs 0 g/d, 6 m	NA	NA	0.30 (-0.52, 1.16) diet	0.66 (-2.25, 3.57) water
Pooled mean difference in weight gain in kg (95% CI)		0.58 (0.29, 0.88) P = 0.0001	0.75 (0.30, 1.19) P = 0.001 [b]	0.34 (0.15, 0.54) P = NR	0.85 (0.50, 1.20) P = NR
Conclusion of systematic review		"The effects of NSB consumption on body weight are difficult to discern"	"Intake of sugar sweetened beverages is a determinant of body weight"	Not provided	"SSB consumption promotes weight gain in adults"

CI = confidence interval; d = day; g = grams; kg = kilograms; m = months; NA = not applicable; NR = not reported; NSB = nutritively sweetened beverage; RCT = randomised controlled trial; SSB = sugar-sweetened beverages; w = weeks
[a] presented trials in this table are those examining SSBs; [b] SSBs and other sugars.

In Thailand, the consumption of sugar is remarkably high. The proportion of sugar as a source of daily carbohydrate intake per capita increased from 13% in 1990 to 22% in 2020[76] (Table 2.1). The average daily sugar consumption in the Thai population was 103.53 grams per capita in 2019, a 45.4% increase over the past ten years since 2010[76]. This level of sugar consumption is more than double the average in other Asian countries and nearly twice the global average[13]. It significantly exceeds the daily recommendations for sugar consumption from the WHO[12]. Various other, albeit outdated, data sources, including studies by Kriengsinyos et al.[14] and Bhadrakom[1], corroborate the finding that Thailand has high sugar consumption levels. For instance, an analysis by Kriengsinyos et al. of a survey from the National Statistical Office of Thailand indicated an average daily sugar consumption of 83 grams per capita in 2013[14].

The increase in sugar consumption in the country is commonly attributed to increased consumption of SSBs[14]. SSB consumption in Thailand took off with the mass commercialisation initiated by Coca-Cola's entry in 1949[111]. Since then, the market has grown significantly with the introduction of various sugar-containing beverage brands[75]. Using the Euromonitor Passport International database[ii] – a global database for SSB consumption, a study has shown that Thailand had the highest per capita sales of SSB-related calories in Asia in 2014[11]. Multiple research publications have emphasised the trend of increasing SSB consumption in Thailand[11,75,112,113]. The frequent daily consumption of SSBs is especially concerning. In 2005, only 5%–8% of Thais aged 15 and older consumed SSBs daily[114,115], however, by 2015, a National Health and Welfare Survey indicated that this figure had increased to 40%[116]. A 2019 longitudinal survey indicated a substantial increase, revealing that 70% of Thais in the 15 and older age group consumed SSBs daily[93]. These variations may be explained by different definitions of SSBs across studies. Another indicator of this upward trend in consumption of SSBs is the ongoing increase in revenue from non-alcoholic beverages, reported by the Thai government, which has persisted even through the COVID-19 pandemic of 2020–2022[117].

Limited information exists on the link between SSB consumption and the risk of obesity in Thailand. A retrospective study analysing a cohort of Thai university students from 2005 to 2009 found a statistically significant correlation between daily SSB consumption and weight gain[114]. Specifically,

[ii] The Euromonitor Passport Database, also known as Passport, is a global market research database developed by Euromonitor. It covers consumption trends of various product categories including SSBs in many countries worldwide. This database is often used in SSB studies. It provides data on all packaged drinking water, soft drinks including sodas, lemonades, and colas, and fruit and vegetable juices, as well as syrups and concentrates for beverage preparation.

https://www.euromonitor.com/our-expertise/passport individuals who consumed SSBs at least once daily gained an extra 0.5 kg over this four-year period compared to those who consumed these beverages less than once a month.

2.4 Sugar-Sweetened Beverage Taxation

Taxes on SSBs have become a global policy intervention with major international agencies like the WHO and the World Bank endorsing this approach as a means to combat obesity and associated health conditions[20,89]. The underlying principle is that imposing taxes on SSBs can increase production costs, which beverage producers may offset by increasing consumer prices, resulting in decreased consumption[18].

The formulation of taxation policy on SSBs was driven by both public health and economic considerations. From a public health standpoint, the policy aims to address the negative health impacts associated with SSB consumption, particularly given that these products are nonessential (with alternative healthy substitutes) and contribute to health problems[118]. From the perspective of economics, an SSB tax is justified by market failure conditions, specifically the negative externalities from costs of treatment for SSB-related obesity and related diseases that necessitate government intervention[119]. In this context, an SSB tax is considered a Pigouvian tax, designed to induce behavioural changes that mitigate the adverse external effects[120].

SSB taxes can be structured in various ways, each with unique public health implications[17]. Excise taxes, a type of indirect tax, are levied on the production or import of specific goods and are often used on products harmful to health[18]. Excise taxes can be broadly categorised into two groups: ad valorem and specific taxes[17]. An ad valorem tax is levied as a percentage of a beverage's value, and a specific tax is levied as a monetary value per quantity. These two types of taxes are usually based on a certain characteristic of the beverage, such as its volume or sugar content. The common structure of the taxes is summarised in Table 2.3. The advantages and disadvantages of these tax structures vary. Ad valorem taxes are better at preserving the real value of the tax against inflation but may not target cheaper products as for the same rate applied, cheaper beverages have a smaller tax compared to expensive beverages. Specific taxes are better at targeting cheaper products, providing predictable revenues, and are less vulnerable to price manipulation from the industry. However, without adjustments for inflation, their value may diminish over time. Generally, specific excise taxes are preferable from a public health perspective. Both types of taxes, when linked to either tiered sugar levels or absolute sugar content, can be effective incentives for industry reformulation of beverages to contain less sugar. A mixed approach, combining ad valorem and specific taxes, can also be considered to maximise benefits and minimise disadvantages. In a 2023 systematic review, researchers found that 88% of the 118 global SSB taxes are excise taxes, with 75% being specific volume-based in high-income countries and 55% being ad valorem or mixed in low-income and middle-income countries[121]. Additionally, 53% of these excise taxes use tiered rates, predominantly defined by beverage type (75%) rather than sugar content (33%).

Table 2.3: Comparison of the structure of common SSB taxes

Subject	Ad valorem		Specific		
	Value-based tax	**Value-based tax (tiered by sugar content)**	**Volume-based tax**	**Volume-based tax (tiered by sugar content)**	**Absolute sugar-content based tax**
Administrative burden (Monitor for tax avoidance, technical capacity to administer and monitor beverage sugar content)	Moderate	Moderate	Low	High	High
Impact of inflation (Need to adjust tax to reflect inflation)	No	No	Yes	Yes	Yes
Behavioural response (Encourage substitution to cheaper goods)	Yes	Yes	No	No	No
Reformulation incentive	No	Yes	No	Yes	Yes
Vulnerability to industry's tactics	High (e.g., price manipulation)	High (e.g., price manipulation)	Moderate	Moderate	Moderate
Country example	Kiribati [a], Thailand	Chile [b]	French Polynesia [c]	United Kingdom [d], Thailand	Mauritius [e]

Source: Reproduced based on Table 4.1 pp. 57–58 of the WHO manual on sugar-sweetened beverage taxation policies to promote healthy diets[17].
[a] 40% of market wholesale value; [b] 10% on SSBs with less than 6.25 g of sugar per 100 mL; 18% on all SSBs with > 6.25 g of sugar per 100 mL; [c] 40 Pacific francs per litre for domestic SSBs and 60 Pacific francs per litre for imported SSBs; [d] £0.18 per litre for drinks with 5–8 g total sugar per 100 mL; £0.24 per litre on drinks with > 8 g total sugar per 100 mL; [e] 0.03 Mauritian rupees per gram of sugar.

In Thailand, before the introduction of an SSB tax, SSBs were taxed under a general excise tax scheme applied to all beverages (except water), levied either a 20% ad valorem tax based on the wholesale price or a specific tax of THB 0.45 (USD 0.013 USD) per 1,000 mL, depending on which results in the higher tax amount. Therefore, with such an excise tax scheme, there were no extra taxes levied on SSBs and therefore no incentives to promote health through lower SSB consumption. In light of this limitation, the proposed new tax on SSBs is designed objectively to reduce the consumption of SSBs containing an excessive amount of sugar. This tax approach combines both ad valorem and specific taxes. It aims to cover four groups of SSBs and is set to be implemented in four phases in 2017, 2019, 2023, and 2025[122]. The four groups of SSBs are as follows:

Group 1: Sugared beverages and additives (0202 group),

Group 2: General sweetened teas, coffees & juices (0203(1) group),

Group 3: Rule-specified sweetened teas, coffees & juices (0203(2) group),

Group 4: Soluble sweetened drink powders (16.90 group).

A summary of Group 1 sugared beverages and additives (0202)[iii], which covers a majority of SSBs consumed such as carbonated and energy drinks in Thailand[92], is presented in Figure 2 (complete details on this group and other groups are presented in Table 8.1 in the supplementary appendix). For this group, the ad valorem tax is set at 14% based on the manufacturer's suggested retail price (MSRP). Meanwhile, the specific tax is based on volume, with rates tiered according to sugar content. The rates of the specific tax for different sugar levels are lower in the 2017 and 2019 phases, increasing in the 2023 and 2025 phases of the tax implementation. Owing to these lower rates in the early 2017 and 2019 phases, changes in prices and consumption of SSBs of all sugar levels during this period are unlikely[8]. By 2025, when the tax is fully implemented, beverages will be taxed as follows: those with more than 14 grams of sugar per 100 mL will incur the highest rate of THB 5 per 1,000 mL (USD 0.143); those with 8 to 14 grams will have a moderate rate of THB 3 per 1,000 mL (USD 0.086); those with 6 to 8 grams will face a low rate of THB 1 per 1,000 mL (USD 0.029); and those with less than 6 grams of sugar or no sugar per 100 mL will not be taxed. This tiered system aims to incentivise beverage manufacturers to reduce sugar content in their products.

The phased implementation, where lower tax rates are applied in the early stages (2019 and 2021), is designed to provide the industry time to adjust their production for reduced sugar content[123]. However,

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[iii] Beverages in the 0202 group include mineral water and soft drinks containing sugar, sweetening agents, or additives, as well as other drinks such as carbonated beverages, energy drinks, and mineral drinks.

some critics argue that the new tax rates may not significantly impact beverage prices[8]. For instance, a report from the World Bank on the proposed tax on SSBs in Thailand noted that “the new excise tax rates are not expected to lead to significant increase in prices of sugar-sweetened carbonated drinks. Meanwhile, price of soda with no sugar will fall from 0.25-0.36 Baht (US$0.008-0.011) per bottle”[89].

Figure 2.2: The proposed tax on SSBs in Thailand (0202 group) compared to the pre-existing general excise tax

Pre-existing general excise tax

Choose the highest from

Ad valorem: 20% on value

Or

Specific: THB 0.45/1,000 mL

Proposed tax on SSBs

Ad valorem: 14% on value

+

Specific (THB/1,000 mL)

Sugar (gram per 100 mL)	2017	2019	2023	2025
0 – ≤ 6	0	0	0	0
> 6 – 8	0.1	0.1	0.3	1.0
> 8 – 10	0.3	0.3	1.0	3.0
> 10 – 14	0.5	1.0	3.0	
> 14 – 18	1.0	3.0	5.0	5.0
> 18	3.0	5.0		

Source: Markchange et al., 2019[91]; Osornprasop et al., 2018[8]
Note: Beverages in the 0202 group include mineral water and soft drinks containing sugar, sweetening agents, or additives, as well as other drinks such as carbonated beverages, energy drinks, and mineral drinks.
Exchange rate of 35 THB = 1 USD in 2022[124]

Economics and Health Behaviours

Health behaviours, such as overeating or engaging in unhealthy practices, have long attracted interest in the field of economics, specifically behavioural health economics. A key framework for examining health behaviour in the field of health economics is Michael Grossman’s Health Demand Model[125]. This framework assumes health as a durable capital stock that depreciates with age. The model assumes that individuals invest in their health through healthcare consumption, healthy behaviours, and lifestyle choices to maintain or improve their health capital. The model emphasises the role of education, presuming educated individuals are often better equipped to process and understand medical information, which makes them more effective in producing health. In the context of Grossman’s model, overconsumption of SSBs can be viewed as an underinvestment in health capital.

The Rational Choice Model offers an explanation for obesity[126,127]. From this traditional economics perspective, obesity can be viewed as a problem of utility maximisation, where people may prioritise short-term happiness or welfare over long-term health. The model suggests that people may become overweight or obese based on their personal utility function, which considers factors such as weight, food intake and other consumption. In this model, individuals are expected to make decisions that maximise their utility, and they have stable, time-consistent preferences. It posits that weight higher than a certain healthy benchmark level can be optimal weight as long as it is the weight providing individuals with the highest utility (or satisfaction). External factors change, like changes in food prices or advancements in technology, can influence consumption choices, and change the individual's optimal weight. Empirical tests of the application of the rational choice model to obesity highlighted that changes in food prices and technology are primary drivers influencing the obesity epidemic[128,129].

The rational choice model was extended to account for seemingly irrational behaviours like addiction in the Rational Addiction Model[130]. This model assumes time-inconsistent behaviour, where individuals make decisions today that their future selves would prefer they had not made, yet these decisions are still considered 'rational' given the individual's utility calculation. According to the model, individuals will consume addictive goods if the perceived benefits outweigh the costs, even when accounting for negative future outcomes such as health risks. The model has played a significant role in health policy, particularly in justifying the imposition of a tax on tobacco[131]. For SSBs, the model can help explain SSB consumption by highlighting the role of perceived benefits and costs in affecting consumption choices. SSBs can be seen as addictive goods, with consumers developing habits and preferences that lead to overconsumption. Individuals may continue to consume these beverages even when aware of the potential health risks, as long as the perceived immediate benefits (e.g., taste) outweigh the perceived future costs (e.g., health risks and medical expenses). Zhen et al. in 2011 examined the implications of the Rational Addiction Model on SSBs in the United States and found that own-price elasticity of SSBs is higher in the long run than the short run, indicating that SSBs are a habit-forming (addictive) good[132]. Similarly, Bhadrakom in 2014 found that, due to habit formation, own-price elasticity of non-alcoholic beverages (a proxy of SSBs) in Thailand is higher in the long run than in the short run[1].

Some limitations of the Rational Addiction Model include that it does not address why individuals, despite their willingness, for instance, struggle to break free from addictive behaviours[133]. This gap has led to the development of behavioural economics, which offers a different perspective. Behavioural economics acknowledges that people are often time-inconsistent. That is, unlike the Rational Addiction Model, it assumes that individuals might make choices today with which their 'future selves' would not agree [134]. This is often due to cognitive biases or limitations, such as hyperbolic time discounting (also known as present bias) and lack of self-control where people overly discount the future in favour of immediate gratification[135]. Individuals with hyperbolic time discounting have a discount rate for future benefits and costs of unhealthy behaviour that is inconsistent with time, and this could mean they make short-term decisions that may deviate from their long-run plan[136]. Empirical studies have examined the role of hyperbolic time discounting in obesity and unhealthy diets. For instance, a 2012 study by Richard and Hamilton discovered that the discount functions of individuals with obesity are quasi-hyperbolic in nature, showing a positive correlation between obesity and higher discount rates[137]. Similarly, a systematic review has provided moderate evidence that high time discounting is a significant risk factor for unhealthy diets, as well as for being overweight or obese[138].

Economics posits that some people struggle with delayed gratification, and psychology may offer insights into why this is the case. Specifically, psychology introduces the concept of ‘hedonic eating’, where people consume food more for pleasure than for its nutritional value or to satisfy hunger[139]. Individuals prone to hedonic eating make food choices that are often based on ‘appetitive motivation’ such as ‘liking’ or ‘wanting’[140]. Liking is the pleasant affective experience of consumption, and wanting is the motivational drive to consume a food reward. Sugar intensifies this tendency toward hedonic eating because of its unique ability to offer immediate gratification. It triggers the release of a neurotransmitter called dopamine in the brain’s reward centre[141,142]. Sugar is a substance that activates the brain’s reward system more effectively than other foods[50]. This unique quality makes sugar highly palatable, leading individuals to consume sugary drinks primarily for pleasure rather than for nutritional value.

The idea of implementing SSB taxes can be examined from the perspectives of both rational choice theory and behavioural economics, with each offering distinct implications. Rational choice theory posits that an increase in cost, due to taxation, will result in reduced consumption, assuming individuals fully recognise the long-term health impacts of their choices. In contrast, behavioural economics accounts for less rational behaviours, cognitive biases, and psychological influences that could sway decision-making. For example, even with a tax-induced price increase, some individuals may still opt to purchase SSBs due to a lack of self-control or misunderstandings about the health implications. Examining these less rational influences is vital for understanding why individuals may not conform to policy incentives, such as taxation, as intended.

2.5 Health Inequity

Health inequity is defined as the unjust differences in health between individuals of different social groups and can be associated with forms of disadvantage such as poverty, discrimination, and lack of access to healthcare[29]. Since health inequity is a normative concept, it typically requires complex methodologies to measure precisely. Health inequality, on the other hand, refers to observable differences in health between individuals (or subgroups) within a population, which are more straightforward to measure. Often, assessing health inequality serves as an indirect means of evaluating the presence of health inequity[29].

Reducing health inequity is a key goal for UN Member States, including Thailand, as they work towards Universal Health Coverage (UHC) in alignment with the Sustainable Development Goals (SDGs)[143]. UHC aims to fulfil two primary objectives: to ensure equitable access to high quality healthcare and to protect individuals from financial risks associated with healthcare costs. Meeting these objectives is essential for improving overall health, as well as for achieving other SDG health targets like preventing premature death from NCDs. Since Thailand introduced UHC in 2002, there have been marked improvements in health equity[144-146]. For instance, the incidence of catastrophic spending (defined as household spending on health exceeding 10% of total household consumption expenditure) decreased from 6.0% in 1996 to 2% in 2015[146,iv]. Furthermore, there was a consistent decrease in mortality inequality in adults across different geographical areas[145]. Yet, ongoing efforts are needed to further reduce health inequity in Thailand for long-term success[147].

According to the WHO, monitoring health inequality is an essential part of enhancing health equity[29]. The WHO recommends using socioeconomic status as one of the key equity stratifiers for monitoring health inequality[29]. Worldwide, obesity is often used as a specific indicator to assess health inequality in a population[148].

The topic of socioeconomic inequality in obesity has been extensively examined in international research[30,149,150], with a summary of the results by gender across national income provided in Table 2.4. An early comprehensive review in 1989 analysed 144 studies[30], while an updated review in 2007 included 333 studies[149]. Both reviews found a consistent relationship between a country's income level and the extent of socioeconomic inequality in obesity. In the 2007 review, there was a negative relationship between socioeconomic status and obesity for women in high-income countries, highlighting a form of socioeconomic inequality. However, in lower-income countries, the relationship was positive for women. For men in high-income countries, the relationship was mostly non-significant or negative, with very few countries showing a positive relationship, pointing to a different pattern of socioeconomic inequality in obesity. A 2012 review focusing on low and middle-income countries showed that socioeconomic inequality in obesity was predominantly positive for both genders in low-income countries[150]. In middle-income countries, the relationship was mixed for men, while for women, most studies found no significant association, but some showed a positive relationship.

Table 2.4: International evidence on the relationship between socioeconomic status and obesity by gender

	Countries' income level		
Gender	Low	Middle	High
Men	Positive	Mixed, lean to positive	More negative
Women	Mostly positive	Mixed, lean to negative	Mostly negative

Source: Compiled based on McLaren (2007)[139] and Dinsa et al. (2012)[140].

[iv] Geographical inequality was measured by the coefficient of variation of the standardised mortality ratio across different areas from 2001 to 2014. The coefficient of variation for the standardised mortality ratio substantially declined from 20.0 in 2001 to 12.5 in 2007, maintaining a level proximate to this value through 2014.

In Thailand, various studies have examined the relationship between socioeconomic status and obesity (Table 2.5)[35-41]. The initial study, published in 1994, suggested a positive correlation between socioeconomic status and obesity. However, this study did not break down the results by gender[35]. Later studies, which used data from the National Health Examination Survey (NHES) from 1997, 2004 and 2009, reported mixed relationships between socioeconomic status and obesity[36-38]. A 2010 study (Seubsman et al.,), using a national cohort of Open University students (The Thai Health-Risk Transition: A National Cohort Study), found a pattern of socioeconomic inequality in obesity[40]. Specifically, men in higher socioeconomic groups had higher rates of obesity, while the reverse was true for women[40]. This pattern continued to hold in the most current study, which analysed data up to the year 2013[41].

Table 2.5: Previous Thai studies on the relationship between socioeconomic status and obesity

Author, year	Data	Data year	N	Age	Method	Obesity classification	SES variables	Results
INCLEN 1994[35]	INCLEN trial	NR	600	35-65	mul reg	BMI (continuous)	p.inc, edu, occ	Positive
Aekplakorn et al., 2004[36]	NHES I	1997	3,220	20-59	log reg	BMI ≥ 30	edu, occ	Negative: edu Positive: occ
Aekplakorn et al., 2007[37]	NHES II	2004	38,323	≥ 18	log reg	BMI ≥ 25	edu	Positive: men Negative: women
Jitnarin et al.,2010[39]	NTFCS	2004/2005	6,445	18-70	log reg	BMI ≥ 23 (overweight or obese)	h.inc, edu	Positive: men Negative: women
Seubsman et al., 2010[40]	Thai Health-Risk Transition	2005	87,134	15-87	log reg	BMI ≥ 25	p.inc, edu, h.ass	Positive: men Negative: women
Aekplakorn et al., 2014[38]	NHES III	2009	19,181	≥ 20	log reg	BMI ≥ 25	edu	Positive: men Negative: women
Yiengprugsawan et al., 2016[41]	Thai Health-Risk Transition	2005, 2009, 2013	9,893	15-87	chi-square statistic	BMI ≥ 25, BMI ≥ 30	p.inc	Positive: men Negative: women

BMI = body mass index; occ = occupation; edu =education; h.ass = household asset; h.inc = household income; log = logistic; mul = multivariate; NHES = National Health Examination Survey; NR = not reported; NTFCS = National Thai Food Consumption Survey; p.inc = personal income; reg = regression; SES = socioeconomic

Studies in Thailand on this topic have generally relied on regression-based analyses, which have faced some criticisms in similar studies[31]. In isolation, these approaches may have a limitation in terms of lacking the sensitivity to capture inequalities in health, particularly in the socioeconomic domain[151]. An alternative method known as the concentration index has been widely used in the field of health economics. This method was suggested to be more accurate than commonly used approaches like the range (e.g., odds ratio or relative risk from regression analysis) and the index of dissimilarity as the concentration index, which is a rank-dependent tool, simultaneously captures:

- the impact of the socioeconomic dimension on inequality in health, while the index of dissimilarity does not;
- the entire population, while analysis of the range of the outcome of interest (e.g. comparing studies' health indicators in the top and bottom socioeconomic groups) might pay no attention to what is happening in intermediate groups;
- changes in the distribution of the population across socioeconomic groups, while analysis of the range disregards the sizes of the groups being compared.

The concentration index has become a popular approach in measuring health inequality acknowledged by international agencies like the World Bank and WHO[29,152]. It has also been used to measure socioeconomic inequality in obesity in various countries[31-34,153-160]. One of the early studies, conducted in the United States in 2004, found that women of lower socioeconomic status had higher rates of obesity during the period from 1988 to 1994[31]. Similarly, a 2008 study in ten European countries found that higher socioeconomic status was associated with lower obesity rates, particularly among women[161]. In lower-income countries, the relationship between socioeconomic status and obesity is inconsistent, showing varied patterns across genders and different countries[33,155,156,158,160].

A decomposition analysis of the concentration index is an approach commonly used to identify factors that contribute to observed socioeconomic inequalities in health outcomes[162]. In terms of obesity, it has been applied in various studies across many countries[32-34,153,155,158]. For instance, studies found that education interacted with income to specifically affect obesity rates among women in lower socioeconomic groups in Canada[32], Spain[34], and the UK[153]. In terms of SSBs, this type of analysis can help gain an in-depth understanding of how SSB consumption affects socioeconomic inequality in obesity. For example, a 2017 study in Indonesia showed that expenditure on SSBs (specifically soft drinks) contributed to a 4.3% change in excess weight inequality from 2000 to 2014. This insight is useful, especially when public health policies, like SSB taxes, aim to reduce health inequities[163]. However, this type of investigation has not yet been conducted for Thailand.

2.6 Economic Evaluations of Public Health Interventions

Economic evaluation is the comparative analysis of different options of action in terms of both costs and consequences[55]. In healthcare, it is an established approach for comparing the costs and benefits of health interventions, aiming to improve decision-making[55v]. Economic evaluation has been firmly integrated into the reimbursement decision-making processes in various countries, including Thailand[164,165]. An important milestone for well-established processes for conducting economic evaluation in Thailand was the publication in 2007 of a national guideline for health technology assessment[166].

There are four main types of economic evaluations[55]. First, cost-utility analysis (CUA) measures the cost per unit of gain in utility, commonly a quality-adjusted life year (QALY)[55,vi], allowing for broad comparisons across diverse interventions. Second, cost-effectiveness analysis (CEA) compares the costs and outcomes of different interventions, but measures effectiveness in natural or disease-specific units like 'life-years gained' or 'cases of obesity prevented'. Third, cost-benefit analysis (CBA) quantifies both costs and benefits in monetary terms, enabling broader comparisons in various fields beyond healthcare. Last, cost-minimisation analysis (CMA) is used when the effectiveness of the alternatives being compared has been shown to be equal; hence, it only compares the costs. CUA is the most preferred type of analysis in various countries, including in Thailand[167].

In the context of SSB taxes, evaluating their costs and benefits can be seen as assessing a public health intervention. This raises concerns that traditional methods of economic evaluation, which were developed for assessing medical technologies in healthcare settings, may have limitations when applied to public health interventions[22,23]. First, unlike medical technologies, public health issues and interventions are complex in various ways, making it difficult to establish effectiveness through

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[v] Currently, approaches in economic evaluation are dominated by a perspective often described as 'extra-welfarist'. This perspective is rooted in belief that a central decision-making authority is necessary for publicly funded healthcare systems, and that maximisation of overall health outcomes should be within the budget constraints imposed by healthcare funders.

[vi] A QALY (quality-adjusted life year) is a measure of health output that combines both the quantity and quality of life. It considers both the years of life lived and the health-related quality of life during those years. Therefore, one QALY is equivalent to one year of life in perfect health.

methods like RCTs. Second, the consequences of public health interventions often extend beyond health and cannot be fully captured by health-related outcomes such as QALYs. For instance, consequences may also include impact areas like improvement in education and reduction in crime. Third, the costs associated with public health interventions often spill over beyond the healthcare sector. Last, public health aims to reduce health inequities, a goal not fully aligned with traditional economic evaluations that were underpinned by the health maximisation concept.

Various reviews have examined how the challenges of public health interventions were addressed in economic evaluation. Weatherly et al.[168] published a landmark study in 2009 on the methodological issues of economic evaluation for public health interventions. The authors found that around one-third of economic evaluations included were based on RCTs (38%; 58 of 154 studies), and considerations of non-health consequences, non-healthcare sector costs, and equity were rare. Later reviews published in 2017 and 2019 have continued to highlight these issues in examinations of various public health interventions (e.g., alcohol prevention)[169-171].

2.7 Summary

In summary, this chapter establishes the background of the health issue (obesity) addressed in this thesis and details the intervention (an SSB tax) under study, as well as provides the relevant theoretical and methodological frameworks underpinning this thesis. Key issues and knowledge gaps related to the implementation of an SSB tax in Thailand are highlighted, emphasising the need for further research into the socioeconomic determinants of obesity inequality and its relationship to SSB consumption. Additionally, the chapter emphasises the need for further research into the specific cost-effectiveness of an SSB tax within the Thai context. Potential methodological challenges faced in the economic evaluation of public health interventions are also discussed. These challenges will be explored further in Chapter 3, which presents a systematic review of economic evaluations of SSB taxes, highlighting methodological concerns and areas that require attention with respect to the assessment of SSB taxes.

Chapter 3: Systematic Review of Economic Evaluations of SSB Taxes

3.1 Preamble

This chapter presents a systematic review of economic evaluations of SSB taxes. The review aims to summarise existing economics evaluations of SSB taxes, and to identify methodological issues. Initially, the review applied assessment criteria to the following methodological domains previously identified for economic evaluations of public health interventions: measuring effects, valuing outcomes, assessing costs, and engaging equity. These domains were adapted to be specified to the application of a tax on SSBs and its potential to affect obesity or SSB-related obesity.

This chapter is presented in the format of a manuscript. The manuscript was published in *Health Policy* on 22nd April 2024. The authorship roles are as follows:

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- Study design: KT.
- Data collection: KT and Terence Khoo (TK)
- Data analysis: KT.
- Writing - original draft: KT.
- Writing - review and editing: Jody Church (JC), PC, RL, SG, and TK.
- Supervision: PC, RL, and SG.
- Validation: KT, RL, and SG.

3.2 Manuscript's details

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3.3 Abstract

Introduction A tax on sugar-sweetened beverages (SSBs) has been proposed as an effective measure to address obesity and obesity-related health issues. The long-term consequences of SSB taxes have been modelled using economic evaluations. However, reviews of economic evaluations of public health interventions in other contexts have raised several methodological challenges, and these issues have not been explored in respect to a tax on SSBs.

Methods A systematic review was conducted to appraise economic evaluations of a tax on SSBs. The literature search was performed in February 2021 for EconLit, Business Source Complete, Medline, and CINAHL. Criteria for assessing studies were developed to align with previously identified methodological issues in economic evaluations of public health interventions and key issues in the evidence for SSB taxes. These include measuring effects, valuing outcomes, assessing costs, and engaging equity.

Results Fourteen economic evaluations of a tax on SSBs were identified. The economic evaluations found that implementing a tax on SSBs could result in cost savings and reduce health inequities. There were technical issues regarding the approaches used to estimate the effects. In particular, there was uncertainty in estimating the impact of SSB consumption and SSB taxes on body weight. There was also uncertainty in valuing the substitution effect where SSB consumers could switch to other similar products. In addition, the evaluations were limited in terms of the information presented. Consideration of non-health consequences both in term of costs and outcomes in the evaluations was not common. More than half of the evaluations provided equity analyses but most of these used informal approaches such as subgroup analyses to inform equity outcomes of the tax.

Conclusion Methodological issues were identified in current economic evaluations examining the impact of a tax on SSBs. Greater transparency of the full details of the evidence and robust analyses is needed for future evaluations.

Keywords. Tax, Sugar-sweetened beverages, Sugary drinks, Economic evaluations, Equity, Public health intervention, Economics, Cost-effectiveness analysis

3.4 Introduction

The role of unhealthy diets and energy overconsumption has been continuously highlighted[172,173] as a leading contributor to the global rise in the prevalence of obesity[174]. In particular, sugar-sweetened beverages (SSBs) are often referred as a possible key leading source for excessive energy intake compared to energy expense[15]. Their high levels of energy-dense ingredients and minimal nutritional values, combined with the efficiency with which they are marketed to the public, has made SSBs a perfect target for health policies[175].

While various measures have been introduced to reduce the consumption of SSBs[176], the World Health Organisation (WHO)[19] has advocated for taxes on SSBs[88,177,178] . The rationale is that, by increasing the SSB price, a tax will discourage consumption among the broad population. Taxes also have the advantage of being feasible and least costly to society to implement[179]. In 2021, there were more than 45 jurisdictions around the world that had implemented a SSB tax[180].

A tax on SSBs is not only an economic instrument but a public health Intervention, given it aims to prevent harmful health effects across the population[181]. SSB taxes have been modelled on the success of prior health taxes such as tobacco and alcohol[182], to determine whether the introduction of SSB taxes represents value for money[183].

Standard economic evaluation is considered to be inadequate to evaluate the complexity of public health interventions[22,23]. Methodological challenges include; measuring effects, valuing non-health outcomes, assessing non-health costs, and engaging equity[168 163,169,171,184]. For example, Hills et al suggest that non-health impacts and equity were not adequately considered in economic evaluation of alcohol prevention[169]. Likewise, Jain et al found equity considerations were not addressed in economic evaluations of the taxation of alcohol and were only addressed in a minority of evaluations of tobacco taxation[163].

Several reviews have examined the methodological approaches adopted to evaluate public health interventions for obesity prevention[185-189]. While many such interventions have been found to be cost-effective, the robustness of these results have often been questioned[185-189]. Reviews have noted, for example, that uncertainty regarding the effectiveness of obesity-related interventions necessarily limits conclusions about their cost-effectiveness[186]; that broader impacts outside health sector have not been adequately addressed in economic evaluations[190]; and that validation of modelling approaches remains a critical challenge for the evaluation of obesity interventions[191].

Due to the popularity of SSB taxes around the world, it is anticipated that many economic evaluations of SSB taxes have been conducted in recent years. However, their potential methodological issues have not been systematically addressed. This review aims, therefore, to identify, describe, and evaluate the methodological issues of current economic evaluations of SSB taxes as a policy to reduce obesity.

3.5 Methods

Literature Search

Four databases, EconLit, Business Source Complete, Medline, and CINAHL, were searched via the EBSCOhost searching platform in February 2021 for literature published in English without specifying date of publication. Based on the PICO(S) framework[192], the search terms were defined as: Population = sugar; Intervention = tax; Comparator = N/A; Outcome = weight, obesity, obese, body mass index; and Study = cost, economic, evaluation, assessment. The asterisk wildcard character (*) was used to include alternative forms of keywords (e.g., tax* to include taxes). The Boolean operator OR was used to combined different keywords within terms. The Boolean AND was used to combine different concepts of the PICO(S) framework, forming the search term "sugar* AND tax* AND ((weight*) OR (obesity) OR (obese) OR (body mass index)) AND ((cost*) OR (economic*) OR (evaluation*) OR (assessment*))". An expanders operator of the searching platform was used to include other related terms to these search terms. Handsearching of references was performed to identify relevant literature not covered in the databases. The search and selection of studies were conducted by a reviewer (KT).

Eligibility Criteria

Studies were included in the review if they: (1) included a full economic evaluation[55]; (2) had SSB taxes as the intervention of interest (variously referred to in the literature as volumetric – tax on the volume or unit of a product- or ad valorem/valoric – tax on the value of a product – excise tax)[90]; (3) focused on the impact of SSB taxes on obesity or harmful obesity-related outcomes, indicated by an appropriately stated rationale in the introduction (background) section of the study or results which report obesity outcomes (e.g., change in obesity prevalence); (4) studied a population aged 18 years or above; (5) were published in English; and (6) were peer reviewed. Selection of eligible studies included an initial title and abstract review, followed by a full paper review to identify studies that met the eligibility criteria.

Assessment Criteria

Assessment criteria used in this review were identified by two approaches. First, the methodological issues in economic evaluations of public health interventions[21,168] were adopted as broad theme of assessment criteria. These include measuring effects, valuing outcomes, assessing costs, and engaging equity. Second, an exploratory review was performed of the broader literature to identify key issues in area of the studied intervention (i.e. a tax on SSBs) and studied health (i.e. obesity, SSBs-related obesity) respective to these methodological areas (details are provided upon request). Multiple guidelines for assessing economic evaluations were also consulted[56,183,193]. A summary of key methodological concerns in this review is presented in Table 3.1.

Table 3.1: Summary of key theme for investigation in this systematic review

Assessment criteria	Methodological challenge for economic evaluation of public health interventions[21,168]	Related issues in the context of a tax on SSBs as an anti-obesity intervention
Effects	**Baseline clinical data** Long and complex causality pathway of public health issues and interventions.	There has been an ongoing debate on the causal role of SSBs on obesity[107]. SSBs might have smaller impact on obesity than has been previously hypothesised[97]. In particular, individuals may compensate for excess calories consumed on one food by reducing consumption of other foods[194].
	Effectiveness Randomised controlled trials (RCTs), the gold standard for measuring effectiveness of heath interventions, are rare for public health interventions (e.g. due to power and sample size requirement).	An indirect measurement of effectiveness measuring change in consumption per unit of change in price (a price elasticity of demand) from observational data is common[195]. Using such indirect approach often came with neglecting impact of substitution effect[196]. More attention is being given to the role of substitution effect (cross price elasticity of demand) where individuals may choose to consume similar products as SSBs[197,198].
Outcomes	Outcome beyond health sectors (education and labour market/productivity, well-being index). Health-related outcomes such as QALYs is not sufficient in representing full impact of public health interventions. An approach such as CBA might be adopted to capture broader outcomes rather than health (i.e. using willingness-to-pay approch[199,200]).	It has been hypothesised that a tax on SSBs might lead to non-health outcomes such as improving in productivity[201]. Yet, this area appears to be inadequately explored.
Costs	Public health interventions might have impact that expand beyond the health sector. For example, criminal justice costs may be reduced with public health interventions targeting substance abuse[21]. Intersectoral costs have been suggested for economic evaluations of public health interventions.	A tax on SSBs tax might lead to non-health costs. For example, deadweight loss (a term in economics referring to the net loss in overall economic welfare contributed by the implementation of a new tax) due to forgone consumption of SSBs due to increasing in price[24]. Increased SSB price may harm local businesses[202] and introduce costs to reformulate SSBs with low sugar to the industries[203].
Equity	Engaging an equity analysis into public health economic evaluations has been encouraged. However, this is emerging methodological research with a few methods developed to support the analysis (extended cost-effectiveness analysis; ECEA and distributional cost-effectiveness analysis; DCEA)[28]. Provision of equity require more detailed data (e.g. prevalence of disease based on informative-equity groups)[204].	Equity analyses have been included in some economic evaluations of health taxes including a tax on SSBs[163], however little has been known about their characteristics. Lower socioeconomic groups might consume more SSBs than those in the higher. This might lead more burden of tax to them (regressivity)[119]. Consumption data and effectiveness are required for each socioeconomic group.

Abbreviations: CBA = cost benefit analysis; RCT = randomised controlled trial; SSBs = sugar-sweetened beverages

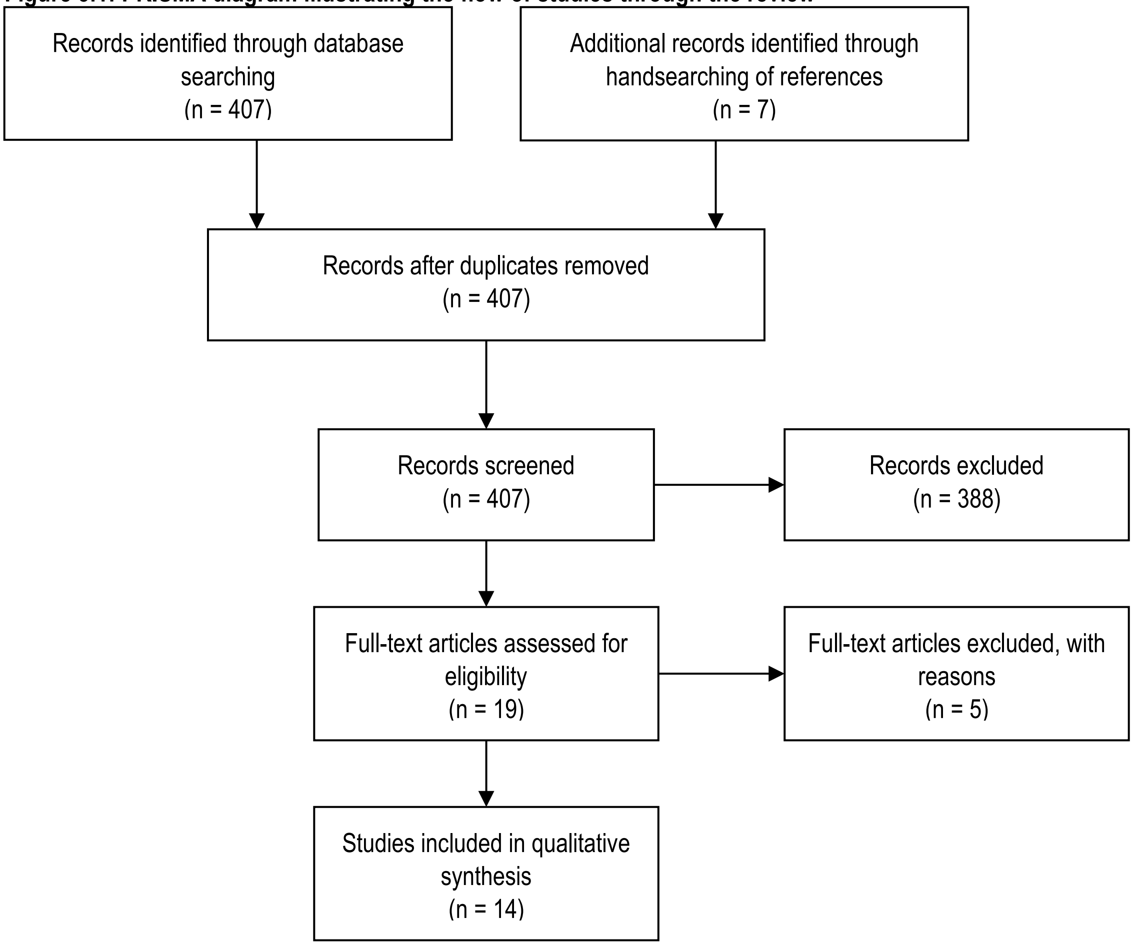
Data Extraction

The data extraction form was developed in Excel to collate the information extracted from the included studies (full details of the data extraction form is provided in Table 8.2 in the supplementary appendix). Methodological concerns were groups according to four themes: effects, outcomes, costs and equity. Extraction of data was performed by two reviewers (TK and KT); any disagreement on data extraction was resolved by discussion. Data were extracted for the following: (1) characteristics of study (authors, year, country/setting, age of population, type of tax, rate of tax, comparator, modelling type, perspective, time horizon, discount rate, sensitivity analysis); (2) rationale (related text in the introduction section of the studies specifying relationship between SSBs and obesity); (3A) effects – baseline clinical data (SSB consumption, source and details of effect size for SSB consumption and weight, adjustment for other sources of energy e.g. consideration of other food consumption, physical activity or adjusting for caloric compensation effect), (3B) effect – effectiveness (source of effectiveness, jurisdiction of the source, value of effectiveness, substitution effect, persistence of effectiveness), (4) outcomes (types of weight outcomes, types health-related outcomes, types of non-health outcomes, results specific to these outcomes), (5) costs (types of health-related costs, types of non-health costs, results specific to these costs), (6) equity (approach, equity-group of interest, measurement and outcome of equity, equity-informative data, equity results), and (7) cost-effectiveness results. Results of costs in the included studies were converted to US dollars in 2021 value using an online web-based tool (CCEMG – EPPI-Centre Cost Converter)[205].

3.6 Results

A summary of the search results and selection of potential studies is presented in Figure 3.1. The search identified 414 studies. 407 were identified via database searches and 7 via handsearching of references. After removing duplicates, 407 were screened for title and abstract and 19 of these were considered for full paper review. Of those 19, five were excluded: two did not focus on obesity[206,207], one did not have adults as the population[208], one evaluated only benefits[209], and one did not focus on evaluation of SSB taxes[210]. A total of 14 studies were thus included in the assessment.

Figure 3.1: PRISMA diagram illustrating the flow of studies through the review



Characteristics of Studies

Characteristics of the 14 included studies are summarised in Table 3.2. Half of the studies were published after 2018 (7/14, 50%)[2,25-27,211-213]. The majority were from high-income countries (10/14, 71%)[24,26,27,53,212-217] including 7 from the USA (50%)[26,27,53,212,214,215,217]. In addition to their adult populations, most studies included children or adolescents as a population of interest (8/14; 57%)[2,24,25,211,212,214,215,218]. A majority of the studies (10/14, or 71%) assessed a volumetric tax[2,25-27,53,211,212,214,215,217]. The most frequently used tax rate was US$0.01 per fluid ounce (equivalent to 29.6 mL), which was implemented in all studies conducted in the USA (7/14, or 50%)[26,27,53,212,214,215,217]. Two studies also evaluated a tax that was based on sugar content. (2/14; 14%)[2,27]. Most reported 'no SSB tax' as a comparator (13/14; 93%)[2,24-27,211-218]. Only half of the included studies (7/14; 50%)[24,26,27,53,213,214,216,218] clearly stated the perspective adopted, which was a societal perspective for just over half (4/7)[24,26,27,214]. The minimum time horizon was ten years, used in six studies (6/14; 43%)[53,211,212,214,215,217], while the maximum was a lifetime that was used in five studies (5/14; 36%)[24,26,27,213,216]. Most of the included studies applied a discount rate (8/14; 57%)[24,26,27,53,211-214] to both costs and outcome and two applied it to costs only (2/14; 14%)[215,217]. The most common discount rate was 3% applied to costs and outcomes in seven studies (7/14; 50%)[24,26,27,53,211,212,214] and costs only in two studies (2/14; 14%)[215,217]. Most studies used a cohort or Markov model (other non-individual models were classified into this type of model) (10/14; 71%)[2,24,25,211,213-218] while four used microsimulation modelling (4/10; 29%)[26,27,53,212]. All studies provided sensitivity analyses (14/14; 100%) including six studies (6/14; 43%)[27,53,213-216] providing both deterministic sensitivity analyses (DSA) and probabilistic sensitivity analysis (PSA), five studies (5/14; 36%) providing only DSA[2,24,25,217,218], and three studies (3/14; 21%)[26,211,212] providing only PSA. Several models[24,25,213,214,216] were built by adapting existing models, in particular a model from the ACE-Obesity study, that was initially developed in Australia[219].

Table 3.2: Characteristics of the included studies

Authors	Country	Target population	Type of tax	Tax rate	Comparator	Type of study	Modelling type [a]	Perspective [b]	Time horizon	Discount rate (cost, outcome)	Uncertainty analysis
Wang et al., 2012[217]	US	26-64 yrs	Volumetric	$0.01/oz	No tax	CEA	Cohort (Markov)	NS	10 yrs	3%, NS	DSA
Basu et al., 2013[53]	US	25-64 yrs	Volumetric (+SNAP)	$0.01/oz	SNAP	CUA	Microsimulation	Government	10 yrs	3%, 3%	DSA, PSA
Mekonnen et al., 2013[215]	US (CA)	All ages	Volumetric	$0.01/oz	No tax	CEA	Cohort (Markov)	NS	10 yrs	3%, NS	DSA, PSA
Long et al., 2015[214]	US	≥ 2 yrs	Volumetric	$0.01/oz	No tax	CUA	Cohort (Markov)	Societal	10 yrs	3%, 3%	DSA, PSA
Manyema et al., 2016[218]	South Africa	≥15 yrs	NS	20%	No tax	CUA	Cohort (Markov)	Health system	20 yrs	No discounting	DSA
Veerman et al., 2016[216]	Australia	≥ 20 yrs	Valorem tax	20%	No tax	CUA	Proportional multi-state life table model (Markov)	Health system	Lifetime	No discounting	DSA, PSA
Lal et al., 2017[24]	Australia	2 to 100 yrs	Sale tax	20%	No tax	CUA	Cohort (Markov)	Societal	Lifetime	3%, 3%	DSA
Basto-Abreu et al., 2019[211]	Mexico	2 to 100 yrs	Volumetric	1 peso/L	No tax	CUA	Cohort (Markov)	NS	10 yrs	3%, 3%	PSA
Long et al., 2019[212]	US (Maine)	All ages	Volumetric	$0.01/oz	No tax	CUA	Microsimulation	NS	10 yrs	3%, 3%	PSA
Saxena et al., 2019 (PH)[25]	Philippines	All ages	Volumetric	₱6/L	No tax	CEA	Cohort (Markov)	NS	20 yrs	No discounting	DSA
Saxena et al., 2019 (SA)[2]	South Africa	≥15 yrs	Volumetric	2.21 cents/g of sugar over 4 g/100mL	No tax	CEA	Cohort (Markov)	NS	20 yrs	NS	DSA
Wilde et al., 2019[26]	US	35 to 85 yrs	Volumetric	$0.01/oz	No tax	CUA	Microsimulation	Societal	Lifetime	3%, 3%	PSA
Lee et al., 2020[27]	US	35 to 85 yrs	(i) Volumetric (ii) Tier	(i) $0.01/oz (ii) (<5 g of added sugar/8 oz: no tax; 5–	No tax	CUA	Microsimulation	Societal	Lifetime	3%, 3%	DSA, PSA

			(iii) Sugar-Content	20 g/8 oz: $0.01/oz; and >20 g/8 oz: $0.02/oz (iii) ($0.01 per teaspoon added sugar							
Kao et al., 2020[213]	Canada	≥ 20 years	Valorem tax	20%	No tax	CUA	Cohort (Markov)	Health system	Lifetime	1.5%, 1.5%	DSA, PSA

Abbreviations: CA = California; CEA = cost-effectiveness analysis; CUA = cost-utility analysis; DSA = deterministic sensitivity analysis; g = gram; L = litre; mL = millilitre; NS = not stated; oz = ounce; PH = Philippines; PSA = probabilistic sensitivity analysis; SA = South Africa; SNAP = Supplemental Nutrition Assistance Program; US = United States; yrs = years.
Note: [a] Unless stated otherwise, non-individual-based models have been classified into cohort (Markov); [b] Societal perspective was chosen if a study adopted another perspective with societal;

Rationale

A summary of the rationale used to establish a relationship between obesity and SSBs in the included studies is provided in Table 3.3. Of the 14 studies, 13 (13/14; 92%) stated a relationship between SSBs and obesity (or weight) in their introduction section[2,24-27,53,211,213-218]. Most of these studies stated that obesity (or weight) was due to SSBs or SSB consumption[24-27,211,214,216-218], while only three studies explicitly mentioned that it was due to increased consumption (including one study stating overconsumption)[2,213,215].

Table 3.3: Rationale used to establish a relationship between obesity and SSBs in the included studies

Study	Related text
Wang et al., 2012[217]	(SSBs) "are a major contributor to the US obesity"
Basu et al., 2013[53]	"Low-income individuals…consume more calories from sugars …they also experience higher rates of obesity…"
Mekonnen et al., 2013[215]	"higher consumption of SSB is associated with excess calorie intake, which leads to weight gain and increased risk of obesity."
Long et al., 2015[214]	"… studies ... have linked SSB consumption to excess weight gain"
Manyema et al., 2016[218]	"relationship between SSB consumption and stroke may be mediated through weight gain and/or hypertension."
Veerman et al., 2016[216]	(SSBs) "are the most commonly recommended target for food taxes, primarily due to the strong association with poor health and obesity"
Lal et al., 2017[24]	"evidence of the association between … (SSB) intake and increased energy intake, leading to weight gain and obesity, is compelling."
Basto-Abreu et al., 2019[211]	"Decreasing the consumption of these beverages is likely to reduce the prevalence of obesity"
Long et al., 2019[212]	Did not provide
Saxena et al., 2019 (PH)[25]	(SSBs) "are a driver of obesity"
Saxena et al., 2019 (SA)[2]	"One contributor (to obesity prevalence) was increased consumption of (SSB)."
Wilde et al., 2019[26]	SSBs "consumption increases the risk of weight gain, obesity"
Lee et al., 2020[27]	"Intake of (SSB) increases weight gain"
Kao et al., 2020[213]	"Overconsumption of (SSB) contributes to childhood and adult obesity"

Abbreviations: PH = The Philippines; SA = South Africa; SSBs = sugar-sweetened beverages

Effects

Baseline clinical data

Table 3.4 presents a summary of baseline clinical data used in the 14 included studies. The studies can be grouped according to whether they provided direct or indirect evidence for an effect of SSB consumption on weight.

Five studies (5/14; 36%) used direct evidence to demonstrate a relationship between SSB consumption and weight, either by combining data from RCTs and non-experimental studies[212,214], or by using data from non-experimental studies only[26,27,211]. Of these 5 studies, additional adjustment for other sources in the model might not be required given it could be reflected in the direct effect evidence. For example, Basto-Abreu et al., 2019 report an experimental study showing that daily intake of SSBs would result in 1.0-kilogram weight change in two years, arguing that this already accounted for compensatory changes in diet or physical activity[211]. Long et al., 2015 assessed a change in SSB intake and impact on weight status without controlling for total energy, therefore adjustment of caloric compensation might not be needed[214].

The remaining nine studies estimated the impact of SSBs on weight indirectly by applying energy balance equations. Of these studies, six[2,24,25,53,216,217] used an equation developed by Hall et al., 2011[220], two (2/14; 14%)[213,218] used an equation developed by Swinburn et al., 2009[221] and one (1/14; 7%)[215] used a conventional rule of 3,500 kcal per 1 pound (lb; 7,700 kcal per 1 kilogram; kg)[222]. Caloric compensation effects were applied in two studies; as part of the base case analysis (assuming 40% of SSB consumption would not result in weight change) in one study[217], and as a scenario analysis (compensation effect of 39%) in another study[215].

Only seven studies detailed the timeframe over which the effect from reduced consumption of SSBs on weight change would occur (7/14; 50%): one year in Kao et al., 2020[213]; two years in Basto-Abreu et al., 2019[211]; three years in Wang et al., 2012[217] and Lal et al., 2017[24]; with the remaining studies using an unspecified, but not indefinite, period of time until a new equilibrium of energy balance was reached. [53,217,218].

All ten of the studies using cohort or Markov models were based on mean SSB intakes [2,24,25,211,213-218]. These mean intakes were often classified by subgroups: gender, age or income. Three of four microsimulation models[26,27,53] used individual data for SSB intake while it was unclear what approach was used in the fourth study[212].

Table 3.4: Evidence used to estimate weight change due to change in SSB consumption in the included studies

Study	Baseline consumption of SSBs	Approach used to estimate impact of SSB consumption on weight				
				Adjustment for other sources of energy		
	SSB intake (min, max)	Source of data	Summary	Caloric compensation effect	Overall other food intake	Physical activity
Wang et al., 2012[217]	Mean by gender, age (33, 0.79 servings/d)	Equation (Hall et al)	100 kJ/d → 1 kg, 50% in 1 yr, 90% in 2 years, 100% in 3 yrs [a]	Yes; 40% (assumption)	-	-
Basu et al., 2013[53]	Individual intake	Equation (Hall et al)	100 kJ/d → 1 kg, 50% in 1 yr, 90% in 2 yrs, 100% in 3 yrs [b]	No	Likely	Unlikely
Mekonnen et al., 2013[215]	Mean (value not reported)	3,500 kcal/lb eq.	32,217 kJ → 1 kg	No, 39% (RCT) in scenario analysis	Unlikely	Unlikely
Long et al., 2015[214]	Mean varied by gender, age (29, 273 kcal/d)	RCT/non-experimental	12 oz/d (~341 mL/d) (SSBs) → 0.39 BMI	Possibly reflected in the source of data		
Manyema et al., 2016[218]	Mean (value not reported)	Equation (Swinburn et al)	94 kJ/d → 1 kg [a]	Unlikely/No	Unlikely	Unlikely
Veerman et al., 2016[216]	Mean by gender, age (71.0, 279.5 g/d)	Equation (Hall et al)	100 kJ/d → ~ 1 kg	Unlikely/No	Unlikely	Unlikely
Lal et al., 2017[24]	Mean by type of SSBs, gender, age (2, 293.6 g/d)	Equation (Hall et al)	100 kJ/d → 1 kg, 100% in 3 yrs	Unlikely/No	Unlikely	Unlikely
Basto-Abreu et al., 2019[211]	Mean by gender, age (36.8, 183.1 kcal/d)	Non-experimental	355 mL/d (soft drink) → 1.0 kg, in 2 yrs	Possibly reflected in the source of data		
Long et al., 2019[212]	Mean varied by gender, age reported (2.7, 23.9 fl oz/d) [b]	RCT/non-experimental	12 oz/d (~341mL/d) (SSBs) → 0.21 to 0.57 BMI	Possibly reflected in the source of data		
Saxena et al., 2019 (PH)[25]	Mean intake by age, income (0.37, 11 mL/yr)	Equation (Hall et al)	94 kJ/d → 1 kg	Unlikely/No	Unlikely	Unlikely
Saxena et al., 2019 (SA)[2]	Mean by gender, age, income (1.26, 5.10 servings/d)	Equation (Hall et al)	94 kJ/d → 1 kg	Unlikely/No	Unlikely	Unlikely
Wilde et al., 2019[26]	Likely to be based on individual data	Non-experimental	BMI<25: 8 oz/d (~237 mL/d) (SSBs) → 0.1 BMI BMI ≥25: 8 oz/d (~237 mL/d) (SSBs) → 0.23 BMI	Possibly reflected in the source of data		
Lee et al., 2020[27]	Likely to be based on individual data	Non-experimental	1 g (added sugar) → 0.005 BMI (baseline BMI<25) 1 g (added sugar) → 0.011 BMI (baseline BMI ≥25)	Possibly reflected in the source of data		
Kao et al., 2020[213]	Mean by type of SSBs, gender, age, income (6.86, 518.65 mL/yr)	Equation (Swinburn et al)	94 kJ/d of energy intake → 1 kg in weight, within 1 yr	Unlikely/No	Unlikely	Unlikely

Abbreviations: BMI = body mass index; d = day, fl oz = fluid ounce; g = gram; kcal = kilocalorie, kg = kilogram; kJ = kilojoules; mL = millilitre; N/A = not applicable; PH = The Philippines; RCT = randomised controlled trial; SA = South Africa; SSBs = sugar-sweetened beverages; yr(s) =year(s)

Note: 'Unlikely' indicates that factor was unlikely to be considered in the model or that it could not be determined; [a] Authors mentioned that weight loss ceases when energy intake once again reaches equilibrium with energy expenditures at a lower body weight; [b] Unclear whether the model was based on individual data or mean.

Effectiveness

A summary of key evidence for the effectiveness of SSB taxes is presented in Table 3.5. Of the 14 studies, 13 (13/14; 93%)[2,24-27,212-218] used own-price elasticity of demand of SSBs as a measure of effectiveness of the taxes. Price elasticity of demand is commonly used by economists to understand how a product's supply and demand changes, as the price of the product changes[24]. Of the 13 studies, six[27,212,214,215,217,218] sourced data from published meta-analyses, six were based on a single non-experimental study[2,24-26,213,216] and one used survey data to estimate price elasticity of demand[53]. The published meta-analyses included three[54,223,224] that were based on non-experimental studies and a fourth[225] that was based on experimental and non-experimental studies. For the included studies from high-income countries (9/9; 100%)[24,26,27,212-217], data for own-price elasticity of demand were based on their own jurisdiction. However, this was not the case for evaluations from lower income countries where such estimates were based on data from another lower income country[2,25,218] suggesting a lack of local data in this setting. The mean values of the own-price elasticity of demand ranged from -0.63 in an Australian study by Veerman et al., 2016[216] to -1.40 in a US study by Basu et al., 2013[53].

The current review also examined whether unfavourable substitution of untaxed goods such as unhealthy high-energy dense foods was addressed in the studies. This can be assessed using cross-price elasticity of demand (i.e., the extent to which changes in the price of one product are likely to alter the consumption of other similar (or substitute) products[196]). Surprisingly, most of the studies using own-price elasticity of demand did not explicitly consider the impact of cross-price elasticity of demand in their base case analysis (9/13; 69%)[2,25-27,212,214-217] (although it was included in a scenario analysis in two studies[214,215]). Nevertheless, most studies provided a justification for the exclusion of the cross-price, including: a lack of evidence[2,25,217], that the proposed substitution effect was judged to have a small impact on weight outcome[26], it was already recognised in their risk model[27], or no cross-price effect was assumed[216]. For example, Lee et al., 2020 argued that a risk model for SSBs was based on long-term prospective studies that implicitly account for average dietary complements or substitutes to SSBs[27].

Most of the included studies did not report the persistence of the effectiveness applied in their models (10/13, 77%)[2,24-27,53,212,215-218] while two assumed that the effectiveness of the SSB tax remains constant throughout the defined time horizon[211,213]. One study assumed reformulation of the product toward lower sugar content to reflect the evaluated tier-based and sugar content-based taxes[27].

Table 3.5: Evidence used for the effectiveness of SSB taxes in the included studies.

Study	Effectiveness measure	Data source	Study setting vs source of data	Value of effect	Substitution effect [a]	Effect duration
Wang et al., 2012[217]	PED	Meta-analysis of non-experimental (Andreyeva et al 2010)	US/US	-0.8	No	NS
Basu et al., 2013[53]	PED	Estimated based on non-experimental data	US/US	-1.40 (SNAP) -1.00 (Non-SNAP)	Yes (e.g. juice)	NS
Mekonnen et al., 2013[215]	PED	Meta-analysis of non-experimental (Andreyeva et al., 2010)	US/US	-0.79 to – 1.00 [b]	No (juice and milk in scenario analysis)	NS
Long et al., 2015[214]	PED	Meta-analysis of non-experimental (Powell et al., 2013)	US/US	-1.22	No (e.g. juice, provided as scenario analysis)	2 years
Manyema et al., 2016[218]	PED	Meta-analysis of non-experimental (Escobar et al., 2013)	South Africa/meta-analysis of multi-countries	-1.30	Yes (e.g. juice)	NS
Veerman et al., 2016[216]	PED	Non-experimental (Sharma et al., 2014)	Australia/Australia	-0.63	N/A [c]	NS
Lal et al., 2017[24]	PED	Non-experimental (Sharma et al., 2014)	Australia/Australia	-0.15 (juice, SES Q1) to -2.3 (cordial, SES Q1)	Yes (e.g. coffee)	NS
Basto-Abreu et al., 2019[211]	Rate of decrease in purchase	Non-experimental (Colchero et al., 2017)	Mexico/Mexico	7.6% annually	No	= time horizon
Long et al., 2019[212]	PED	Meta-analysis of non-experimental (Powell et al., 2013)	US/US	-1.22	No	NS
Saxena et al., 2019 (PH)[25]	PED	Non-experimental (Colchero et al., 2015)	PH/Mexico	-0.97 (Q5 inc) to -1.12 (Q1 inc)	No	NS
Saxena et al., 2019 (SA)[2]	PED	Non-experimental (Colchero et al., 2015)	South Africa/Mexico	-0.98 (Q5 inc) to -1.26 (Q1 inc)	No	NS
Wilde et al., 2019[26]	PED	Non-experimental (Wada et al., 2015)	US/US	-0.66	NA	NS
Lee et al., 2020[27]	PED, Reformulation [e]	Meta-analysis of experimental/non-experimental (Afshin et al., 2017)	US/US	-0.67	NA	NS
Kao et al., 2020[213]	PED	Non-experimental (Lundy 2015)	Canada/Canada	-0.89 (Q5 inc) to -0.91 (Q1 inc)	Yes (diet, plain milk)	= time horizon

Abbreviations: inc = income; NS = not stated; PED = price elasticity of demand; PH = Philippines; Q = quintile; SA = South Africa; SES = socioeconomic status; SNAP = Supplemental Nutrition Assistance Program; US = United States

Note: [a] Switching to other weight-unhealthy goods e.g. juice. Substitution effect is most often represented by cross-price elasticity of demand; [b] Unclear varied by which factors; [c] Authors justified that no such effect in the studied setting; [e] The study assumed that, over 10 years, half of SSBs in the highest tax rate (tier 3) would be reformulated to the next lowest tax rate (tier 2), and half of SSBs in the middle tax tier (tier 2) would be reformulated to the lowest tier (no tax). For the sugar content tax, SSBs would be reformulated to reduce overall sugar content by 25% gradually over 10 years.

Outcomes

A summary of outcomes is presented in Table 3.6. Outcomes including QALYs, disability-adjusted life years (DALYs) and health-adjusted life years (HALYs) were used in most studies (10/14;

71%)[24,26,27,53,211-214,216,218]. Specific health outcomes, such as deaths averted (3/14; 21%)[2,25,217] and SSBs-related diseases averted (1/14; 7%)[215] were less commonly reported. In general, non-health outcomes were not considered. More than half of the studies (8/14; 57%)[2,24,25,27,53,214,216,217] estimated the revenue gained from SSB taxes, which was assumed to be a transfer payment in most of the studies. The exception was the study by Basu et al., 2013 in which the authors included the tax revenue as cost-saving[53].

Most of the studies (10/14; 71%)[24,25,53,211-214,216-218] reported body weight outcomes following implementation of a tax, either as a decrease in mean change in BMI[25,53,212-214,216,218], mean change in weight[216,217], or a decrease in the prevalence of obesity[211-214,216-218]. The reduction in obesity ranged from 0.21% [211] to 3.80% [218]. The reduction in mean weight ranged from 0.23 kg [214] to 1.33 kg [53]. The two studies using direct evidence for weight outcome and SSB consumption reported mean reductions of ~0.23 and 0.49 kg[212,214]. Studies using the energy balance equation typically reported a larger change in weight reduction per capita (1.33 kg in Basu et al., 2013[53], 1.10 kg (aged 20 – 24 years) in Lal et al., 2017[24], 1.04 kg (females aged 20 -24 years in third income quintile) in Saxena et al., 2019[25], and 0.95 kg (males in first income quintile) Kao et al., 2020[213]). However, two further studies using energy balance equation reported relatively low weight change of 0.41 kg[217] and 0.49-0.55 kg[216]. These lower values could be due to the application of the caloric compensation effect and relatively low own-price elasticity of demand in Wang et al., 2012[217], and the low own-price elasticity of demand in Veerman et al., 2016[216].

Table 3.6: Type of outcomes in the included studies and their results

Study	Mean reduction in BMI (kg/m^2)	Mean reduction in weight (kg)	Reduction in prevalence of obesity (cases, %)	Major outcomes [b]	Non-health outcomes [a]
Wang et al., 2012[217]	NR	0.41 (reported as 0.90 pound)	867,000, 1.5%	↓26,000 death	$13 billion/yr (tax revenue)
Basu et al., 2013[53]	0.46	1.33 [a]	NR	↑26,000 QALYs	NR [c] (tax revenue)
Mekonnen et al., 2013[215]	NR	NR	NR	↓1.8–3.4% DM ↓0.5–1% CHD ↓0.5–0.9% MI (incidence)	No
Long et al., 2015[214]	0.08 (adult)	0.23 (adult) [a]	0.99% (adults)	↓101,000 DALYs ↑871,000 QALYs	12.5 billion/yr (tax revenue)
Manyema et al., 2016[218]	0.19; F 20-24yrs, 0.17; M 20-24yrs	0.55; F 20-24yrs [a], 0.49; M 20-24yrs [a]	220,000, 3.8% M, 2.4% F	↓550,000 DALYs	No
Veerman et al., 2016[216]	0.10 M, 0.06 F	0.36 M, 0.17 F	2.7% M, and 1.2% F	↑170,000 HALYs	A$400 million/yr (tax revenue)
Lal et al., 2017[24]	NR	0.40 (55-64 yrs) to 1.10 (20-24 yrs) [d]	NR	↑175,300 HALYs	A$642.9 million/yr (tax revenue)
Basto-Abreu et al., 2019[211]	NR	NR	293,900, 0.21%	↓5,840 DALYs ↑55,300 QALYs	No
Long et al., 2019[212]	0.17	0.49 [a]	10,400, 0.82%	↑3,560 QALYs	No
Saxena et al., 2019 (PH)[25]	0.31 M 20-24yrs Q3 inc 0.36 F 20-24yrs Q3 inc	0.90 M 20-24yrs Q3 [a] 1.04 F 20-24yrs Q3 [a]	NR	↓5,913 death	$813 million/yr (tax revenue)
Saxena et al., 2019 (SA)[2]	NR	NR	NR	↓8,000 death	$450 million/yr (tax revenue)
Wilde et al., 2019[26]	NR	NR	NR	↑0.02 QALYs/person	No
Lee et al., 2020[27]	NR	NR	NR	↑2,470,000 QALYs	$80.4 billion (tax revenue)
Kao et al., 2020[213]	0.21 F Q5 inc to 0.33 M Q1 inc	0.61 F Q5 [a] to 0.95 M Q1 [a]	1.18% F Q5 to 1.89% M Q5	↓690,000 DALYs	No

Abbreviations: B = billion; BMI = body mass index; CHD = coronary heart disease; DALYs = disability-adjusted life years; DM = diabetes; F = female; inc = income; HALYs = health-adjusted life years; kg = kilogram; m = metre; M = male; MI = myocardial infarction; NR = not reported; PH = Philippines; Q = quintile; QALYs = quality-adjusted life years; SA = South Africa; US = United States; yr(s) = year(s)
Note: [a] Converted by reviewers from BMI assumed height of 1.7 metres; [b] Most of studies reported more than one outcomes. Major outcome in this review was prioritised as QALY/DALY/HALY > LY > death > cases from diseases averted; [c] The study did not separately report results from tax revenue but included it as a part of the cost-saving results (see Table 3.7); [d] Extracted from figure by reviewers.
Note: [a] most studies did not claim that tax revenue is an outcome of a tax on SSBs.

Costs

A summary of costs in the included studies is presented in Table 3.7. All the studies estimated healthcare costs (stated as medical costs in some studies) (14/14; 100%)[2,24-27,211-218]. Other health related costs include out-of-pocket (OOP) costs (3/14; 21%)[2,24,25] and informal healthcare costs, such as travel costs (2/14; 14%)[26,27]. Most studies estimated non-health costs (9/14; 64%)[2,24,26,27,53,212,214,216] , such as the cost for the administration of tax collection, and the legislative costs associated with passing the tax bill (6/14; 43%)[24,26,27,212,214,216]. Other non-health costs included productivity loss (2/14; 14%)[26,27] and deadweight loss (2/14; 7%)[24,53]. After the implementation of the tax, studies consistently estimated a reduction in healthcare costs. Savings ranged from US$ 82.68 million[212] to US$ 75.24 billion[27] although, given large differences in the size of the study population, comparisons are difficult to make. Intervention costs were minimal, representing 2%[214] to 7%[24] of healthcare costs avoided. Deadweight loss was estimated to be US$ 45.54 million per year by Lal et al., 2017[24], accounting for about 8% of consumer surplus (the difference between the price paid and the value a consumer places on a good) estimated in that study. Deadweight loss was also included by Basu et al., 2013 but the estimate was not clearly reported[53]. Given the high healthcare cost savings and relatively low implementation costs, SSB taxes were found to be cost-saving in all 14 studies.

Table 3.7: Types of costs in the included and results (US dollars in 2021)

Study	Perspectives [a]	Costs (health)		Cost (non-health)		Estimate total costs
		Type	Estimate	Type	Estimate	
Wang et al., 2012[217]	NS	Medical costs	- $19.90 B	NE	N/A	- $19.90 B
Basu et al., 2013[53]	Government	Medical costs	-$0.11 B	Subsidies and taxes costs, deadweight loss	-$15.23 B (subsidies and taxes costs [b]) Unclear for deadweight loss [c]	-$15.34 B
Mekonnen et al., 2013[215]	NS	Direct medical costs	- $374.64 M to - $725.87 M	NE	N/A	- $374.64 M to - $725.87 M
Long et al., 2015[214]	Societal	Healthcare costs	- $26.65 B	Implementation costs (government, industry)	$485.55 M	-$26.20 B
Manyema et al., 2016[218]	Health system	Healthcare costs	- $1.13 B	NE	N/A	- $1.13 B
Veerman et al., 2016[216]	Health system	Healthcare costs	- $504.23 M	Implementation costs (government)	$22.85 M	NR
Lal et al., 2017[24]	Societal	Healthcare costs, OOP	- $1,434.87 M (healthcare costs), -$249.63 M (OOP)	Implementation costs (government, industry), deadweight loss	$99.02 M (implementation costs), $45.54M/yr (deadweight loss)	NR
Basto-Abreu et al., 2019[211]	NS	Direct medical costs	- $103.46 M	NE	N/A	- $103.46 M
Long et al., 2019[212]	NS	Healthcare costs	- $87.48 M	Implementation costs (government, industry)	$4.86 M	- $82.68 M
Saxena et al., 2019 (PH)[25]	NS	Medical costs, OOP	- $19.46 B (medical costs), - $1.15 B (OOP)	NE	N/A	NR
Saxena et al., 2019 (SA)[2]	NS	Medical costs, OOP	- $403 M (medical costs), - $ 261 M (OOP) [d]	Productivity costs	$ 2.32 M/yr	NR
Wilde et al., 2019[26]	Societal	Healthcare costs, informal health care costs	- $51.78 B (total)	Implementation costs (government, industry)	$2.12 B	-$49.66 B
Lee et al., 2020[27]	Societal	Formal healthcare costs, informal healthcare costs	- $57.55 B (formal healthcare costs), -$0.04 (informal healthcare costs)	Implementation costs (government, industry), productivity costs	$1.71 B (implementation costs) -$19.36 B (productivity costs)	- $75.24 B
Kao et al., 2020[213]	Health system	Healthcare costs	- $2.08 B to - $1.81 B	NE	N/A	- $2.08 B to - $1.81 B

Abbreviations: B = billion; M = million; N/A not applicable; NE = not estimated; NS = not stated; OOP = out-of-pocket; PH = Philippines; SA = South Africa; US = United States; yr = year; ZAR = South African rand

Note: Estimate reflects incremental cost of tax policy vs comparator. [a] Broadest perspective was stated in this review if there were more one perspectives in an included studies; [b] As stated in the study, this reduction in costs included increase in tax revenue. [c] the study stated that deadweight loss was 32% of baseline cost of the subsidy scenarios (one scenario in the study); [d] extracted from graph by reviewers.

Equity

A summary of the equity considerations is presented in Table 3.8. Eight of the 14 studies (57%)[2,24-27,213-215] provided equity analyses alongside their economic evaluation. Of these, six[2,24-27,213] had been published within three years prior to the search date. Four studies used proposed approaches to analyse equity. Of these, two used the concentration index (CI) [24,213] which originally emerged within health economics as a tool to measure socioeconomic inequalities in health[226], and two studies used extended cost-effectiveness analysis (ECEA) [2,25], one of the earliest analytical frameworks to incorporate equity into economic evaluations[227]. Of the other four studies, three used subgroup analyses (3/8; 38%)[26,27,215] and one used a qualitative evaluation (1/8; 13%)[214] to investigate equity impacts.

The main equity consideration in all eight studies was related to socioeconomic status (SES) and this was most often classified using five quintiles of SES[2,24,25,213]. Four of the studies [2,24,25,213] detailed approaches used for equity analyses in their methods section.

Equity impacts were investigated by analysing health outcomes by SES after implementation of the tax. For example, four studies included generic health outcomes (QALYs, DALYs, HALYs) in their equity analyses[22,24,26,27,213]. Non-health measures used for equity analysis included tax paid in six studies[2,24-27,213], and OOP payment and catastrophic expenditure averted in two studies. Most of the studies used specific consumption (7/8; 88%)[2,24-27,213,215] and effectiveness (6/8; 75%)[2,24-27,213] data according to their equity group of interest.

Of the eight studies that included equity, the majority (6/8; 75%)[24,26,27,213-215] reported that the SSB tax reduced inequality. For example, Lal et al., 2017[24] and Kao et al., 2020[213] found that the SSB tax is more beneficial with respect to health impacts to individuals in lower SES groups, compared to individuals in upper SES groups. However, the tax was reported to be regressive with a higher burden on the lower SES in most studies (5/8; 63%)[24,26,27,213,214]. Another group of studies did not clearly state whether the tax improves equity[2,25], but their results suggest that the health benefits of the tax favour those of higher SES groups while the tax burden will be greater in the higher SES group, indicating the tax is progressive in nature. The finding that an SSB tax impacts those of higher SES groups suggests that SSB consumption and obesity is more prevalent in the high SES groups as was the case in the Philippines, Saxena et al., 2019 (PH)[25]

Table 3.8: Equity analyses in the included studies

Authors	Setting	Key feature of methods	Equity group of interest	Method explained	Tool	Key measurement	Decision rule	Use of equity-informative data	Suggest that tax improves equity?	…and how	Tax burden
Mekonnen et al., 2013[215]	US (CA)	Subgroup analysis	SES (low vs full population)	No	Subgroup analysis	Related-disease event, death	NS	Likely (consumption)	Yes	Lower SES gained more outcomes	No analysis
Long et al., 2015[214]	US	Qualitative evaluation	SES	No	Group discussion	N/A	NS	N/A	Likely to favour the tax	'substantial health benefits accrue to low-income consumers'	Regressive
Lal et al., 2017[24]	Australia	Concentration index	SES (SES Indexes for Areas -5 levels)	Yes	Concentration index	Health gained including HALY (OOP healthcare costs saved, tax paid)	Yes	Yes (consumption, effectiveness)	Yes	CI < 0 (HALY gained)	Regressive
Saxena et al., 2019 (PH)[25]	Philippines	ECEA	SES (income, 5 levels)	Yes/partly [a]	ECEA	Disease event, death, OOP, cases catastrophic expenditure averted, tax paid (revenues)	NS	Yes (consumption, effectiveness)	Did not say	Unlike to improve the inequity in term of health [b]	Progressive
Saxena et al., 2019 (SA)[2]	South Africa	ECEA	SES (income – 5 levels)	Yes/partly [a]	ECEA	Death, cases of poverty averted, cases catastrophic expenditure averted, tax paid (revenues)	NS	Yes (consumption, effectiveness)	Did not say/unclear	Unlike to improve the inequity in term of health [b]	More tax burden in higher SES [b]
Wilde et al., 2019[26]	US	Subgroup analysis	SES (reflected in 6 consumer categories)	No	Subgroup analysis	Health gained including QALY, tax paid	NS	Yes (consumption per microsimulation, effectiveness)	Yes	Health gains and overall health care cost reductions of the lower income were higher.	Regressive [b]
Lee et al., 2020[27]	US	Subgroup analysis	SES (income-2 levels and race/ethnicity)	No	Subgroup analysis	Health gained including QALY, tax paid	NS	Yes (consumption, effectiveness)	Yes	Lower SES gained greater health and economic benefits.	Regressive
Kao et al., 2020[213]	Canada	Concentration index	SES (income – 5 levels)	Yes	Concentration index	Health gained including DALY, tax paid	No	Yes (consumption, effectiveness)	Yes	CI < 0 (DALY)	Regressive

Abbreviations; CA = California; CI = concentration index; DALYs = disability-adjusted life years; DCEA = extended cost-effectiveness analysis; HALYs = health-adjusted life years; N/A = not applicable; NS = not stated; OOP = out-of-pocket; PH = Philippines; QALYs = quality-adjusted life years; SA = South Africa; SES = socioeconomic status; US = United States

Note: [a] ECEA is a method specific to equity analysis in economic evaluations; [b] Reviewers' judgement based on results presented.

3.7 Discussion

This review identified 14 economic evaluations examining the impact of SSBs. Collectively, these evaluations demonstrated that SSB taxes are moderately effective at reducing obesity. SSB taxes were also found to be cost saving and to have potential in addressing health inequity. However, the review identified several common methodological issues that could introduce uncertainty to the evaluations. These issues related primarily to the approaches used to estimate the effect of SSB consumption and the impact of SSB taxes on body weight. The review found only limited consideration of non-health consequences both in term of costs and outcomes in the evaluations. Most of the evaluations included equity analyses but they typically used informal approaches to inform equity outcomes of the taxes.

The review illustrates the challenges inherent in estimating the effects of public health interventions. The relationship and effect size between SSB consumption and weight is the most important feature in the models, given that the evaluations rely on linking the SSB tax to reduced SSB consumption and improvement in the modelled outcome. However, given that the cause of obesity is complex[228], isolating the impact of SSBs on weight is not straightforward. This review found that the economic evaluations of SSB taxes simplify the computational approach to estimate weight affected due to SSB consumption. In most studies, there is an underlying assumption that *any* SSB consumption is considered 'excess' consumption, and should therefore be prevented. This is more obvious for those evaluations using energy balance equations to equate calorie intake from SSB consumption to weight gain. The energy balance equations are designed to predict weight change from overall daily change in energy consumed, rather than from a specific source of energy change from a single product [220]. To estimate weight changes from a specific source of energy, such as SSBs, requires the knowledge (or assumption) that other sources of dietary energy are held constant (or their impact on weight gain is known). This assumption may be optimistic based on the evidence that suggests a caloric compensation effect whereby individuals adjust for excess calories consumed on one food by reducing consumption of other foods[109,229-231]. Applying the energy balance equation without adjusting for a caloric compensation effect may, therefore, overestimate the effect of SSBs on weight. Indeed, in this review, the studies that used the energy balance equation predicted a larger weight reduction when compared to the studies that used direct evidence. An additional complication is the fact that people who consume SSBs often have other unhealthy behaviours, such as reduced physical activity and an unhealthy diet[107]. Hence, it is reasonable to question how much SSBs contribute to weight gain, compared to these other factors. Unfortunately, these factors were not considered in the studies included in this review.

Effectiveness of the SSB tax was typically measured in terms of its ability to reduce SSB consumption, which was then modelled to estimate weight reduction and gain in long-term health outcome. Effectiveness was mostly described as price elasticity of demand, usually derived from non-experimental studies. There is limited evidence regarding persistence of tax effects given that observations to date have had a follow-up period after implementation of the tax of less than 2 years[195]. Further research is required on the long term effects of the SSB tax[232]. Using interrupted time series analysis or difference-in-difference techniques, these studies play an important role in the evaluation of public health interventions, rather than RCT[21].

A further technical issue identified in this review was that cross-price elasticity of demand was not explicitly considered by most of the included studies. This is consistent with a previous review that noted cross-price elasticity data were typically not applied in evaluations of public health intervention[196]. While switching to a healthier option of an untaxed good, such as bottled water, is a favourable outcome from an SSB tax policy, in theory, SSB consumers may opt to consume other unhealthy energy-dense foods that avoid the SSB tax, such as juice or sweet snack[195,197,198]. Some studies may be justified in excluding cross-price elasticity of demand because they used direct evidence of weight change from SSBs in which substitution effect from other foods was already incorporated in the risk estimate (e.g. Wilde et al., 2019[26]). For other studies, cross-price elasticity might have been omitted due to a lack of robust evidence for how SSB consumers modified their consumption in response to a SSB tax[119].

A further uncertainty is whether lower SES groups are more responsive to changes in price due to the regressive nature of an SSB tax. However, there is recent evidence suggesting that people in different SES groups act differently in response to price change, with some evidence suggesting that those in higher SES groups might be more sensitive to a change in price of SSBs[195]. The explanation for these apparent differences in price sensitivity is unclear. There is some evidence that signalling that an SSB price increase resulted from a tax can reduce demand for SSBs beyond a price increase in general[233]. While it is possible that more highly educated individuals (higher SES) may be more sensitive to price signalling than those in lower SES groups, there is some evidence against such a difference in signalling effects[233]. Apparent differences in price elasticity related to SES may be confounded by the level of SSB consumption at baseline, which was not usually accounted for in studies examining the price elasticity of demand; although several studies indicate that those with higher levels of consumption SSBs were not as responsive to a change in the price of SSBs compared to those with moderate of lower levels of SSB consumption[232,234-236]. This price insensitivity in those with higher consumption of SSBs may indicate that SSB consumption might have an addictive element relating to behavioural factors. This accords with a previous review suggesting that behavioural factors matter in evaluation of public health interventions[193].

There has been concern that there is inadequate information on the predictive quality and validity of obesity models[188,191]. The estimated weight changes in models were unstable to be validated with external empirical data. For example, Basu et al., 2013 estimated mean reduction in BMI after SSB taxes of 0.46 after 10 years, which might be proportionally large compared to a real change in BMI in the US adult population for a similar timeframe (increase in BMI of around 0.80 during 2005-2014)[174]. This highlights that more attention is still necessary for validation of obesity model.

There has been an encouraging trend to quantify more intersectional consequences of public health interventions[22,23]. However, how to properly address such impacts is an area of ongoing research[193] with several issues for debate[200,237]. This review found that the use of CUA or health outcome such as QALY and DALY was common in the evaluations of a tax on SSBs and this finding is consistent with other recent reviews examining public health interventions in alcohol and tobacco control[169,238]. The use of health outcome measures such as QALY has become dominant in health research in recent years. This approach is based on the principle aiming to maximise health of the population. CUA offers a practical method in measuring health outcomes. However, some researchers have critiqued CUA, arguing that it is limited in not valuing the broader consequence of interventions to society[239].

As an alternative to CUA, the cost benefit analysis (CBA) might be applicable given the intervention is a tax on SSBs, however, it was not used in any studies. CBA aims to maximise welfare of the population, often measured through a willingness-to-pay approach (WTP) and might help operationalise non-health outcomes into the analysis[199,200]. Indeed, the NICE guidelines, which mainly advocate the use of CUA, suggest that *"a CBA is sometimes the most appropriate method of analysis for public health guidance"*[240].

However, CBA has a number of shortcomings. In particular, WTP allows individuals to value their health differently from each other, often resulting in social values for an intervention that exceed what governments are willing to pay, thus becoming less relevant to policy making in health[199,239]. Valuing health and non-health impacts in terms of money could also lead to ethical issues[199,240]. Furthermore, using WTP to achieve equity objectives is questionable given that it is influenced by income and represents demand rather than need[240]. Researchers therefore should be aware that CBA comes with both advantages and disadvantages and there is no universal rule when to adopt it as a form of evaluation.

In term of costs, public health interventions often spill over into other sectors of society and addressing the cost impacts outside of the health sector is justified in economic evaluations of SSB taxes[193,241]. This review found that some non-health costs were addressed in most studies. However, it is questionable whether the analyses of non-health costs are comprehensive enough with estimated non-health costs being small relative to estimated healthcare costs. Some costs that would make the tax less favourable such as consumer welfare forgone, were estimated in only a few studies[24,53]. However, one might argue that the pleasure of drinking SSBs may need to be valued in terms of the impact of pleasure loss due to lower consumption. This could be valued in terms of a consumer surplus, measuring whether an individual would be willing to pay more for the product than the actual price they paid[242-244]. Another view is that consumer welfare effects should not be considered. For example, one study explicitly questioned the inclusion of consumer welfare forgone: "*We do not believe that current consumer decisions regarding SSB intake meet the assumptions underlying a potential lost consumer surplus analysis of perfectly rational decision makers operating with full information*"[214]. Others have argued that welfare loss is a more important consideration if it occurs unequally across the population[232]. Nevertheless, estimation of such broad costs would fit better within a cost-benefit framework, but this was not adopted in any of the included studies.

Another issue is that costs to industry were not as well captured in the analyses. While these were included in all studies adopting a societal perspective, they appeared incomplete. For example, only accountant salaries were included in the implementation costs in Lal et al 2017[24]. It is likely that there would be other costs to industry due to changes in business activities arising from the imposition of an SSB tax, e.g., costs to reformulate an SSB with a lower sugar concentration, package relabelling and marketing costs[203]. Including these costs is crucial if the societal perspective is to be considered.

Equity is one of the most promoted topics in health economics of public health over the past decade[22,204]. In response to this, methodological research to incorporate equity into economic evaluation has gained attention among researchers[28]. Our review found a high proportion of economic evaluations which included equity analyses. This is in line with previous reviews which indicate a growing trend for equity analyses to be included in economic evaluations of public health interventions[245], including within the assessment of health taxes[163].

The current review found that an SSB tax is largely considered to have a positive impact on equity given that there were greater absolute distributional benefits identified in the health of the poor. This is somewhat expected given the concentration of the problem (obesity and SSB overconsumption) in that population. Another point of view is that equity analysis in economic evaluations is likely to be performed in health conditions and interventions where results were expected to favour equity, i.e. those most affecting the poor[204]. Our review suggests that, in line with previous reviews[163,245], evaluations of equity focused on the analysis of the impact on health outcomes among socioeconomic groups. There are differences in approaches used to combine equity with economic evaluations from the included studies, but these might be roughly classified into two groups; those using informal approaches for equity analysis such as subgroup analysis, and those using formal approaches specifically developed to deal with an equity issue in health economic evaluation (such as the ECEA). The types of equity analyses used were dominated by informal approaches, such as subgroup analysis, which are a quick and convenient way to summarise results into equity-informative groups of interest.

Equity analysis in economic evaluations is particularly complex, with methodological challenges in properly incorporating a concept of fairness into efficiency analysis and regarding appropriate methods to measure health inequality (inequity)[246]. Today, two emerging methods devoted to the inclusion of equity analyses into economic evaluations are ECEA and distributional cost-effectiveness analysis (DCEA)[204]. These should be considered for those researchers aiming to assess equity implications as part of economic evaluations.

Equity is a value-laden concept, therefore, subjective interpretation of results is unavoidable[247 248]. This review found two patterns associated with equity results. One group of studies[24,27,213,214] found that the tax favoured the health of the poor while being regressive. Those studies often justified the regressivity of the tax by highlighting that the tax will improve the health of the poor more. In this case, the studies appear to interpret a favourable distribution of health benefit that outweighs the unfavourable distribution of the tax. The other group of studies reported results indicating that the outcome of interest was greater in the rich while the tax was potentially progressive[2,25]. The progressive nature of the tax in these studies could relate to the concentration of the problem, including SSB overconsumption and prevalence of obesity in lower SES groups that were relatively low compared with higher SES groups. The authors of these studies appear to have judged that an unfavourable distribution of outcome (burden of tax) outweighs a favourable distribution of health benefit. To avoid selectively reporting equity results, the pre-specified parameters of the preferred health equity (equality) outcomes for the intervention under investigation should be clearly stated prior to conducting the desired analyses. It is important to note that this review did not aim to critique whether such interpretations of equity findings are appropriate or inappropriate, but rather to demonstrate that the results of equity analyses are prone to interpretation.

Equity is about distribution of resources. As such, distributional data rather than average values are required to make an analysis informative. The current review suggests that better disaggregated data are needed to enable more detailed investigation of the effects of SSB taxes as they affect different SSB consumers (e.g. by SES). In addition, to better reflect the impact of taxes on equity, more complex modelling techniques, such as microsimulation, could be employed[204], allowing individual results to be flexibly aggregated according to SES group.

Strengths and Limitations

This review provides a timely assessment for economic evaluations of one of the most currently popular policies to improve healthy food consumption – SSB taxes. Rather than adopting available checklists that offer general assessment criteria for the quality of economic evaluations[249], the framework for quality assessment in this review was strengthened by using assessment criteria that comprehensively cover critical areas of challenges for economic evaluations of public health interventions, including key issues specific to evidence regarding SSB tax and obesity. This review suggests several important issues about modelling techniques for SSBs and obesity that have not been explored to date, such as the use of energy balance equation. Several findings in this review are generalisable to other studies, outside of economic evaluations, which model the effect of SSBs on obesity[93,250-253], notably its findings in relation to the estimation of the effect size of SSBs on obesity. This review also contributes to the evaluation of the use of equity in economic evaluation.

This review was restricted to the evaluation of obesity outcomes rather than other health outcomes related to obesity such as diabetes or heart diseases. Thus, it did not investigate the qualitative aspects of those mediated estimates (e.g., without BMI as a mediator, SSBs may have a direct effect to diabetes). Some of the included studies did not have obesity as the primary outcome but had obesity outcomes, such as BMI, as a mediator to other related disease. The results from this review may not be fully generalisable to economic evaluations of SSB tax focusing on other health problems such as dental disease or cancer as the effect of SSB consumption might have a direct link to these diseases not via weight outcome. And while we have undertaken an assessment of equity in economic evaluation in this review, there is a need for the development of a formal framework for the assessment of evidence presented in this field.

3.8 Conclusion

There are several methodological issues in the existing economic evaluations of a tax on SSBs. The primary one relates to the techniques used to quantify the effects. This requires more appreciation for related evidence including consideration of compensation and substitution effects. Most studies focus on the importance of health outcomes and health costs when evaluating the impact of the tax, with broader impacts of the tax being less well understood. Equity analyses were based on informal approaches of aggregating and comparing health outcomes according to the equity group of interest. The translation of theoretical approaches for practical inclusion of equity into economic evaluations is needed for future evaluations.

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Chapter 4: Socioeconomic Inequality in Obesity in Thailand

4.1 Preamble

As highlighted by Chapter 3, incorporating an assessment of equity impacts into economic evaluations is becoming essential, especially for public health interventions like SSB taxes. This emphasises the importance of a thorough understanding of health inequality within the population. However, this remains inadequately explored in Thailand. Given that a tax on SSBs in Thailand was proposed to address the rise in obesity rates, this second study uses obesity as an indicator of poor health and investigates its distribution across socioeconomic domains. The study employed the concentration index, a specific approach to measure socioeconomic-based health inequality. It further employed the decomposition analysis to explore the potential role of various factors, including SSB consumption, in influencing this inequality in Thailand. These approaches are widely accepted for examining health inequality, yet have never been applied in the context of obesity in Thailand.

This chapter is presented in the format of a manuscript currently under review at *International Journal of Obesity*. The authorship roles are as follows:

- Conceptualisation: Kittiphong Thiboonboon (KT), Richard De Abreu Lourenco (RL), and Stephen Goodall (SG).
- Study design: KT.
- Data collection: KT.
- Data analysis: KT.
- Writing - original draft: KT.
- Writing - review and editing: Jody Church (JC), RL, and SG.
- Supervision: JC, RL, and SG.
- Validation: KT, JC, RL, and SG.

4.2 Manuscript's Details

Title: Exploring Socioeconomic Inequality in Obesity in Thailand: A Decomposition Analysis

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4.3 Highlights

- A large, nationally representative dataset was used to examine socioeconomic inequality in obesity in Thailand.
- For men, obesity was concentrated among those with higher socioeconomic status, while for women, it was more prevalent among those with lower socioeconomic status.
- There were variations in socioeconomic inequality in obesity across different regions of the country.
- Factors such as education and health problems account for a significant portion of these inequalities.
- Policies should prioritise measures that address both obesity and poverty, especially in women confronting health problems.

4.4 Abstract

Background Understanding differences in obesity prevalence across socioeconomic groups can assist in integrating equity into evidence-based health planning in Thailand. This study aims to examine socioeconomic inequality in obesity in Thailand.

Methods The study analysed data from Thailand's 2021 Health Behaviour of Population Survey (HBS), with 19,891 men and 29,182 women aged 25–59 years. Body mass index (BMI) was used to identify individuals with obesity using three approaches: obesity, BMI ≥30 kg/m^2; overweight or obesity, ≥25 kg/m^2; or using BMI as a continuous variable. A concentration index (CI) was applied to assess inequality in obesity according to socioeconomic status measured by equivalised household income. A decomposition analysis studied factors contributing to this inequality.

Results For men, the CI ranged from 0.009 using the continuous BMI measure to 0.104 using the overweight or obesity measure. These positive values suggest that obesity is concentrated among men of higher socioeconomic status. Conversely, for women, the CI ranged from -0.007 using the continuous BMI measure to -0.072 using the overweight or obesity measure. The negative values suggest that obesity is concentrated among women of lower socioeconomic status. CI values vary by region, ranging from 0.256 (obesity concentrated among higher socioeconomic status) in the North for men to -0.128 (obesity concentrated among lower socioeconomic status) in the Central region for women. In men, higher education is associated with obesity and is a primary driver of the inequality in obesity, explaining 28.2% to 52.8% of the inequality. In women, lower education is associated with obesity, explaining 30.9% to 41.5% of the inequality. Comorbid health conditions are more prevalent in women of lower socioeconomic status, explaining 12.7% to 28.4% of the inequality. Unhealthy behaviours such as frequent consumption of sugar-sweetened beverages explained a small proportion of the inequality (e.g., 3.1% in men).

Conclusion Socioeconomic inequality in obesity exists in Thailand. Policymakers should prioritise measures that simultaneously address obesity and income to help those women who experience the dual burden of health problems and poverty.

4.5 Introduction

Obesity is a major global public health issue. According to the World Health Organization (WHO), there were over 650 million adults living with obesity worldwide in 2016[58], and the number is expected to reach 1 billion by 2030[254]. Studies have demonstrated that individuals with obesity have a 1.3 times higher risk of premature mortality compared to those with normal weight[66,255]. This is attributed to the increased prevalence of non-communicable diseases among individuals with obesity, such as type 2 diabetes, cardiovascular disease, chronic kidney disease, certain types of cancer, and musculoskeletal disorders[256,257]. Individuals with obesity have a four times higher risk of developing severe COVID-19 related comorbidity[67].

While the growth rate of obesity has slowed in developed countries over the past decade, it has increased in developing countries as their economies advance[258]. Thailand is no exception. Economic progression alongside shifts in nutrition over several years has contributed to an increase in the prevalence of obesity in the country[73-75]. According to the Food Balance Sheet issued by the United Nations, per capita daily caloric intake in Thailand increased by 25% over the past 30 years[76]. In light of this, according to a survey in 2019, more than half of the Thai population has been considered as having excess weight compared to just one-fifth of the population 30 years ago[6,68]. Among Southeast Asian countries, Thailand has the highest prevalence of people with overweight and obesity, second only to Malaysia[68].

Obesity has serious economic implications for Thailand. The country's obesity-related costs, such as medical expenses and costs due to premature death, rose from 0.13% of its GDP in 2009 to 1.3% in 2019[7,80]. Moreover, it is projected that Thailand will face the highest economic burden from obesity compared to seven other countries with varying income levels, with obesity-related costs reaching 4.9% of its GDP by 2060, surpassing the projected figures for the same year of high-income countries like Australia (2.3%) and Spain (2.4%)[7].

Historically, obesity is used as a surrogate marker of social inequalities in the developed world, as it is more prevalent among lower socioeconomically vulnerable populations[30,149]. However, inequalities in obesity have become apparent across and within countries, regardless of their income level, as it becomes more prevalent among lower socioeconomic groups in less developed countries[16]. According to a report from the World Bank, the poorest women in low- and middle-income countries (LMICs) such as Brazil, China, Indonesia, and Sub-Saharan Africa have experienced a faster increase in rates of obesity[64]. In Thailand, the growth in overweight and obesity in those who are vulnerable (e.g., lower socioeconomic status) would be a significant concern to policymakers, and addressing these health inequities remains a challenge[145,147].

Integrating health equity into evidence-based health planning is an important goal that requires data on health inequalities. According to the WHO, socioeconomic factor is one of the common policy-relevant equity stratifiers used to assess health inequality (other such as gender and race)[29]. Within the literature, obesity is among the most often used as an indicator of health inequality in the population[148]. In Thailand, some research has shed light on the correlation between obesity and socioeconomic factors [35-41]. However, these studies often fall short in fully highlighting the extent of socioeconomic inequality related to obesity. The methods used in these studies, primarily regression-based analyses, are often considered less appropriate and not a specific approach for addressing health inequality[31,151]. Specifically, they have been known to be less sensitive when examining health inequality within the socioeconomic domain[31].

In Thailand, there is a need for analyses that can provide a comprehensive understanding of the socioeconomic factors behind the growth rate of obesity, as well as factors contributing to socioeconomic inequality in obesity across different population groups. This knowledge is crucial for the successful implementation of health and food policies to control its emergence and reduce effects on welfare. For example, due to a substantial proportion of the population consuming sugar-sweetened beverages (SSB)[116] and the link between overconsumption of SSB and obesity[259], Thailand has prioritised public health policies that impose higher taxes on SSB to reduce their consumption and thereby address health inequality. A deeper understanding of the interplay between SSB overconsumption, socioeconomic status and obesity could enhance policymaking. Therefore, this study aims to examine socioeconomic inequality in obesity in Thailand and explore the factors that contribute to this inequality.

4.6 Methods

Existing literature

A focused review of the literature shows that there have been some investigations of the relationship between obesity and its socioeconomic determinants in Thailand[35-41]. The earliest study was conducted in 1994 but did not identify a pattern between obesity and socioeconomic status[35]. However, in 2010, a pivotal study revealed a shift in the pattern of obesity in Thailand towards the pattern commonly seen in higher-income countries, indicating an inverse association between socioeconomic status and obesity in women, based on 2005 data[40]. This finding was later confirmed by another study using data up to 2013, which also suggested that Thai men exhibited a pattern of obesity similar to that of lower-income countries, where obesity was positively correlated with socioeconomic status in men[41]. However, there were limitations in the existing studies conducted in Thailand. None of these studies used the specific method recommended for measuring socioeconomic inequality[35-41]. Besides, some studies used obesity classifications that limited the comparison of their results with international studies[37-40].

The concentration index (CI) is a method specifically developed to measure health inequality according to the socioeconomic domains, with a distinct advantage of high sensitivity in capturing health inequalities within these domains, offering more precision than other popular methods like regression-based analysis[260]. It has been widely used to investigate the link between socioeconomic status and obesity[31-34,153-160]. The first application of the CI approach to obesity was in a study published in 2004 from the USA. Using data for 1988–1994, researchers found a negative relationship between socioeconomic status and obesity in the USA, with a stronger correlation observed in women and the middle-aged group (aged 41–49 years)[31]. Later in 2008, similar research examined inequality in obesity across high-income European countries, and found a negative relationship between socioeconomic status and obesity, particularly prominent in women and the middle-aged group[161]. In contrast, studies from LMICs such as South Africa[155], Indonesia[33], and Iran[156] consistently suggested positive relationships for both genders. In a study from Malaysia, a positive relationship was found in men, but it was negative for women[160]. In Brazil, a positive relationship was also found in men while no inequality was identified for women[158]. Several studies decomposed the CI to gain deeper insight into the impact of factors contributing to inequality, alongside socioeconomic status. For instance, in 2007, a study highlighted the role of education and other demographic factors in contributing to the inequality in obesity in Spain[34]. Similarly, a 2014 decomposition analysis in Canada revealed that inequality in obesity could be explained by various factors, including demographics, immigration, education, drinking habits, and physical activity[32].

Data and Variables

Data

Variables used in this study are summarised in Table 4.1. Data were obtained from the Health Behaviour of Population Survey in 2021 (2021 HBS), conducted by the National Statistics Office in Thailand[57]. This was a nationally representative household survey undertaken between February and May 2021 to collect individual health behaviour data. The study included 19,891 men and 29,182 women, aged 25 to 59, who completed the survey themselves. Proxy responses were excluded due to potential incomplete data, especially the lack of information on physical activity, and the possibility of response bias arising from proxies not accurately capturing or representing the views, behaviours or characteristics of the individuals they are responding for[261]. This approach aimed to maintain data accuracy and mitigate potential distortions in results. The survey collected data on sociodemographic characteristics, weight and height, and various healthy lifestyle behaviours. Population weights are applied in the analysis to adjust for imbalances between the sample and the target population, ensuring more accurate and representative estimates[262]. All statistical analyses were performed using Stata 17 software[263].

Obesity variables

The WHO defines obesity as a medical condition characterised by excessive adiposity to the extent that it can impair health[58]. Body mass index (BMI) is a surrogate marker of adiposity, and has been commonly used in previous similar research[32,33]. BMI is conveniently calculated as weight in kilograms (kg) divided by height in metres squared (m^2). This study used three approaches for the classification of weight status: obesity, defined as having a BMI of 30 kg/m^2 or higher[264]; overweight or obesity, defined as having a BMI of 25 kg/m^2 or higher[264]; and using BMI as a continuous variable (continuous

BMI). By classifying obesity using these three approaches, the study aimed to provide a comprehensive understanding of patterns in obesity[153]. The analysis included underweight individuals (BMI <18.5 kg/m^2) but recognising that being underweight might not be healthier than being obese, the results excluding underweight individuals are provided.

Socioeconomic status variables

Various variables can be used to measure socioeconomic status[265]. In this study, equivalised household income was used to represent the socioeconomic status of an individual. It is calculated using the square root scale method recommended by the Organisation for Economic Co-operation and Development (OECD) of dividing total household income by the square root of household size[266]. Using income at the household level rather than the individual level has been shown to be a more precise measure of socioeconomic status[267], and has been previously used in similar research[31,32,161].

Explanatory variables

To explore the factors linked to obesity and socioeconomic status, an initial literature review was carried out. This investigation examined theoretical frameworks[228] and prior empirical studies[9-31,35] for the aetiology of obesity and to identify risk (or protective) factors associated with obesity. Sociodemographic factors, such as age, marital status, area of residence, and type of job, were included in the analyses[9-31,35]. Behavioural factors such as consumption of SSBs, leisure-time physical activity, and smoking status were included in the analysis. Evidence from meta-analyses suggested that SSB consumption was linked to obesity[96,98]. Smoking might be linked to reduced appetite and decreased weight while the opposite is true for those quitting smoking[268,269]. The study also included the health status of individuals, using the occurrence of non-communicable diseases a person had. Region of residence was controlled for using dummy variables as food culture and economic development are highly heterogeneous across the country[1,270].

Table 4.1: Obesity variables and explanatory variables

Variable	Definition
Dependent variable	
Obesity	1 if BMI ≥ 30, 0 otherwise
Overweight or obesity	1 if BMI ≥ 25, 0 otherwise
BMI	BMI as a continuous variable (weight in kilograms divided by height in metres squared)
Explanatory variables	
Age	Age in years
Income (household equivalised income)	Continuous, total monthly net equivalised household income
Education	Total years of education
Marital status	1 if ever married, 0 otherwise
Area of residence	1 if living in an urban area, 0 otherwise
Work-related physical activity	1 if not involved with daily tasks that do not require considerable physical effort, excluding exercise, 0 otherwise
Main meal	Number of main meals per day
SSBs	Number of servings of sugar-sweetened beverages (SSBs) per month
Fat intake	Number of days per month consuming foods that are high in fat
Snacks	Number of days per month consuming snacks
Source of food	1 if the most frequent source of food is non-home cooked, 0 otherwise
Food label consideration	1 if never seen or unsure, 2 seen but no impact, 0 seen and has impact
Leisure-time physical activity	Number of days per month partaking in high or moderate physical leisure activity
Smoking status	1 if a current smoker, 2 if ex-smoker, 0 otherwise
Alcohol drinking status	1 if at least 1 to 2 days per week of heavy drinking in past 12 months, 0 otherwise
Health problem	1 if having any non-communicable disease (high blood pressure, diabetes/high blood sugar, high blood lipids/high cholesterol, stroke/paralysis, heart disease/coronary artery disease, chronic lung disease/emphysema/asthma, cancer/tumour, depression, and osteoarthritis/degenerative arthritis), 0 otherwise
Controlled variables	
Region of residence	
Bangkok	1 if living in Bangkok, 0 otherwise
Central	1 if living in the Central region, 0 otherwise
North	1 if living in the North region, 0 otherwise
Northeast	1 if living in the Northeast region, 0 otherwise
South	Base level (excluded)

BMI = body mass index; SSBs = sugar-sweetened beverages

Statistical analysis

Concentration index

The CI was first developed by researchers including Wagstaff, Van Doorslaer and Paci in 1989[226], and subsequently became a recognised method for measuring health inequality[29]. The standard mathematical expression for the index for a population of size n was proposed as:

$$C = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{h_i}{h}(2R_i^y - 1)\right]$$

where *h* denotes health and *y* is a socioeconomic variable (e.g., income) and R_i^y is the fractional rank of an individual *(I)* according to any chosen socioeconomic variable[271]. This standard version was later modified into various versions to suit different measurement scales[272]. The corrected version of the CI, also known as Wagstaff's index, is typically used for binary health outcomes[32,33] and was used in this study for the two categorical classifications of obesity (i.e., obesity, and overweight or obesity). This study used the standard CI for the continuous BMI outcome, as it best measures the degree of inequality in the distribution of the continuous variable among different population subgroups. The result from the CI is reported as a number between -1 and 1, with a value of 0 indicating no inequality, a positive value indicating that the occurrence of the outcome (e.g., obesity) is more concentrated among higher socioeconomic groups, and a negative value indicating the outcome is more concentrated among lower socioeconomic groups. Within this study, the CI is also explored by the population region of residence, illustrating potential differences in obesity outcomes as influenced by differences in food culture and economic development across the country as captured by region[270].

Decomposition

To further explain inequality in obesity in Thailand, decomposition analysis was adopted. This helps identify what other variables apart from income (i.e., equivalent household income – the chosen socioeconomic variable) contribute to the inequality results. With this analysis approach, the inequality is explained by the outcome (i.e., obesity variables)'s elasticity with respect to the explanatory variable (E) and the degree of concentration of the explanatory variable across income groups (C_k)[151]. Elasticity represents the change in the outcome of interest for every one-unit change in the explanatory variable. A positive sign suggests an increase, and a negative sign indicates a decrease in the outcome due to a positive change in the explanatory variable. The concentration of the explanatory variable (C_k) describes the distribution of this variable across groups that vary by socioeconomic status based on income. A positive (negative) C_k value suggests that the explanatory variable is more common among individuals with higher (lower) socioeconomic status. The contribution of any explanatory variable to the inequality is the product of the health variable's elasticity with respect to that variable and its distribution across groups that vary by socioeconomic status (C_k). For instance, if education is strongly related to obesity (E) and it is also unevenly distributed across groups by socioeconomic status (C_k), a significant portion of the inequality in obesity, as represented by the CI, can be attributed to the impact of education. This study applied the standard version[32,154] of decomposition analysis, based on an additive regression model assuming that health has a linear relationship with the known covariates of interest associated with obesity, as presented in Table 4.1[162]. In line with prior research, the analysis for the CI and decomposition is conducted separately for each gender[33,153,158].

4.7 Results

Characteristics of the Study Population

The results in Table 4.2 summarise the characteristics of the study population by gender. The mean age of the population was 45.12 years for men and 45.40 years for women. The majority of participants were of normal weight (65.59% of men, 61.23% of women), while about one-third were considered to be overweight or obese (overweight in 25.61% of men and in 25.24% of women, and obesity in 4.93% of men and in 8.76% of women). The mean BMI of the population was 23.77 for men and 24.03 for women. The mean years of education were 9.22 for men and 9.10 for women. Half of the participants lived in urban areas (51.82% of men, 50.70% of women). The mean monthly servings of SSBs consumed were 13.99 for men and 9.33 for women. There was a significant difference in smoking habits, with 41.56% of men currently smoking compared to just 1.58% of women. This high smoking rate among men aligns with the prevalence of smoking in the Thai population[273]. Lastly, more women (21.68%) reported having a health problem, as indicated by the presence of at least one non-communicable disease, compared to men (16.77%).

Table 4.2: Characteristics of the study population

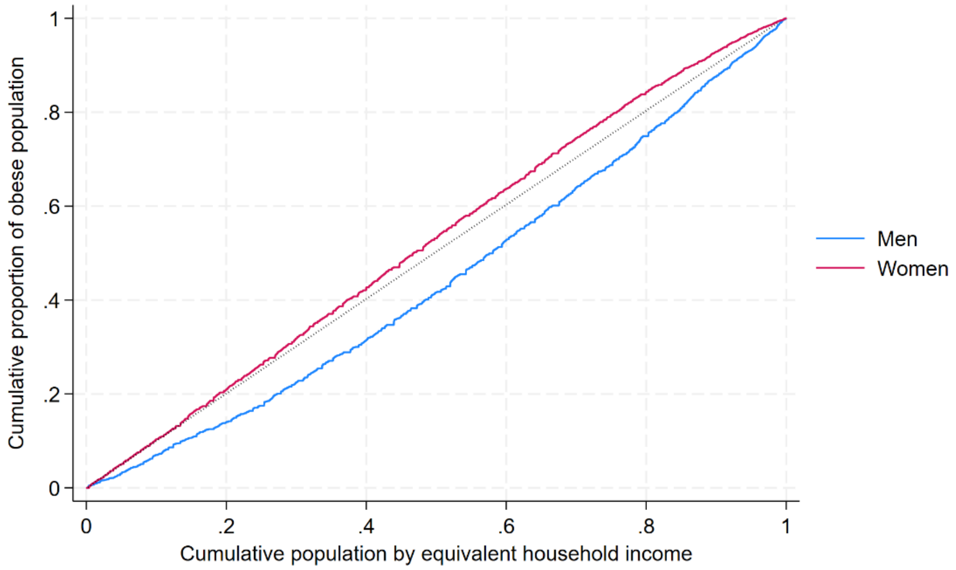
Variables		Male (N = 19,891)	%	Female (N = 29,182)	%
BMI, mean (sd)		23.77 (3.44)		24.03(4.15)	
Weight classification	Underweight (BMI < 18.5)	769	3.87	1,391	4.77
	Normal (BMI 18.5 to < 25)	13,046	65.59	17,869	61.23
	Overweight (BMI 25 to < 30)	5,095	25.61	7,365	25.24
	Obese (BMI ≥ 30)	981	4.93	2,557	8.76
Age, mean (sd)		45.12 (9.57)		45.40 (9.44)	
Income (household equivalised income), THB mean/month (sd)		14,664 (12,452)		13,758 (11,710)	
Years of education, mean (sd)		9.22 (4.19)		9.10 (4.38)	
Marital status	Single	4,133	20.78	3,672	12.58
	Ever married	15,757	79.22	25,510	87.42
Area of residence	Non-urban	9,584	48.18	14,387	49.30
	Urban	10,307	51.82	14,795	50.70
Work-related physical activity	Hard	7,586	38.14	4,387	15.03
	Light	12,305	61.86	24,795	84.97
Main meals, mean per day (sd)		2.89 (0.35)		2.89 (0.34)	
SSBs, servings/month (sd)		13.99 (18.38)		9.63 (15.74)	
Fat foods, days/month (sd)		10.15 (8.90)		10.15 (8.65)	
Snacks, days/month (sd)		2.51 (5.28)		2.84 (5.50)	
Source of foods	Home cooked	14,001	70.39	23,810	81.59
	Non-home cooked	5,890	29.61	5,372	18.41
Food label consideration	Never or unsure	7,873	39.58	8,903	30.51
	Ever seen but not impacting decision on foods	5,474	27.52	7,839	26.86
	Ever seen and impacting decision on foods	6,544	32.90	12,440	42.63
Leisure-time physical activity, days/month (sd)		4.54 (9.21)		3.83 (8.61)	
Smoking status	Never	8,316	41.81	28,533	97.78
	Current	8,267	41.56	460	1.58
	Ex-smoker	3,308	16.63	189	0.65
Alcohol drinking status	Not drinking, sometimes	18,597	93.49	29,034	99.49
	Being heavy drinker	1,294	6.51	148	0.51
Health problem	No	16,556	83.23	22,854	78.32
	Yes	3,335	16.77	6,328	21.68

BMI = body mass index; sd = standard deviation; SSBs = sugar-sweetened beverages; THB = Thai Baht

Concentration Index Results

A concentration curve of obesity in men and women is presented in Figure 4. In men, the curve lies below the equality line (CI is negative), showing obesity is concentrated among men of higher socioeconomic status, indicating that the inequality in obesity is pro-rich. In contrast, in women, the curve lies above the equality line (CI is positive), showing that obesity is concentrated among women of lower socioeconomic status, indicating that the inequality in obesity is pro-poor.

Figure 4.1: Concentration curve for obesity in Thai adults



Note: the dotted line represents the equality line, suggesting no relationship between obesity and income.

A summary of the base case results for the CI is presented in Table 4.3. For men, the CI values are as follows: 0.099 for obesity, 0.104 for overweight or obesity, and 0.009 for continuous BMI. For women, the CI values are: -0.068 for obesity, -0.072 for overweight or obesity, and -0.007 for continuous BMI. When the underweight population is excluded from the results, the direction of the CI remains consistent, but the point estimates are somewhat lower. For instance, the CI value for obesity is 0.079 in men and -0.062 for women (as detailed in Table 8.3 of the supplementary appendix). All these values are statistically significant, highlighting an inequality in obesity relating to socioeconomic status that is pro-rich in men and pro-poor in women. The CI values vary across the regions and some distinct patterns are observed. For men, the strongest pro-rich result is found in the North, especially for obesity in which the concentration index of 0.256 is more than double the index of the country. For women, the strongest degree of pro-poor inequality is found in the Central region (obesity) where the region CI of -0.128 is roughly double the country's value.

Table 4.3: Concentration index results of obesity in Thailand

	Men				Women			
	N	Obesity	Overweight or obesity	Continuous BMI	N	Obesity	Overweight or obesity	Continuous BMI
Country	19,891	0.099***	0.104***	0.009***	29,182	-0.068***	-0.072***	-0.007***
Region								
Bangkok	901	0.099	0.040	0.005*	1,173	-0.115	-0.046	-0.007*
Central	6,136	-0.017	0.069***	0.006***	8,484	-0.128***	-0.087***	-0.008***
North	4,321	0.256***	0.151***	0.014***	6,178	-0.013	-0.034	-0.002
Northeast	4,763	0.000	0.061**	0.006***	7,568	-0.079**	-0.085***	-0.009***
South	3,370	0.083	0.111***	0.009	5,779	-0.065**	-0.087***	-0.008***

BMI = body mass index; N = number of observations

* p-value < 0.10; ** p-value < 0.05; *** p-value < 0.01

The p-value associated with the CI indicates the probability of observing the calculated concentration index under the assumption that there is no significant difference in health outcome distribution across socioeconomic groups i.e., no health inequality (i.e., the CI is zero).

Decomposition Results

The results of the decomposition analysis for men are presented in Table 4.4 and for women in Table 4.5 (graphs are presented in Figure 8.1 and Figure 8.2 in supplementary appendix). In general, socioeconomic factors including income and education explain a substantial part of the inequality in obesity in both genders. The results also suggest that various factors interact with income (the chosen socioeconomic factor), which contributes to the inequality in obesity in Thailand.

Specifically, the results indicate that income and education are the primary contributors to the pro-rich inequality in men across the three obesity measures. While income influences this inequality, it is not because of an association between income and obesity (as evidenced by lack of statistical significance in elasticity; E). Instead, it is due to the uneven distribution of income across the population (C_k of 0.384). Education has a greater contribution than income to the inequality, due to its robust positive correlation with obesity and higher concentration among higher socioeconomic men (C_k of 0.113). Living in urban areas also contributes between 9.2% (in continuous BMI) and 15.1% (in obesity) to the inequality. Additionally, the results indicate that SSB consumption is associated with a high rate of obesity and is concentrated among higher socioeconomic men, contributing 3.1% of the pro-rich inequality (overweight or obesity, and continuous BMI). In contrast, engaging in leisure physical activity decreases the pro-rich inequality since it is associated with a decreased chance of obesity and is prevalent among higher socioeconomic groups. Current smoking has a noticeable contribution to increased pro-rich inequality (10.3% in continuous BMI and 6.1% in overweight or obesity) because smoking is negatively associated with weight and is more prevalent among lower socioeconomic men.

Table 4.4: Decomposition of income-related inequality in three obesity approaches in men in Thailand

	Obesity				Overweight or obesity				Continuous BMI			
	E	C_k	Con.	%Con.	E	C_k	Con.	%Con.	E	C_k	Con.	%Con.
SSBs	-0.034	0.070	-0.003	-2.4%	0.045**	0.070	0.005	3.1%	0.004**	0.070	0.0003	3.1%
Age	-0.896***	-0.012	0.011	10.9%	0.029	-0.012	0.000	-0.3%	0.001	-0.012	0.0000	-0.2%
Income (household equivalised income)	-0.024	0.384	-0.010	-9.4%	0.032	0.384	0.018	11.9%	0.004	0.384	0.0015	16.6%
Education	0.461***	0.113	0.055	52.8%	0.259***	0.113	0.042	28.2%	0.031***	0.113	0.0035	39.0%
Married status (ref: never married)												
Ever married	0.058	-0.008	0.000	-0.5%	0.053*	-0.008	-0.001	-0.4%	0.010***	-0.008	-0.0001	-0.9%
Area (ref: non-urban)												
Urban	0.088	0.171	0.016	15.1%	0.017	0.171	0.004	2.9%	0.005**	0.171	0.0008	9.2%
Work-related physical activity (ref: hard)												
Light	0.057	0.099	0.006	5.7%	0.040	0.099	0.006	3.8%	0.004	0.099	0.0004	4.9%
Main meal	0.335	-0.005	-0.002	-1.6%	-0.018	-0.005	0.000	0.1%	0.011	-0.005	-0.0001	-0.6%
Fat intake	0.113*	0.031	0.004	3.5%	0.088***	0.031	0.004	2.6%	0.008**	0.031	0.0002	2.7%
Snacks	0.014	0.078	0.001	1.1%	-0.010	0.078	-0.001	-0.7%	-0.001	0.078	-0.0001	-1.1%
Source of food (ref: home-cooked)												
Non-home cooked	-0.143***	0.222	-0.034	-32.2%	-0.024***	0.222	-0.008	-5.1%	-0.001	0.222	-0.0001	-1.4%
Food label consideration (ref: seen and have impact)												
Never seen or unsure	-0.009	-0.140	0.001	1.3%	0.007	-0.140	-0.001	-1.0%	0.001	-0.140	-0.0001	-1.1%
Seen but no impact	0.003	0.043	0.000	0.1%	0.024	0.043	0.001	1.0%	0.003**	0.043	0.0001	1.4%
Leisure-time physical activity	-0.064***	0.214	-0.014	-13.9%	-0.009	0.214	-0.003	-1.8%	-0.002	0.214	-0.0003	-3.8%
Smoking status												
Current	-0.088	-0.103	0.010	9.2%	-0.062***	-0.103	0.009	6.1%	-0.009***	-0.103	0.0009	10.3%
Ex-smoker	0.006	-0.030	0.000	-0.2%	0.017***	-0.030	-0.001	-0.5%	0.001**	-0.030	0.0000	-0.4%
Drinking status (ref: never/light)												
Heavy	-0.012	-0.015	0.000	0.2%	-0.002	-0.015	0.000	0.0%	-0.001*	-0.015	0.0000	0.1%
Health problem (ref: no)												
Yes	0.171*	-0.006	-0.001	-1.1%	0.065***	-0.006	-0.001	-0.4%	0.007***	-0.006	0.0000	-0.4%
		Explained	0.040	38.7%		Explained	0.073	49.5%		Explained	0.0070	77.5%
		Unexplained	0.059	61.3%		Unexplained	0.031	50.5%		Unexplained	0.0020	22.5%
			0.099	100.0%			0.104	100.0%			0.0090	100.0%

* p-value < 0.10; ** p-value < 0.05; *** p-value < 0.01
The p-value indicates association of explanatory variable with obesity (elasticity)
BMI = body mass index; C_k = concentration of covariate variable across income; Con. = contribution; E = elasticity; ln = logarithm; ref = reference; SSBs = sugar-sweetened beverages

The results of the decomposition analysis indicate that education significantly impacts inequality in obesity for women, similar to men. Specifically, this study finds that education increased the pro-poor inequality in women as higher education was negatively associated with obesity, and there was a higher rate of higher education among women with higher socioeconomic status (C_k of 0.123). Additionally, the analysis showed that income increased the pro-poor inequality as it was negatively associated with obesity and income was highly unequally distributed across the population (C_k of 0.393). Other factors that increased the pro-poor inequality included ever being married and having a health problem, as both were positively associated with weight and were concentrated among women with lower socioeconomic status. Having a health problem contributed between 12.7% (overweight or obesity) to 28.4% (obesity) of the pro-poor inequality. Furthermore, the results show that eating non-home cooked foods more often increased the pro-poor inequality as it was negatively associated with weight and was concentrated among women with higher socioeconomic status. In contrast, SSB consumption reduced inequality as it was positively associated with weight (but statistically insignificant) and SSB consumption was higher among women with higher socioeconomic status.

In both genders, the results suggest that several unhealthy behaviours, including consuming fatty foods and snacks, were more concentrated in populations with higher socioeconomic status. While most of the results were consistent across the three measures of obesity, some discrepancies were apparent. For example, being in older age groups for men contributed 10.9% of the inequality of obesity measure, while it had a very small contribution of less than 1.0% in the being overweight or obesity measure as well as the continuous BMI measure. This is similar to women, where age had a high (negative) contribution of 28.7% to the inequality in the obesity measure but not for the other two obesity approaches.

Table 4.5: Decomposition of income-related inequality in three obesity approaches in women in Thailand

	Obesity				Overweight or obesity				Continuous BMI			
	E	**C_k**	**Con.**	**%Con.**	**E**	**C_k**	**Con.**	**%Con.**	**E**	**C_k**	**Con.**	**%Con.**
SSBs	0.026	0.094	0.003	-3.5%	0.016	0.094	0.0022	-2.1%	0.001	0.094	0.0001	-1.6%
Age	-1.148***	-0.017	0.021	-28.7%	0.025	-0.017	-0.0006	0.6%	0.000	-0.017	0.0000	-0.1%
Income (household equivalised income)	-0.034	0.393	-0.015	19.6%	-0.028**	0.393	-0.0153	15.2%	-0.003**	0.393	-0.0012	13.9%
Education	-0.205**	0.123	-0.027	37.1%	-0.181***	0.123	-0.0312	30.9%	-0.028***	0.123	-0.0035	41.5%
Married status (ref: never married)												
Ever married	0.288***	-0.046	-0.014	19.3%	0.232***	-0.046	-0.0149	14.7%	0.037***	-0.046	-0.0017	20.0%
Area (ref: non-urban)												
Urban	-0.028*	0.166	-0.005	6.8%	-0.011	0.166	-0.0025	2.5%	0.000	0.166	-0.0001	0.7%
Work-related physical activity (ref: hard work)												
Light	0.133**	0.034	0.005	-6.6%	0.040	0.034	0.0019	-1.8%	0.009**	0.034	0.0003	-3.6%
Main meal	-0.754**	-0.003	0.003	-3.7%	-0.371**	-0.003	0.0017	-1.7%	-0.046**	-0.003	0.0002	-1.8%
Fat intake	0.112**	0.029	0.003	-4.7%	0.065***	0.029	0.0026	-2.6%	0.010***	0.029	0.0003	-3.4%
Snacks	0.008	0.088	0.001	-1.1%	-0.002	0.088	-0.0003	0.3%	0.000	0.088	0.0000	-0.4%
Source of food (ref: home-cooked)												
Non-home cooked	-0.063***	0.236	-0.016	21.8%	-0.050***	0.236	-0.0165	16.3%	-0.006***	0.236	-0.0014	16.3%
Food label consideration (ref: seen and have impact)												
Never seen or unsure	-0.012	-0.162	0.002	-2.9%	-0.019*	-0.162	0.0042	-4.2%	-0.001	-0.162	0.0002	-2.4%
Seen but no impact	0.065***	0.009	0.001	-0.9%	0.013	0.009	0.0002	-0.2%	0.002*	0.009	0.0000	-0.2%
Leisure-time physical activity	-0.012	0.166	-0.002	2.8%	-0.011*	0.166	-0.0025	2.5%	-0.001	0.166	-0.0001	1.5%
Smoking status												
Current	0.013**	-0.139	-0.002	2.6%	-0.001	-0.139	0.0002	-0.2%	0.000	-0.139	0.0000	-0.1%
Ex-smoker	-0.001	-0.087	0.000	-0.1%	0.000	-0.087	0.0000	0.0%	0.000	-0.087	0.0000	-0.1%
Drinking status (ref: never/light)												
Heavy	-0.003**	-0.001	0.000	0.0%	-0.001	-0.001	0.0000	0.0%	0.000***	-0.001	0.0000	0.0%
Health problem (ref: no)												
Yes	0.185**	-0.104	-0.021	28.4%	0.088***	-0.104	-0.0129	12.7%	0.012***	-0.104	-0.0013	15.1%
		Explained	-0.064	86.3%		Explained	-0.084	82.8%		Explained	-0.0079	95.2%
		Unexplained	-0.004	13.7%		Unexplaine	0.012	17.2%		Unexplained	-0.0004	4.8%
			-0.068	100.0%			-0.072	100.0%			-0.0083	100.0%

* p-value < 0.10; ** p-value < 0.05; *** p-value < 0.01
The p-value indicates association of explanatory variable with obesity (elasticity)
BMI = body mass index; C_k = concentration of covariate variable across income; Con. = contribution; E = elasticity; ln = logarithm; ref = reference; SSBs = sugar-sweetened beverages

4.8 Discussion

This study examined socioeconomic inequality in obesity among adults in Thailand using data obtained from a nationally representative survey conducted in 2021[57]. The findings revealed a distinct pattern of inequality in terms of gender, with obesity being concentrated among men of higher socioeconomic status and among women of lower socioeconomic status. The decomposition analysis revealed a complex interplay of multifactorial influences on inequality, including income, education, health conditions, and various unhealthy behaviours.

This study suggests that the recent pattern of socioeconomic inequality in obesity among men in Thailand, based on data up to 2021, remains consistent with findings from the last study in Thailand assessing socioeconomic status and obesity using data up to 2013 and mirrors patterns observed in less economically developed countries[149,150]. In women, the pattern of inequality in obesity aligns with previous research, which has shown a trend of obesity transitioning from higher to lower socioeconomic groups as in economically advanced nations as early as 2005[37,40]. This combination of patterns is often observed in countries transitioning towards more advanced economies. Previous literature suggests that once a country's annual GDP per capita reaches approximatelyUS$8,000[70], the challenge of obesity extends beyond individuals of higher socioeconomic status to also affect those of lower socioeconomic status. It is therefore possible that Thailand with a GDP per capita of US$7,000 in 2021 will experience a shift of the obesity burden in men toward people of lower socioeconomic status in the near future. Consequently, the pattern of the shifting burden of obesity observed in higher-income countries is already apparent in certain regions of Thailand. For instance, the Central region – the most developed part of Thailand - exhibits strong pro-poor inequality in women[149]. In contrast, the economically lagging North region has patterns typical of less developed nations, with strong pro-rich inequality for men[274]. Consequently, the socioeconomic inequality in obesity in Thailand exists at both the national level and within regions.

The decomposition analysis suggests that socioeconomic factors including a degree of inequality in income and education themselves have a pivotal role in the inequality in obesity in both genders. Specifically, women with less education were identified as another group vulnerable to obesity, similar to previous studies[32,34,153], contributing significantly to the pro-poor inequality in women. This high impact of education is consistent with previous research in Thailand that education is a central factor in explaining obesity trends[37,38]. Moreover, the results suggest a significant interaction between income and obesity, which might impact health, especially in women. This interaction is important to consider as it demonstrates that, regardless of whether income explains obesity or vice versa, it has a greater impact on the health of women in lower socioeconomic groups than women in higher socioeconomic groups.

It may be tempting for policymakers to assume that since obesity is not concentrated among men in the disadvantaged group, the health inequity issue for Thai men is not a concern. Such an interpretation would be misleading. While this study found a lower level of obesity in socioeconomically disadvantaged Thai men, it remains unclear if this is a result of healthier behaviours among that group or other factors that impact body weight. For instance, smoking can be seen as a protective factor for obesity[268,269] and high smoking rates among Thai men, particularly in the socioeconomically disadvantaged group, may explain the lower rates of obesity among them relative to the obesity rates of more socioeconomically advantaged men[268,269]. It is important to recognise that obesity and smoking should not be viewed as separate health issues, but rather as critical contributors to premature death, particularly from non-communicable diseases[275]. Normal weight may not be an appropriate benchmark for determining good health in Thai men, and socioeconomically disadvantaged men still have a risk of premature death and may even face an increased risk of mortality given that smoking doubles the risk of all-cause mortality compared to obesity, which only increases the risk of mortality by a third[276]. This has implications for the study of obesity in other low and middle-income countries where smoking is prevalent and disproportionately concentrated among socioeconomically disadvantaged groups[277].

The study results have several implications for government efforts to improve the health of the Thai population. First, as the study shows, high inequality in income leads to health inequality. Therefore, promoting more social equality, both in terms of income and education, should be considered alongside promoting health in order to reduce health inequity across socioeconomic groups. It might be reasonable to prioritise policy to jointly address poverty and health of women living with obesity in lower socioeconomic groups as they show a clear sign of vulnerability. Second, the findings suggest that there is a need for regional public health authorities to play a more significant role in addressing specific regional issues affecting obesity, expanding the current centralised policies. Moreover, the study provides insight into a policy under consideration in Thailand regarding SSB taxes. As SSBs contribute minimally to the overarching inequality in obesity and are primarily consumed by the higher socioeconomic groups, the effectiveness of tax policies aimed at reducing SSB consumption in elevating the health of lower socioeconomic groups while also mitigating health inequities, warrants further in-depth analysis. Specifically, more detailed research is needed to understand the relationship between socioeconomic status and SSB consumption in Thailand. Lastly, addressing health inequities in men may require efforts beyond just obesity-focused approaches. For example, initiatives could aim to decrease smoking rates among men from lower socioeconomic backgrounds.

Health inequality is a challenging subject, and the complexity of the CI has been widely discussed in literature[29,246,278-280]. This study sheds light on a specific methodological challenge tied to the use of the CI when assessing obesity; that of how obesity is measured relative to other weight categories. It became evident during this study that excluding underweight individuals from the analysis reduced the degree of the inequality, indicating a possible higher underweight prevalence among lower socioeconomic individuals. This emphasises that researchers need to be aware that excess weight (and lack of excess weight) is not a true binary outcome representing 'healthy' (and 'unhealthy'), but rather a transformed continuous outcome of BMI, with the opposite side of excess weight being a combination of both normal weight ('healthy') and underweight. The presence of underweight individuals, some of whom may represent malnutrition ('unhealthy'), alongside those of normal weight ('healthy') complicates the measurement of inequality. Future studies should be explicit about their approach to handling underweight individuals, providing details in the methods section, particularly in studies on developing countries with high rates of malnutrition and underweight[281].

One strength of this study is its use of a large, nationally representative dataset of Thai adults. The methodology used is specific to measuring health inequality and has not been previously used for Thailand. The study also used the international definition of obesity, enabling comparison with international studies. Furthermore, this study compared three measures of excess weight to encompass various definitions of excessive adiposity, ensuring a more comprehensive depiction of inequality. The consistency of the results across these approaches further strengthens the study's findings.

There are some limitations to this study. The findings in this study are specific to adult populations (aged 25 to 59) and may differ in younger or older individuals. Given the cross-sectional survey nature of the data it may not be possible to make causal inferences in this study. On the other hand, some factors analysed may be influenced by the outcome, making them endogenous[32]. For instance, there might be reverse causality existing with physical activity where it cannot be ascertained whether physical activity directly causes lower obesity rates or if obesity affects individuals' likelihood of exercising. Nonetheless, the analysis provides insight into which subgroups of the population to target for relevant policy intervention to have the greatest impact on reducing health inequity. Moreover, the prevalence of obesity and overweight in the dataset used for this study appears to be lower than that from other national sources (e.g., 2019 National Health Examination Survey[6]). This discrepancy might be partly attributed to the self-reported information on height and weight used in the survey[282]. Such an approach is known to be less accurate than objective measures, potentially leading to the over-reporting of height and under-reporting of weight[283], which would have the effect of fewer people being categorised as obese with a BMI based measure as used in this study.

4.9 Conclusion

This study investigated socioeconomic inequality in obesity in Thailand. The findings indicated a concentration of obesity among men of higher relative to lower socioeconomic status, while women of lower relative to higher socioeconomic status had a concentration of obesity. These mixed patterns of the inequality between genders are similar to those observed in countries in transition to higher income. Additionally, there are variations in inequalities across regions associated with levels of regional development, with highly developed regions showing patterns similar to high-income countries, while less developed regions display patterns aligned with less developed countries. The decomposition analysis revealed a complex interplay of multiple factors, with income playing a significant role in the inequality in obesity. Education, health problems, and various unhealthy behaviours emerged as important contributors to the observed inequalities. There were also co-occurring conditions of obesity and health problems in women in lower relative to higher socioeconomic groups, emphasising the need for interventions that address both economic disadvantage and obesity to support women experiencing this dual burden. Unhealthy eating behaviours, including the consumption of SSBs, contribute to inequality. However, such behaviours are more prevalent among those of higher socioeconomic status. More research is needed with respect to the potential success of policies aimed at these behaviours in reducing socioeconomic inequity. Lastly, addressing health inequities in men may necessitate strategies beyond obesity-focused measures, such as initiatives to decrease smoking rates among men from lower socioeconomic backgrounds.

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Chapter 5: Characteristics of Frequent SSB Consumers in Thailand

5.1 Preamble

The previous chapter suggests that socioeconomic status might play a role in SSB consumption and could interact with and contribute to the inequality in obesity in Thailand. The systematic review chapter also emphasised the importance of understanding how SSB consumption might vary across social groups, which has implications for equity analysis. Furthermore, a thorough investigation of the target population's characteristics can serve as part of a situational analysis, which is vital for evidence-based health policy planning. However, in Thailand, this critical step has been inadequately addressed. Thus, this chapter seeks to understand further the influence of socioeconomic status and other population characteristics on SSB consumption in Thailand.

This chapter is presented in the format of a manuscript currently under review at *Public Health*. The authorship roles are as follows:

- Conceptualisation: Kittiphong Thiboonboon (KT), Richard De Abreu Lourenco (RL), and Stephen Goodall (SG).
- Study design: KT.
- Data collection: KT.
- Data analysis: KT.
- Writing - original draft: KT.
- Writing - review and editing: Jody Church (JC), RL, and SG.
- Supervision: JC, RL, and SG.
- Validation: KT, JC, RL, and SG.

5.2 Manuscript's Details

Title: Sugar-Sweetened Beverage Consumption in Thailand: Determinants and Variation Across Socioeconomic Status

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5.3 Highlights:

- A large, nationally representative dataset was analysed to explore characteristics and determinants of sugar-sweetened beverage (SSB) consumption in Thailand.
- Higher socioeconomic status and unhealthy behaviours like smoking, unhealthy food consumption, as well as insufficient leisure-time physical activity are linked to increased SSB consumption.
- Food choices, influenced by motivations tied to addiction concepts of 'liking' and 'wanting', correlate with higher SSB consumption.
- Higher SSB consumption aligns with overall food consumption in high socioeconomic individuals, smoking, insufficient exercise, and the 'liking' and 'wanting'-driven food

5.4 Abstract

Introduction Reducing consumption of sugar-sweetened beverages (SSBs) is a primary public health goal in Thailand, but information on the characteristics of SSB consumers remains limited. Therefore, the aim of this study is to gain in-depth knowledge about the characteristics of SSB consumers in Thailand.

Methods The study used data from the Health Behaviour of Population Survey conducted by Thailand's National Statistics Office between February and May 2021, containing information from 49,128 participants aged 25–59. Information related to SSB consumption was sourced from a survey question about the consumption of bottled non-alcoholic beverages with sugar. Analysis of SSB consumption included the number of SSB servings consumed per month and being a daily SSB consumer. A two-part model and logistic regression analysis was employed to examine how SSB consumption was influenced by underlying demographic, socioeconomic, behavioural, habitual and health factors. Decomposition analysis was conducted to understand how the impact of these factors affecting SSB consumption varied across socioeconomic groups.

Results Frequent SSB consumers were associated with being of higher socioeconomic status. These consumers often exhibited various unhealthy behaviours such as smoking, consuming unhealthy foods, and having low leisure-time physical activity. They also showed distinct patterns in their food choices, driven by appetitive motivations such as 'liking' and 'wanting'. The decomposition analysis revealed that SSB consumers with lower socioeconomic status also engaged in behaviours like smoking, drinking, using appetitive motivations for food choices, and having low leisure-time physical activity. In contrast, SSB consumers with higher socioeconomic status paired SSB consumption with a broader intake of foods, both healthy and unhealthy.

Conclusions SSB consumption in Thailand is multifactorial, varied by socioeconomic status. These insights are crucial for policy formulation aimed at reducing SSB consumption in the country. Policymakers should explore interventions that address overall unhealthy behaviours alongside those targeting overconsumption of SSBs.

5.5 Introduction

Reducing high sugar intake has been strongly recommended by the World Health Organization (WHO) due to its adverse effects on health[284]. Among the dietary sources of high sugar content, sugar-sweetened beverages (SSBs) stand out as a primary concern, as they represent the largest source of free sugars in the diets contributing to a significant portion of daily caloric intake for many individuals[20]. Their widespread accessibility, combined with extensive advertising, often leads to overconsumption, replacing more nutritious food options in individuals' diets[17]. This overconsumption of SSBs is a public health concern, as growing evidence indicates that high SSB consumption increases risks of obesity as well as many health conditions such as type 2 diabetes, cardiovascular disease, dental caries, and specific types of cancer[96,285-287].

The global patterns of SSB consumption have attracted significant attention from public health experts, policymakers, and researchers in recent years[11,288]. One prominent trend is the decline in SSB consumption in various higher-income countries; for example, between 2009 and 2014, sales of SSBs decreased in North America, Australasia and Western Europe[11]. In contrast, growth in SSB consumption has been observed in several less-developed regions of the world[11,288]. In those regions, SSB consumption is one of the indicators of the nutritional transition towards energy-dense foods, influenced by economic improvement[10]. This transition is evident in Thailand, where there has been a marked shift towards energy-dense foods, especially over the past two decades[73]. Consumption of sugar in Thailand is double that of Asia's average[76], and Thailand has the highest SSB-related calories sold per capita per day in this region[11]. SSBs are a large source of sugar consumed in Thailand, and significantly contribute to the daily intake of sugar among the population, exceeding the recommended level of less than 50 grams per capita per day[14]. As much as 40-70% of the Thai population consumes SSBs daily[94,116]. This situation has become more worrying as many studies suggest that the trend of increasing SSB consumption continues [11,112,113].

Internationally, research has highlighted the broad factors that influence SSB consumption[42-48]. In high-income countries, in addition to the finding that individuals of lower socioeconomic status tend to consume more SSBs[46,47,289], studies also discovered that SSB consumption is multifactorial extending beyond easily observable external factors to internal factors such as habit, intention and attitudes[290]. Moreover, as SSBs are regarded as palatable foods with instant gratification properties, literature from behavioural economics and psychology emphasises that deeper factors, such as cognitive susceptibility, might play a role in the consumption of such foods[291,292]. In terms of public health, because of their significant impact on health outcomes, differences in SSB consumption can also represent one of the pathways by which health inequalities are generated and sustained in the population, and therefore one potential focus for promoting health equity[34,293]. These elements have been limitedly addressed in existing literature in Thailand[1,94,116].

In Thailand, where approaches to reduce SSB intake have been consistently considered by policymakers[123], conducting a thorough situational analysis of SSB consumers is vital for informed health policy formation[17]. Situational analysis can provide an understanding of the profile of the target population, such as their socioeconomic status, preferences, and behaviours. These analyses can also help assess the opportunities and challenges or risks of implementing a proposed policy, like a tax on SSBs in the country[8,17]. By understanding the socioeconomic profile of those consuming SSBs, policymakers can assess how the effects of these taxes might be distributed, particularly as the taxes have been advocated to address health inequity in the population[17]. Furthermore, insight into the profile of regular SSB consumers can shed light on the risks posed by a new tax, such as an unfair tax burden, that may fall on vulnerable populations, including those in socioeconomically disadvantaged groups[51]. This study, therefore aims to provide a nuanced analysis of the complex interplay between the multiple determinants affecting SSB consumption in Thailand.

5.6 Data and Methods

Data

The study used data from the Health Behaviour of Population Survey provided by the National Statistics Office in Thailand[57]. This nationally representative survey, carried out from February to May 2021, interviewed Thais, gathering information on demographics, socioeconomics and behaviours. A total of 49,128 participants aged 25 to 59, who completed the survey themselves, were included in this study. Answers provided on behalf of others, or proxy responses, were excluded because of potential inaccuracies, missing data (particularly on physical activity), and the risk of bias[261]. To ensure the representativeness of the entire population, existing weighting factors from the survey were applied throughout the analysis, accounting for sampling design, nonresponse, and potential biases.[262]. SSB-related data was derived from a survey question that inquired participants about their consumption of prepackaged non-alcoholic beverages containing sugar.

Outcomes of interest

In the Health Behaviour of Population Survey, the participants were asked to indicate how often they consumed a 250 millilitre (mL) serving of prepackaged non-alcoholic beverages containing sugar over the past 30 days. Response options were daily, 5–6 days a week, 3–4 days a week, 1–2 days a week, less than 1 day a week (1–3 days a month) or never. Those who reported consumption were further asked to specify the number of servings per day. In this study, there were two outcomes of interest or dependent variables related to the consumption of SSBs: the number of SSB servings per month and the likelihood of being a daily consumer of SSBs. To calculate the number of SSB servings consumed per month, categorical data representing the frequency of consumption was transformed from days a week into days per month. For instance, participants reporting a consumption frequency of 5–6 days a week were converted to an equivalent of 23.57 days a month (calculated as 5.5 days multiplied by 30/7). This value was then multiplied by the daily SSB servings consumed by each participant. Participants who reported no consumption or a consumption frequency of less than 1 serving a week (i.e., less than 4 servings a month) were considered 'non-consumers' (i.e., zero consumption of SSBs). Since the literature has emphasised the impact on health outcomes from overconsumption of SSBs, specifically consuming SSBs on a daily basis[65,294], the second outcome of interest was the likelihood of being a daily SSB consumer. This is a binary outcome of being a daily SSB consumer versus those who consumed SSB less than daily or not at all.

Explanatory variables

An extensive literature review was conducted to investigate factors previously identified as influencing SSB consumption[1,42-45,48,94,108,116,289,295-298]. This revealed a range of demographic, socioeconomic, behavioural, habitual and health factors influencing SSB consumption for investigation in this study (Table 5.1). Demographic factors included gender, age and marital status, while socioeconomic factors included education, income quintiles, levels of work-related physical activity, and area of residence[94]. The inclusion of work-related physical activity was important since Thailand has a significant manual labour force that might depend on SSBs for energy[94]. Behavioural factors included in this study were smoking status, alcohol consumption, intake of other unhealthy foods (such as fatty foods, fast foods, or snacks), vegetable and fruit consumption, the number of main meals consumed daily, the source of foods, consideration of food labels, and leisure-time physical activity[94,116,296]. Previous studies also indicate that SSB consumption is associated with other unhealthy behaviours, such as smoking and alcohol consumption[44,94,296]. Furthermore, evidence suggests that SSB consumption might partly offset individuals' primary meals[108]. Weight status, determined by BMI, and health conditions based on non-communicable disease (NCD) status were also integrated into the study[94]. Additionally, the study accounted for habitual factors influencing food choices obtained from one question from the survey that addressed the primary reasons for food choice, probing aspects like personal liking, wanting, taste, price, nutritional value, cleanliness, and convenience. Appetitive motivations for foods, such as 'liking' and 'wanting', are intrinsically linked to psychological processes connected to the brain's reward system, specifically dopamine[140]. 'Liking' pertains to positive feelings like pleasure or enjoyment derived from an experience, whereas 'wanting' is a more goal-oriented behaviour driven by reward anticipation. Those people especially responsive to these reward pathways might consume more palatable foods like SSBs as they provide immediate sweetness-induced gratification, appealing to taste and triggering the brain's reward system[141,142].

Table 5.1: Definition of SSB variables and explanatory variables

Variable	Definition
Dependent variables	
Number of SSB servings per month	Continuous, total 250 mL servings of prepackaged non-alcoholic beverages containing sugar consumed per month
Daily SSB consumption	1 if consume at least one serve of prepackaged non-alcoholic beverages containing sugar daily, 0 otherwise
Explanatory variables	
Gender	1 if male, 0 otherwise
Age	Age in years
Marital status	1 if ever married, 0 otherwise
Socioeconomic status	Five quintiles of socioeconomic status measured by total monthly equivalised household income
Education	Total years of education
Work-related physical activity	1 if involved in daily tasks that require moderate work-related physical effort, 2 if involved in daily tasks that require high work-related physical effort, 0 otherwise
Area of residence	1 if living in an urban area, 0 otherwise
Smoking status	1 if a current smoker, 2 if ex-smoker, 0 otherwise
Alcohol drinking status	1 if a former drinker, 2 if consume 1–4 days a week (occasionally), 3 if consume ≥ 5 days a week (usually), 0 otherwise
Unhealthy foods	1 if consume either fatty foods, junk foods, or snacks ≥ 5 days a week, 0 otherwise
Vegetable	1 if consume vegetables ≥ 5 days a week, 0 otherwise
Fruit	1 if consume fruit ≥ 5 days a week, 0 otherwise
Main meal	Number of main meals per day
Source of food	1 if the most frequent source of food is non-home cooked, 0 otherwise
Food choice	1 if buying foods based on taste, 2 if on nutrition, 3 if on price, 4 if on conveniences, 5 if liking, 6 if wanting, 0 otherwise (cleanliness [a])
Food label consideration	1 if never seen or unsure, 2 if seen but no impact, 0 otherwise (seen and has impact)
Leisure-time physical activity	1 if self-reported insufficient leisure-time physical activity but willing to do more in 1 month, 2 if self-reported insufficient leisure-time physical activity but willing to do more in 6 months, 3 if self-reported insufficient leisure-time physical activity and have no plan or unclear to do more, 0 otherwise (sufficient)
Weight status	1 if underweight (BMI < 18.5), 2 if overweight (BMI 25 to < 30), 3 if obese (BMI ≥ 30), 0 otherwise (normal weight)
Health problem	1 if have any non-communicable disease (high blood pressure, diabetes/high blood sugar, high blood lipids/high cholesterol, stroke/paralysis, heart disease/coronary artery disease, chronic lung disease/emphysema/asthma, cancer/tumour, depression, and osteoarthritis/degenerative arthritis), 0 otherwise
Controlled variables	
Region of residence	
Bangkok	1 if living in Bangkok, 0 otherwise
Central	1 if living in the Central region, 0 otherwise
North	1 if living in the North region, 0 otherwise
Northeast	1 if living in the Northeast region, 0 otherwise
South	Reference

BMI = body mass index (estimated as weight in kilograms divided by squared height in metres); mL = millilitre; SSBs = sugar-sweetened beverages

[a] This study assumed that all beverages meet a basic standard of cleanliness or hygiene, thus, it can be posited that cleanliness does not directly impact SSB consumption. Therefore, this analysis focuses on how other factors influence the decision to consume sugary drinks relative to cleanliness.

Statistical analyses

The statistical approach used to examine the number of SSB servings per month was a two-part model[299]. This is a specific regression method developed to handle a significant proportion of zeroes in outcome data (i.e., in this study, those who had no consumption of SSBs). In the first part of the model a logistic regression was used to model the probability of being a SSB consumer (>1 serving a week), as affected by underlying explanatory factors. In the second part of the model, frequent SSB consumers were identified from among those who are SSB consumers using an ordinary least squares (OLS) regression. Incremental consumption by different characteristics of consumers was calculated using marginal effects. The relationship of the binary outcome of daily consumption of SSBs (versus less than daily) with other explanatory variables was analysed using a logistic regression model, in line with a previous study[94]. In this model, odds ratios were reported as indicators of the strength and direction of the relationship between the explanatory variables and the likelihood of daily SSB consumption[300]. Given the diverse economic and food culture within Thailand[1,270], regional dummy variables were incorporated to control for the heterogeneity of these effects across the five regions of Thailand.

To explore further whether the patterns of SSB consumption differ across socioeconomic domain in the population, a decomposition analysis was conducted[151]. This approach is commonly used in public health research to understand inequalities in various health behaviours in population[301-303]. For example, it has been used to assess socioeconomic-driven inequalities in tobacco use among individuals in various countries, highlighting influences like wealth, area of residence and gender[301]. In context of SSBs, this approach can provide a deeper understanding of how various factors, when combined with different socioeconomic statuses, distinctly influence SSB consumption. This, in turn, could potentially impact health and health equity. This study used the standard version of the decomposition analysis, which is based on an additive regression model[152,162]. The decomposition analysis is a function of the outcome (i.e., SSB consumption)'s elasticity with respect to the explanatory variable (elasticity; E) and the degree of concentration of the explanatory variable across socioeconomic groups (C_k)[151]. The socioeconomic position of individuals was represented by an equivalised household income calculated using the square root scale method recommended by the Organisation for Economic Co-operation and Development (OECD) of dividing household income by the square root of household size[266]. Results from the decomposition analysis were reported in terms of elasticity (E), representing the change in the outcome (SSB consumption) associated with a one-unit change in the explanatory variable, with a positive sign on E indicating an increase, and a negative sign on E indicating a decrease in the outcome due to a positive change in the explanatory variable. The degree of concentration of the explanatory variable across groups categorised by socioeconomic status was reported, denoted as C_k. A negative C_k indicates a higher prevalence of the respective variable among lower socioeconomic individuals, while a positive C_k suggests a higher prevalence among those of higher socioeconomic status. For instance, if fat intake is associated with obesity (E) and it is also unequally distributed across socioeconomic groups (C_k), a portion of the inequality in obesity, as represented by the CI, can be assigned to the impact of fat intake.

All analyses were performed using Stata 17 software[263]. To test for the presence of multicollinearity among the predictor variables, a correlation analysis was performed using Stata's correlate ('corr') command.

5.7 Results

A summary of the characteristics of the studied population is presented in Table 5.2. The sample of 49,128 participants consisted of 40.48% men and 59.52% women, with an average age of 45.30 years and an average education of 9.15 years. Most participants (84.06%) were ever-married. Of the participants, 20.36% indicated SSB consumption of five days or more per week. About half (50.51%) reported light work-related physical activity. Being a current smoker and a usual drinker were reported at 17.77% and 9.28% respectively. Data on dietary habits showed that 8.42% consumed unhealthy foods at least five days per week, and 77.08% mainly relied on home-cooked meals. Influences on food choices were primarily attributed to wanting at 22.22%, taste at 18.97%, cleanliness at 18.55%, and liking at 16.97%, whereas 12.13% considered nutrition when making food choices. Of the participants, 32.61% had an excess weight (25.40% overweight and 7.21% obesity), and 19.72% reported at least one health problem.

For the presence of multicollinearity, overall, the results suggest that most of the variables have weak or no correlation ($-0.3 \leq r < 0.3$), except for smoking and alcohol consumption that have a moderate correlation with gender (more smoking and alcohol consumption in men than women) ($-0.7 \leq r < 0.7$)[304]. Additionally, the correlation among the predictor variables was tested using the variance inflation factor

(VIF) using the 'vif' command, suggesting no evidence of multicollinearity as the mean VIF values were less than 10[305].

Table 5.2: Descriptive statistics of the included population

Characteristics (N = 49,128)		All participants	SSB 0 - <1 d/w	SSB 1-4 d/w	SSB ≥5 d/w
All participants		100.00%	46.64%	33.00%	20.36%
Gender	Men (vs women)	40.48%	33.54%	42.62%	52.90%
Age, mean (sd)		45.30 (9.50)	46.68%	43.98%	44.29%
Marital status	Ever-married (vs single)	84.06%	86.49%	82.21%	81.50%
Years of education, mean (sd)		9.15 (4.31)	8.80 (4.32)	9.44 (4.26)	9.47 (4.28)
Income, mean (sd)		10,567 (11,726)	11,741 (11,726)	13,350 (11,348)	11,521 (12,698)
Work-related physical activity	Light	50.51%	53.08%	51.78%	42.57%
	Moderate	42.25%	40.47%	41.65%	47.33%
	High	7.23%	6.45%	6.57%	10.10%
Area of residence	Urban (vs non-urban)	51.15%	49.25%	52.04%	54.09%
Smoking status	Never	75.12%	79.68%	74.00%	66.51%
	Current	17.77%	14.08%	18.72%	24.69%
	Ex-smoker	7.11%	6.24%	7.28%	8.81%
Alcohol drinking status	Never/rarely	70.30%	74.53%	69.06%	62.64%
	Former	15.62%	15.06%	15.70%	16.75%
	Occasionally	4.81%	3.81%	4.42%	7.71%
	Usually	9.28%	6.60%	10.82%	12.91%
Unhealthy foods	5–7 days a week (vs <5 days a week)	8.42%	7.51%	6.53%	13.56%
Vegetables	5–7 days a week (vs <5 days a week)	53.84%	54.81%	48.06%	61.00%
Fruit	5–7 days a week (vs <5 days a week)	25.78%	26.51%	19.60%	34.13%
Main meal, mean per day (sd)		2.89 (0.34)	2.89 (0.34)	2.90 (0.33)	2.87 (0.38)
Source of foods	Home cooking (vs non-home cooked)	77.08%	81.67%	74.96%	70.01%
Food choice	Cleanliness	18.55%	20.04%	17.49%	16.87%
	Taste	18.97%	18.50%	19.99%	18.41%
	Nutrition	12.13%	14.22%	10.86%	9.39%
	Price	5.47%	6.11%	5.06%	4.67%
	Convenience	5.69%	4.63%	5.87%	7.83%
	Liking	16.97%	15.79%	17.58%	18.69%
	Wanting	22.22%	20.71%	23.15%	24.16%
Food label consideration	Never or unsure	34.13%	37.05%	30.60%	33.14%
	Seen but no impact	27.17%	25.08%	28.44%	29.91%
	Seen and have impact	38.70%	37.87%	40.96%	36.94%

Leisure-time physical activity	Sufficient	13.16%	12.83%	13.79%	12.91%
	Insufficient, willing to do more in 1 m	6.04%	6.16%	5.95%	5.92%
	Insufficient, willing to do more in 6 m	9.96%	9.21%	11.10%	9.84%
	Insufficient, no/unclear willing to increase	70.83%	71.80%	69.15%	71.34%
Weight classification	Underweight	4.40%	4.41%	4.31%	4.54%
	Normal	62.98%	63.10%	63.07%	62.59%
	Overweight	25.40%	25.03%	25.58%	25.94%
	Obese	7.21%	7.46%	7.04%	6.93%
Health problem (s)	Yes (vs no)	19.72%	22.60%	17.13%	17.33%

d = day; m = month; THB = Thai Baht; vs = versus; w = week

The results from the two-part model and the logistic regression examining the determinants of SSB consumption are summarised in Table 5.3.

In the two-part model, the results indicated that SSB consumers are more likely to be men, younger, in a higher socioeconomic group (i.e., relative to quintile 1), live in urban areas, be current or former smokers, consume alcohol regularly, have a frequent intake of unhealthy and non-home cooked foods, and base their food decisions on taste, liking and wanting. Additionally, they are more likely to be overweight and have lower leisure-time physical activity. For those identified as SSB consumers, the OLS part of the model suggests that factors such as being a man, being in higher socioeconomic quintiles, living in an urban area, and frequent consumption of unhealthy foods or non-home cooked foods are likely to increase SSB consumption. Additionally, the model indicates those with moderate or high work-related physical activity, as well as those with frequent consumption of fruit and vegetable consume more SSBs. The marginal effect results largely mirror the determinants observed either in the logit or OLS on the factors influencing additional consumption of SSBs beyond the average consumption of 11.680 servings per month (a constant). For instance, men consumed 2.519 more SSB servings a month than women. Additionally, the marginal effect results suggest that those in the higher socioeconomic groups consumed between 2.181 (quintile 4) to 2.426 (quintile 5) more servings a month than the lowest socioeconomic group (quintile 1); and that current or ex-smokers consumed 1.931 or 1.481 more servings a month than those who had never smoked. Moreover, the results suggest that individuals who chose food based on liking or wanting consumed 1.863 or 1.422 more SSB servings, respectively than the reference group (cleanliness).

In the logistic model, the determinants influencing daily SSB consumption are largely similar to those observed in the two-part model. For example, the model emphasises that individuals with a higher likelihood of consuming SSBs daily are those with higher socioeconomic quintiles, moderate or high work-related physical activity, current smokers, frequent consumption of unhealthy foods as well as fruit or vegetable, and base food decisions on 'liking'.

Among other results, all the models suggest an inverse relationship between the number of meals per day and consumption of SSBs. Similarly, all the models suggest that those with a health problem and base their food decisions on price are less likely to consume SSBs. However, factors such as marital status and education were not found to be associated with the consumption of SSBs in any of the models.

Table 5.3: Results from the two-part model and the logistic model

Variable	SSB servings per month: Two-part model			Daily consumption: Logistic model
	Logistic	OLS	Incremental consumption (average marginal effect)	
Men (ref: women)	1.353***	0.098***	2.519***	1.435***
Age (year)	0.977***	-0.001	-0.119***	0.996*
Ever-married (ref: never married)	0.971	0.023	0.123	1.102
Education (years)	1.004	-0.001	0.007	1.003
Socioeconomic quintiles (ref: quintile 1)				
Quintile 2	1.135***	0.094***	1.532***	1.216***
Quintile 3	1.307***	0.111***	2.396***	1.398***
Quintile 4	1.281***	0.101***	2.181***	1.310***
Quintile 5 (highest)	1.334***	0.106***	2.426***	1.284***
Work-related physical activity (ref: light)				
Moderate	1.025	0.055***	0.719***	1.277***
High	1.095	0.107***	1.658***	1.502***
Living in urban (ref: non-urban)	1.085***	0.044***	0.867***	1.126***
Smoking status (ref: never)				
Current	1.340***	0.049**	1.931***	1.361***
Ex-smoker	1.213***	0.050*	1.481***	1.165*
Alcohol drinking status (ref: never/rarely)				
Former	1.147***	0.033*	1.009***	1.249***
Occasionally	1.171***	0.109***	2.041***	1.195***
Usually	1.477***	0.015	1.944***	1.340***
Unhealthy foods for 5–7 d/w (ref: <5 d/w)	1.229***	0.274***	4.588***	2.078***
Vegetable for 5–7 d/w (ref: <5 d/w)	1.015	0.049***	0.613***	1.371***
Fruit for 5–7 d/w (ref: <5 d/w)	0.910**	0.211***	1.997***	1.876***
Main meal (number per day)	1.090**	-0.118***	-0.918***	0.819***
Non-home cooked (ref: home-cooked)	1.127***	0.090***	1.609***	1.247***

Food choice (ref: cleanliness)				
Taste	1.166***	0.029	1.045*	0.933
Nutrition	0.966	-0.067**	-0.826**	0.753***
Price	0.856**	0.000	-0.719	0.796**
Convenience	1.145*	0.055	1.246**	1.292***
Liking	1.353***	0.040*	1.863***	1.221***
Wanting	1.366***	-0.001*	1.422***	1.054
Food label consideration (ref: never/unsure)				
Seen but no impact	1.287***	-0.009	1.079***	1.172***
Seen and have impact	1.202***	-0.037**	0.442*	0.979
Leisure-time physical activity (ref: sufficient)				
Insufficient, willing to do more in 1 month	1.029	-0.007	0.054	1.151
Insufficient, willing to do more in 6 months	1.150**	-0.002	0.610	1.156*
Insufficient, no/unclear willing to do more	1.012	0.024	0.314	1.179**
Weight status (ref: normal)				
Underweight	0.870**	0.060**	0.003	0.915*
Overweight	1.127***	0.013	0.699***	1.028**
Obese	1.052	-0.012	0.099	1.156
Health problem (ref: no health problem)	0.880***	0.007	-0.514**	0.928*
Constant	0.738*	2.780*	11.680***	0.065
Controlled regions (dummy: South)				
Bangkok	1.559***	0.019	2.233***	1.538
Central	2.385***	0.116***	5.477***	1.937
North	1.164***	-0.019	0.479	1.075
Northeast	1.332***	0.021	1.549***	1.212
Number of observations	49,128	26,250	49,128	49,128
Wald chi^2(40)	1,821.60	-		1,313.13
Prob > chi^2	0.000	-		0.000
Pseudo R^2	0.0676	-		0.080
Prob > F	-	0.000		-
Adj R-squared	-	0.079		-

d = day; THB = Thai Baht; vs = versus; w = week
*** = p-value < 0.01, ** = p-value < 0.05, * = p-value < 0.10; ref = reference group

A summary of the results of the decomposition analysis is presented in Table 5.4 (percentage contribution of factors to SSB consumption in Thailand is presented in Table 8.4 and Figure 8.3 in the supplementary appendix). The results suggest that various factors jointly influence SSB consumption based on socioeconomic status. Focusing on those modifiable factors that have unfavourable implications, it was observed that factors explaining more consumption of SSBs by those of lower socioeconomic status include being current smokers, usual drinkers, making food decisions using taste, liking or wanting, and engaging less in physical leisure activity, which are more prevalent in this group. On the other hand, frequent consumption of unhealthy foods, being overweight, as well as being occasional drinkers, explain the increased SSB consumption among those of higher socioeconomic status. Frequent consumption of fruit or vegetables also explains increased SSB consumption among individuals with higher socioeconomic status.

Table 5.4: Results from the decomposition analysis of SSB consumption

Variable	C_k	E	
		SSB servings per month	Daily consumption
Men (ref: women)	-0.009	-0.263***	-0.421***
Age (year)	-0.015	-0.480***	-0.173*
Ever-married (ref: never married)	-0.033	-0.006	0.055
Education (years)	0.122	-0.031	-0.025
Socioeconomic quintiles (ref: quintile 1)			
Quintile 2	-0.476	0.026***	0.026***
Quintile 3	-0.095	0.049***	0.059***
Quintile 4	0.338	0.068***	0.066***
Quintile 5 (highest)	0.785	0.065***	0.063***
Work-related physical activity (ref: light)			
Moderate	-0.023	0.023**	0.074***
High	-0.176	0.006**	0.021***
Living in urban (ref: non-urban)	0.164	0.020*	0.055***
Smoking status (ref: never)			
Current	-0.085	0.028***	0.047***
Ex-smoker	0.013	0.007**	0.008*
Alcohol drinking status (ref: never/rarely)			
Former	-0.018	0.019***	0.027***
Occasionally	0.055	0.023***	0.018***
Usually	-0.059	0.010***	0.016***
Unhealthy foods for 5–7 d/w (ref: <5 d/w)	0.073	0.042***	0.072***
Vegetable for 5–7 d/w (ref: <5 d/w)	0.017	0.012	0.119***
Fruit for 5–7 d/w (ref: <5 d/w)	0.112	0.046***	0.143***
Main meal (number per day)	-0.004	-0.483***	-0.403***
Non-home cooked (ref: home-cooked)	0.219	0.071***	0.080***
Food choice (ref: cleanliness)			
Taste	-0.013	0.019***	-0.013
Nutrition	0.120	-0.006	-0.023***
Price	-0.153	-0.001	-0.010**
Convenience	0.010	0.010***	0.014***
Liking	-0.039	0.031***	0.030***
Wanting	-0.064	0.028***	0.007
Food label consideration (ref: never/unsure)			
Seen but no impact	0.024	0.026***	0.040***
Seen and have impact	0.112	0.010	-0.009
Leisure-time physical activity (ref: sufficient)			
Insufficient, willing to do more in 1 month	0.077	0.000	0.006
Insufficient, willing to do more in 6 months	0.073	0.005	0.011*
Insufficient, no/unclear willing to do more	-0.065	0.047	0.104**
Weight status (ref: normal)			
Underweight	-0.026	0.000	-0.003*
Overweight	0.007	0.022***	0.010**
Obese	-0.022	0.003	0.008
Health problem (ref: no health problem)	-0.052	-0.005	-0.007*

E = elasticity, the change in the outcome associated with a one-unit alteration in the explanatory variable, with a positive sign indicating an increase and a negative sign indicating a decrease in the outcome due to a positive change in the explanatory variable

C_k = the degree of concentration of the explanatory variable across socioeconomic status was denoted as Ck. A negative Ck indicates a higher prevalence of the respective variable among lower socioeconomic individuals, while a positive Ck suggests a higher prevalence among those of higher socioeconomic status)

d = day; ref = reference; SSB = sugar-sweetened beverage; w = week

*** = p-value < 0.01, ** = p-value < 0.05, * = p-value < 0.10, The p-value indicates association of explanatory variable with SSB consumption obtained from the regression coefficient from the linear regression model.

5.8 Discussion

This study examined the factors influencing the consumption of SSBs in Thailand. The results showed that various demographic, socioeconomic, behavioural, habitual and health factors were associated with higher SSB consumption. Specifically, frequent SSB consumers were associated with higher socioeconomic status, exhibited several unhealthy behaviours such as smoking, consuming unhealthy foods, being less active, and using appetitive motivations to choose foods. The study also revealed a distinct relationship between SSB consumption and socioeconomic status. Those of lower socioeconomic status often pair SSB consumption with smoking, regular drinking, appetitive motivations for choosing foods, and limited physical activity. Conversely, those of higher socioeconomic status combine SSB consumption with increased consumption of foods overall, regardless of whether the foods are healthy or unhealthy.

The findings of this study, indicating that lower socioeconomic individuals had lower SSB consumption or that educational attainment had no link to SSB consumption, were inconsistent with conventional economic frameworks that often predict an inverse relationship between such factors and unhealthy behaviours[291,306,307]. This discrepancy can be explained by the fact that there is a different interaction between SSB consumption and socioeconomic status across countries. In high-income countries, SSBs are often identified as inferior goods, in which SSB consumption decreases with growing income, while the opposite remains true for several low- and middle-income countries[308]. In a high-income setting, SSBs might be perceived by the wealthy as a cheap product associated with those of lower socioeconomic status. In low and middle-income countries including Thailand, overconsumption of foods, whether healthy or unhealthy, appears to be more prevalent among individuals of higher socioeconomic status[309], and this pattern is observed in this study. This can be attributed to factors such as greater affordability and the cultural influence that associates unhealthy foods with wealth and status, leading high-income individuals to consume more[310].

The extensive literature discusses how certain demographic, socioeconomic and behavioural characteristics impact the consumption of SSBs either locally in Thailand[1,94,116] or internationally[42-45,48,289,295-298]. This study further explores the less apparent psychological aspects, revealing that some individuals might be more susceptible to instant gratification from SSBs than others. Those driven by appetitive motivations, such as liking and wanting, were found to consume more SSBs. Especially, these food-related decisions have been linked to brain mechanisms with addiction behaviours, from the increased dopamine[140]. While these mechanisms have been acknowledged in psychological research[311,312], they remain underrepresented in social science studies. Integrating these insights could further illuminate another cause of SSB consumption, beyond just identifying who consumes these beverages, but also why they do so. Specifically, their decision to purchase and consume SSBs is not limited to economic conditions or self-discipline, but could be indicative at a deeper level of the possible existence of an inherent addictive susceptibility[42]. Future research may aim to understand the underlying factors, such as environment, psychosocial elements, or biology that influence these individuals' food motivations. This could lead to more effective and compassionate policies in addressing SSB consumption. In addition, the study reveals that SSB consumption is just one behaviour in an overall cluster of unhealthy behaviours. Frequent SSB consumers were also found to engage in other unhealthy behaviours like smoking, being less physically active, and overeating. These behaviours are related with lower self-control, as discussed in the literature[291]. In behavioural economics, these individuals are often observed to have a higher positive time preference, where they prioritise immediate rewards over the long-term benefits such as improved health and reduced risk of chronic diseases[291,313]. Changing behaviours in these populations can therefore be challenging as relying solely on individuals' willpower may not be adequate to encourage people to discontinue their unhealthy behaviours[314]. There is evidence to suggest that the food industry is aware of this cluster of susceptibilities and exploits them, targeting vulnerable individuals often referred to as 'heavy consumers' for profit[315].

This study indicates the potential unequal distribution of benefits from any policy to reduce consumption of SSBs in which the benefits would accrue more to people of higher socioeconomic status due to their higher consumption of SSBs than to people of lower socioeconomic status. This also might indicate the potent milder tax regressivity if Thailand imposed a tax on SSBs. The regressivity of SSB taxes, where they disproportionately burden those of lower socioeconomic status[316], might be mitigated since they consume fewer SSBs. However, merely considering the level of SSB consumption is not enough when assessing the impact of SSB taxes[17]. For example, previous studies have indicated that there is an association between socioeconomic status and people's degree of price responsiveness to SSBs[195,317], which could yield distinct policy benefits for various socioeconomic groups. It is essential to concurrently evaluate these relevant factors, especially in their health outcomes. Such evaluations are frequently conducted in modelling studies[56].

Several policy implications can be drawn from this study. First, the findings suggest that individuals who consume SSBs frequently are also likely to engage in various other unhealthy behaviours which highlights the need to address such clusters of unhealthy behaviours collectively[318]. Secondly, it is necessary for policies to address the underlying behavioural factors that contribute to SSB consumption, taking into account the complex and interconnected nature of these factors. For example, the finding that individuals displayed addiction-like behaviours towards SSBs could be suggestive evidence that they might respond less predictably to a price increase from a policy such as a tax on SSBs[319]. Due to habit formation, this can make it challenging for them to abruptly stop SSB consumption[132]. Therefore, it might be more sensible for a gradual shift of these consumers towards beverages with reduced sugar content. One way to facilitate this is through a dual tax mechanism: taxing high-sugar drinks more heavily while offering tax incentives for beverages with lower sugar or alternative sweeteners, thereby making them more financially appealing. Lastly, it is crucial to ensure that the approach chosen addresses the unique challenges of lower socioeconomic groups. For example, given the observed high prevalence of smoking and alcohol consumption in lower socioeconomic groups, it is vital to note that these groups might already be burdened with other health-related taxes[51]. Introducing subsidies for healthy foods could offset the financial impact of an SSB tax if introduced in Thailand.

This study has several strengths, primarily its use of an extensive and representative dataset from the Thai population. The study expands existing knowledge in Thailand on how other various factors influencing SSB consumption[1,94,116]. The decomposition analysis reveals unique patterns of SSB consumption across different socioeconomic groups, a dimension not explored in prior research.

The study has several limitations. First, the data did not differentiate between the types of SSBs. Previous research in Thailand suggested that different types of SSBs are consumed differently across the population. For example, energy drinks were consumed more among individuals of lower socioeconomic status and individuals engaged in labour-intensive work, while carbonated beverages were consumed more by those of higher socioeconomic status[94]. Second, the self-reported dietary data may be prone to bias, particularly in certain populations such as those who have excessive weight who may underreport their overall diet[320]. Nevertheless, this study suggests that being overweight associated with increased consumption of SSBs. Third, the survey's reliance on past-30-day consumption may be prone to recall bias and could underestimate consumption levels. However, this time frame may be reasonable as shorter periods such as 24-hour dietary recalls may not reflect usual consumption patterns[321]. Fourth, it is possible that an inverse relationship exists, whereby individuals who have health problems may report lower SSB consumption due to their intention to avoid such beverages[94]. Lastly, the findings in this study are specific to adult populations (aged 25 to 59) and may not be replicable in younger or older demographics.

5.9 Conclusion

In Thailand, individuals of higher socioeconomic status typically consume more SSBs. Those who frequently consume SSBs often exhibit various unhealthy behaviours, some of which are akin to addiction. These tendencies are particularly pronounced among individuals with lower socioeconomic status. This insight should be considered when formulating policies aimed at reducing SSB consumption in Thailand. Policymakers should prioritise interventions that address overall unhealthy behaviours alongside those targeting the overconsumption of SSBs.

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Chapter 6: Cost-Effectiveness of a Tax on SSBs to Reduce Obesity in Thailand

6.1 Preamble

This chapter presents an economic evaluation of a tax on SSBs in Thailand. The study aims to address various issues highlighted in previous chapters associated with assessing the value and equity implications of implementing a tax on SSBs. Specifically, Chapter 3 highlighted several issues regarding the impact of SSB consumption on weight. Therefore, this study carefully considers how to estimate the effect of SSBs on weight. Particularly, the evaluation accounts for a likely significant compensation effect where SSBs offset other foods, reducing their impact on weight.

Chapter 4 raised concerns that since consumption of SSBs is more prevalent among those of higher socioeconomic status, interventions to address their consumption might have a limited impact in reducing socioeconomic-based inequity. This highlights the need for further analysis on this issue. This evaluation addresses these concerns. Specifically, the study acknowledges that the impact of a tax on SSBs might vary by socioeconomic group. The study also details the potential long-term consequences for health and economic outcomes across different socioeconomic groups. In line with Chapter 4, the study employs a concentration index approach to assess potential improvements in equity resulting from an SSB tax.

Informed by Chapter 5, the study considers habitual factors and includes those with appetitive motivations for foods. Acknowledging the diverse characteristics of consumers that might influence the outcomes, a microsimulation model has been developed to capture details at the individual level, specifically characteristics influencing SSB consumption as informed by Chapter 5.

Chapter 6 is presented in the format of a manuscript currently under review at *Health Economics*. The authorship roles are as follows:

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- Data analysis: KT.
- Writing - original draft: KT.
- Writing - review and editing: JC, RL, and SG.
- Supervision: JC, RL, and SG.
- Validation: KT, JC, RL, and SG.

6.2 Manuscript's Details

Title: Assessing the Cost-Effectiveness of a Tax on Sugar-Sweetened Beverages in Thailand – Economic and Equity Impacts

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6.3 Highlights

- Using a microsimulation model, this study evaluated the economic and equity impacts of taxing sugar-sweetened beverages (SSBs) in Thailand.
- Both a proposed tax which is based on tiers of sugar content (tier-based tax) and a hypothetical 20% tax on value (ad valorem tax) could reduce obesity and improve health, demonstrating cost-effectiveness.
- These taxes potentially promote health equity as they offer more significant health benefits to the socioeconomically disadvantaged; however, they also impose a financial burden on them.
- The success and benefits of the taxes depend heavily on how the beverage industry responds to implementing a tax.

6.4 Abstract

Introduction Thailand is planning to implement a higher tax on sugar-sweetened beverages (SSBs) to discourage excessive consumption and improve public health. This study evaluates the potential effects of such an SSB tax on health outcomes, its economic implications, and impact on health equity in Thailand.

Methods A microsimulation model was developed to compare the cost-effectiveness of the proposed tier-based tax and a hypothetical 20% ad valorem tax with the status quo of a pre-existing general excise tax. The model simulates the long-term health and economic consequences of the taxes of approximately 50,000 individuals from a nationally representative survey. The incremental cost-effectiveness cost per quality-adjusted life years (QALYs) gained was estimated. The model also projected the tax burden and economic losses resulting from the taxes. The concentration index was used to measure the distribution of net health benefit (NHB) across socioeconomic quintiles.

Results The model projects that the tier-based tax and the 20% ad valorem tax would prevent an average weight gain of 22 grams and 70 grams per person over their lifetime, respectively. This converts to a reduction of 0.86 cases of excess weight per 1,000 individuals for the tier-based tax and 2.83 cases for the 20% ad valorem tax. The tier-based tax is projected to yield an additional 1.36 QALYs and save $712 per 1,000 individuals, whereas the 20% ad valorem tax is expected to provide 4.38 QALYs and save $2,411 per 1,000 individuals. Consequently, both taxes are considered to be dominant relative to the status quo - resulting in lower costs but higher health outcomes. The concentration index results are -0.11 for the tired-based tax and -0.12 for the 20% ad valorem tax, suggesting that both taxes provide more NHB for individuals in lower socioeconomic quintiles. The total tax burden is estimated at $106 million for the tier-based tax and $2,119 million for the 20% ad valorem. Both taxes disproportionally affect lower socioeconomic groups. The results are highly sensitive to assumptions regarding the beverage industry's reactions to the implementation of the taxes.

Conclusion This study demonstrates that increasing taxes on SSBs in Thailand improves health outcomes, is cost-effective and may improve health equity. The impacts of the taxes rely heavily on the response from the SSB industry, therefore monitoring industry response to the taxes is recommended. Concurrent interventions to minimise the adverse effects of tax regressivity should also be explored.

Keywords: Sugar-sweetened beverages (SSBs), Thailand, Cost-effectiveness, Microsimulation model, Socioeconomic status, Health outcomes, Tax burden, Quality-adjusted life years (QALY), Productivity loss, Health inequality

6.5 Introduction

Over the past 30 years, there has been a notable increase in obesity rates in Thailand. A 2019 national survey revealed that more than half of Thai adults are now in a weight range defined as either overweight or obese[79], a sharp increase from just one-fifth three decades ago[71]. This concerning trend is primarily attributed to the shift toward high-calorie foods, coinciding with advancements in the Thai economy[5,73]. As obesity rises, the impact on public health intensifies. For instance, individuals with obesity have a risk of premature death that is 4.57 times greater than those who are not obese[82]. The Global Burden of Disease Study showed an 85.2% increase in morbidity and mortality attributed to obesity-related diseases from 1990 to 2017 in Thailand. This growth rate significantly surpasses the average of 56.7% observed in comparable middle-income countries[81]. Economically, the consequences of the increased obesity in Thailand are equally severe. The country's obesity-related costs, which were estimated at only 0.13% of the national gross domestic product (GDP) in 2009, rose to 1.3% in 2019 and are projected to surge to 4.9% by 2060[7].

Sugar-sweetened beverages (SSBs), often criticised for their high sugar content providing excessive calories without significant nutrition[175], have been considered worldwide as a critical factor in overnutrition in populations and represent an increased risk for obesity[11]. This criticism has placed SSBs at the centre of attention for public health policies. A tax on SSBs has emerged as one solution to curb obesity, supported by international agencies such as the World Health Organization (WHO)[20] and the World Bank[89]. For example, in 2022, the WHO published a guideline on taxing SSBs, and the World Bank maintains a dedicated database exclusively on SSB taxes – the Global SSB Tax Database[322]. According to the database, in 2023, more than 100 countries have already implemented a tax on SSBs.

Thailand's SSB consumption is remarkably high. Research reveals that a significant proportion of the Thai population, as much as 70%, consumes SSBs daily[323]. This rate of consumption often results in many surpassing the daily recommended sugar intake[14]. In fact, when compared to other Asian countries, Thailand has often been ranked as the country with the highest SSB consumption[112,113]. For example, data from the Euromonitor Passport International database on global beverage sales trends revealed that Thailand has the highest calories sold per capita per day from SSBs compared to other

Asian countries like Japan, Malaysia, and the Philippines[11]. Recognising this trend, policymakers in Thailand, following global efforts, are considering implementing a tax on SSBs to reduce their consumption[8].

The proposed SSB tax in Thailand is structured as a specific tax tiered by sugar content, in combination with an ad valorem tax[8]. While the proposed tax has a dual strategy, the emphasis of the tiered system is on lower taxes for less sugary beverages, incentivising the industry to reformulate their products[8]. Such a tax structure has been successful in specific countries, such as in the United Kingdom, where nearly half of all SSB products available reduced the amount of sugar in their beverages in response to the implementation of the tax[324,325]. Yet, while the efficacy of a tax structure is undeniable in health tax successes[326], a comprehensive evaluation of different SSB tax structures remains limited. For example, of many existing economic evaluations of SSB taxes[2,24-27,53,211-218], only one investigated the potential impacts of varying tax structures[27,327].

In the Thai context, it remains undetermined whether the proposed tax or alternative approaches, such as a 20% ad valorem tax often evaluated in other countries[24,213,216,218], would be more effective in reducing SSB consumption[19]. The cost-effectiveness of such measures, a crucial consideration for health interventions in Thailand[166], has yet to be clarified. Furthermore, since addressing health equity is a primary objective for public health interventions like SSB taxes[328], understanding their potential impact across different population groups is important. Additionally, SSB taxes do not solely bring benefits but various challenges[24]. For example, studies have shown that health-related taxes[329] as well as SSB taxes[317], often impose a greater financial burden on those with lower socioeconomic status in many countries. This risk needs to be examined in Thailand as well. To support evidence-based policy planning in Thailand, an economic evaluation was conducted to comprehensively assess the impact of SSB taxes, focusing on their health benefits, cost-effectiveness, economic impacts, and equity implications.

6.6 Methods

SSB tax options

The proposed tax on SSBs in Thailand is complex, integrating both specific and ad valorem taxes. It is further complicated by its proposed application that varies by type of SSBs and with multiple other components, such as exemptions for certain sugared beverages and phased implementation[8]. Evaluating such a detailed version of the tax is also limited by data availability. Therefore, this study evaluates a simplified version of the proposed tax, which is structured as a combination of both specific and ad valorem taxes, as summarised in Table 6.1. The ad valorem tax is set at 14% of the manufacturer's suggested retail price (MSRP) for beverages. Meanwhile, the specific tax is volume-based, with rates tiered by sugar content; SSBs with higher sugar content will incur a higher rate. Given the tiered nature of Thailand's SSB tax, this study calls the assessed tax the 'tier-based tax'. The tier-based tax was compared with the 'status quo' where a pre-existing general excise tax (not SSB-specific) was levied at the greater value of either 20% of its price or 0.45 THB per 1,000 mL. The study also examined the implications of adding a 20% ad valorem tax to the pre-existing general excise tax, a measure that has been frequently investigated in other studies.

Table 6.1: Summary of a tier-based tax for SSBs proposed in Thailand evaluated in this study

Sugar per 100 mL (grams)	Pre-existing general excise tax (status quo)	Tier-based tax	
		Ad valorem	Specific (per 1,000 mL)
0 – ≤6	Choose the higher taxed price between a 20% ad valorem tax and a 0.45 THB/L (0.013 USD) specific tax	14%	0
> 6 – 8		14%	1 THB (0.029 USD)
> 8 – 10		14%	3 THB (0.086 USD)
> 10 – 14		14%	5 THB (0.143 USD)
> 14 – 18		14%	
> 18		14%	

mL = millilitre; THB = Thai Baht; USD = United States dollars
Note: the exchange rate of 35 THB = 1 USD in 2022.

Study population

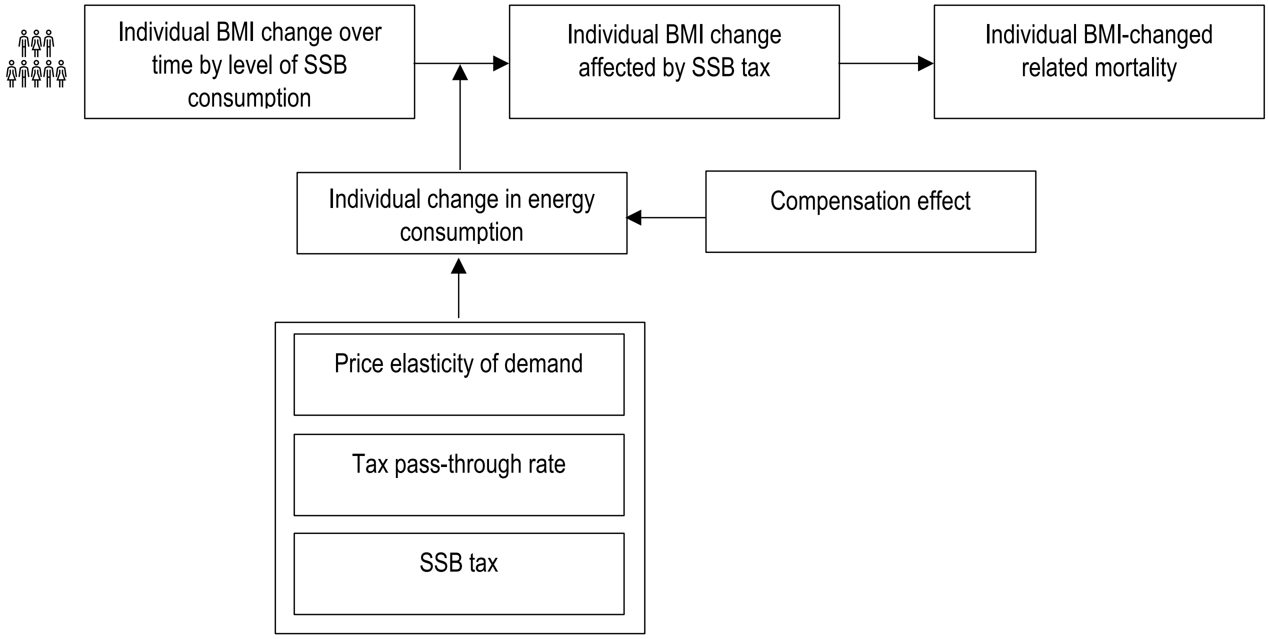
The study population is a cohort of approximately 50,000 Thai adults aged 25–59 sourced from the Health Behaviour of Population Survey in 2021[57]. This cross-sectional nationally representative survey carried out in Thailand in 2021 collected data covering demographics, socioeconomics, and various health behaviours. This study used information from that survey on individuals, such as age, gender, weight, height, SSB consumption, income, and food habits. For SSB consumption, participants were asked about their consumption frequency of prepackaged non-alcoholic beverages containing sugar over the past 30 days, specifically the number of days and the number of 250 mL servings. The survey suggested that 16% of the participants had daily SSB consumption. This study used a mean sugar content in SSBs of 12 g per 100 mL (i.e. 30 g per one 250 mL serving) consistent with a previous study in Thailand modelling the impact of SSBs on weight[93]. Individuals were classified into five socioeconomic quintiles using the equivalised household income (the squared root scale[266]). Non-SSB consumers were included in the model as it is important for distributional analysis such as examining results by socioeconomic status and weighting and tax burden analysis[330].

Model structure

The study population was modelled individually for their long-term outcomes using a microsimulation model, named ThaiMicroSim, developed using Excel[331]. The model's schematic is presented in Figure 6.1. Key parameters and assumptions are summarised in Table 6.2. All other parameters, assumptions, and further explanation of the model are provided in Table 8.5 in the supplementary appendix.

The computational step in the model starts by projecting the trajectory of weight development throughout an individual's lifetime, in the absence of a tax on SSBs. Published data from a local follow-up cohort called the "Thai Health-Risk Transition: a National Cohort Study" were used in this step, which reported variations in weight development based on level of SSB consumption (daily, 3–6 days a week, < 3 days a week, and no consumption), gender, and age[114]. Additionally, the model assumed that individuals gain weight until the age of 60 years, following literature suggesting that body weight peaks around the ages of 55 to 60 years[332,333]. Next, using the weight outcomes generated in the previous step and the consistent height parameters (assuming maximum height reached at age 18 to 22 and is assumed to remain unchanged[334]), the model computes each individual's body mass index (BMI; weight in kilograms divided by height in metres squared). Subsequently, the derived BMI was used to classify the weight status of each individual into one of four categories based on the WHO classification[264]: underweight (BMI < 18.5), normal weight (BMI 18.5 to < 25), overweight (BMI 25 to < 30), and obese (BMI ≥ 30) (Table 8.6 in the supplementary appendix). These weight classifications were used to assign related consequences such as health-related quality of life (HRQoL), costs, and mortality rates to individuals within the model.

Figure 6.1: Model structure



Effectiveness of an SSB tax

The tax is expected to reduce the level of SSB consumption, subsequently reducing caloric intake (from changes in sugar consumption) and thereby influencing an individual's weight development. Estimating changes in consumption includes two aspects: change in price and change in consumption respective to that change in price (Figure 8.4 and Table 8.7 in the supplementary appendix).

The change in price due to the tax relies on three components: the value of products at baseline, i.e., the price without taxes also known as the MSRP; the tax rate; and tax pass-through rate. An assumed mean suggested retail price per 100 mL serving of THB 2.96 estimated from a local study was applied[91]. Tax pass-through indicates the industry's reaction to the tax, deciding whether to absorb it or pass it onto consumers. A meta-analysis informed the model's assumption of an 82% tax pass-through rate onto consumers for the tier-based tax[335]. For the 20% ad valorem tax, a slightly reduced pass-through rate of 70% was assumed, considering that SSBs are likely a highly competitive product, and evidence suggests that the pass-through rate of ad valorem taxes for such goods is lower than for specific taxes[336]. The formula for the change in price can be denoted as: 'suggested retail price' * 'tax' * 'tax pass-through rate'.

The change in consumption due to a change in price is often termed price responsiveness or, more specifically in economics literature, as the own-price elasticity of demand. This metric, indicating the percentage change in consumption resulting from a price shift, is crucial for determining tax effectiveness[54]. Given the absence of studies specifically examining own-price elasticity of demand for SSBs in Thailand, own-price elasticity of demand for SSBs was derived from a Thai study on non-alcoholic beverages, of which about 90% are estimated to be sweetened beverages[1]. Based on this research, the current study estimated five levels of own-price elasticity of demand, tailored to the five socioeconomic quintiles featured in the model. The estimated price response used in the model was most pronounced in the lowest socioeconomic quintile, at -1.58, and least pronounced in the highest quintile, at -0.42. This trend aligns with findings from several countries with comparable economic contexts[2,25]. The tax's effectiveness in terms of reduced SSB consumption in this study is therefore the product of ('suggested retail price' * 'tax' * 'tax pass-through rate') * 'own-price elasticity'.

Accounting for food habits

SSBs are often considered highly appealing due to their ability to activate the brain's reward system, leading to behaviours resembling addiction[337]. Certain individuals have a greater susceptibility to such addictive tendencies, making them less likely to modify their consumption patterns even when faced with price increases[319,338]. In the Thai context, prior research using the same dataset indicated a higher consumption of SSBs among individuals driven by appetitive motivation towards food[327]. Therefore, this study accounted for such food habits by assuming that individuals guided by appetitive motivations are less price-sensitive, with a price elasticity of -0.40, the lowest value derived from the relevant study on own-price elasticity of demand in Thailand[1]. This assumption is corroborated by studies indicating that high SSB consumers demonstrate reduced price sensitivity[234,235] as well as findings in addiction research, such as in tobacco use, that reveal a similar inelastic price elasticity of -0.48 for tobacco products[339]. Integrating these habitual factors aligns with recommendations that economic evaluations of public health interventions should incorporate the influence of population behaviours[193,338].

Beverage reformulation

A tier-based tax system, which levies lower rates on beverages with less sugar and higher rates on those with more sugar, is designed to incentivise the industry to produce a higher proportion of low-sugar beverages[17]. As a result, consumption patterns are expected to shift towards increased intake of low-sugar drinks and decreased intake of high-sugar drinks. The baseline distribution of SSBs across the four sugar-content tiers was sourced from a Thai research study[91]. Beverages in each tier are subject to distinct tax rates, leading to variations in their prices. Given the proposed tax structure, the new prices for beverages in the model are expected to decrease for those SSBs of <10 g per 100 mL and increase for those with higher sugar content compared to the current prices (status quo). When accounting for consumer price responsiveness, these price alterations induce shifts in consumption, resulting in a new distribution within the six tiers in the presence of the SSB tax.

Other key factors in the model

While various elements influence the efficacy of the proposed tax, three factors are pivotal in the model: the compensation effect, the substitution effect, and the duration of these effects. First, the compensation effect represents the condition wherein individuals offset their consumption of one product by reducing their intake of another[229]. Consequently, if the energy derived from SSBs leads to a decrease in the consumption of other items, the weight gain might be less than what would be directly attributed to SSBs alone. Existing literature indicates there is a significant compensation effect linked to SSBs[109,230,231] including a Thai study[114]. This study estimates that only 10% of weight changes in the model can be attributed to SSB consumption. Second, the substitution effect comes into play when consumers react to SSB price increases by switching to similar, but untaxed or less-taxed products (e.g., snacks, candy, or ice cream)[17]. This is recognised in economic studies as cross-price elasticity. However, the nuances of this effect remain debated[119]. Given the tiered tax structure, the model posits that consumers are more likely to shift towards beverages with reduced sugar content (reflecting the industry's reformulation) rather than turning to other high-sugar alternatives[17]. However, as the substitution effect might be more pronounced in ad valorem tax systems[17], the model assumes a 20% substitution effect for the 20% ad valorem tax. Third, the duration of effects from a tax over time is uncertain, influenced by variables like inflation[17]. Additionally, existing evidence on the consequences of SSB tax implementation was based on studies of short observational duration, most often at three years[195]. Given these concerns, this study conservatively assumed that the tax's impact on SSB consumption remains for ten years.

Outcomes

This study models health and non-health outcomes. Health outcomes of interest include obesity-related outcomes of change in weight, BMI, obesity, and overweight prevalence, life-years (LY) gained, and quality-adjusted life years (QALYs) gained. The likelihood of death for individuals with normal weight is considered equivalent to the background mortality rate of the Thai population[340]. For those who are underweight, overweight, or obese, adjustments were made using published hazard ratios that compare these weight categories to the normal weight category[66]. Data on HRQoL by weight status were obtained from a local Thai study[82].

Non-health outcomes include the tax burden and the economic impact of the SSB tax. The tax burden at the individual level was calculated as '$\text{quantity}_{\text{taxed}}$' * ('$\text{price}_{\text{taxed}}$' – '$\text{price}_{\text{prior tax}}$')' i.e. where '$\text{quantity}_{\text{taxed}}$' is '$\text{quantity}_{\text{prior tax}}$' * ('1 – elasticity' * 'tax')[24] (as illustrated in Figure 8.5 in the supplementary appendix). The economic impact was estimated with a concept of deadweight loss in economics literature which is used as a measure of market inefficiency and was used in a previous study evaluating SSB tax in Australia[24]. The deadweight loss at the individual level was calculated as '0.5' * ('$\text{price}_{\text{taxed}}$' – '$\text{price}_{\text{prior tax}}$') * ('$\text{quantity}_{\text{prior tax}}$' – '$\text{quantity}_{\text{taxed}}$')[24]. The calculation of the tax burden and deadweight loss requires information on the elasticity of SSB supply. However, due to limited knowledge about the supply side[341], this study, for simplicity, assumes a horizontal supply curve, reflecting the highly competitive market of multiple SSB producers in Thailand[91].

Costs

The study uses a societal perspective. Implementation and administration costs were assumed to be 2% of tax revenue (based on a specific tax) and equally distributed at 1% of tax revenue each for government and industry[206]. For a tier-based tax, an additional 1% of tax revenue was included for government costs to address potential higher administrative requirements to administer the tax and monitor beverage sugar content[17]. Medical costs for the treatment of obesity and overweight-related illnesses were obtained from a previous cost-of-illness study of obesity in Thailand[80]. The model also included the potential of averting productivity losses from obesity-related diseases as a result of the taxes. This was estimated as a loss of income from premature death and work-related absenteeism calculated from the gross national income (GNI) per capita (in 2022)[342]. All costs were inflated to the year 2023 using the Thai consumer price index[343] and reported in United States dollars (at a rate of THB 35.00 per USD 1 in mid-2022[124]). Further details on the estimation of costs can be found in the 'Costs' section and Table 8.8 in the supplementary appendix.

Cost-effectiveness analysis

The incremental cost-effectiveness ratio (ICER) was estimated as the ratio of incremental costs per QALY gained[56]. The study also estimated the net health benefit (NHB) to assess the health gains from an intervention with the health losses from the opportunity cost, which is the value of the best alternative use of the resources [56]. The opportunity cost was assumed to be equivalent to the Thai cost-effectiveness threshold of US$5,000 (THB160,000) per QALY[344]. A positive NHB suggests the new intervention improves overall health, while a negative NHB suggests the benefits do not outweigh health losses from other unfunded health interventions. Reporting of the study follows the reporting guidance for health economic evaluation (CHEERS 2022: Table 8.9 in the supplementary appendix)[345]. Compliant with the Thai health technology assessment guidelines[346], the model adopts a lifetime horizon, and future costs and health outcomes are discounted at a rate of 3%. The model is structured in yearly cycles.

Consideration of health equity

Data on health inequalities offer a basis for integrating equity into evidence-based health planning and evaluating if existing or future health interventions support equity[29]. The equity impact in this study was assessed by examining differences in predicted health outcomes gained across socioeconomic quintiles. Outcomes specific to these quintiles were detailed and reported. Additionally, this study employed the concentration index to summarise the NHB[152,330] (more details in the supplementary material). The use of NHB to assess health equity in economic evaluation is aligned with a recent approach that suggested combining equity with cost-effectiveness analysis[330]. The concentration index ranges from -1 to 1. A concentration index value near zero indicates a health outcome evenly distributed across the socioeconomic quintiles. A value below zero suggests the outcome is more prevalent among lower socioeconomic quintiles, whereas a value above zero suggests a greater prevalence among higher socioeconomic quintiles.

Sensitivity analyses

Several uncertainties affecting the potential impacts of SSB taxes have been highlighted in the literature[18,24,27,213,347]. Moreover, experiences from the implementation of related health taxes, such as tobacco taxes, suggest that the industry can play a significant role in determining the impact of the tax[348]. Therefore, a thorough sensitivity analysis was conducted to assess the robustness of the model results to variations in parameter inputs and for potential changes in supplier/industry behaviour. This included variation in input values such as duration of effects, compensation effect, price responsiveness, and tax rates, as well as well an alternative assumption regarding food habits. In addition, an important area of inquiry involved testing the impact of potential adverse responses from industry, such as reducing the tax pass-through rate and employing different pricing strategies (e.g., manipulation of MSRP) to mitigate the impact of an SSB tax.

Table 6.2: Summary of key model inputs and assumptions

Parameter	Description	Value	References
Characteristics of the population	Individual level characteristics such as SSB consumption, age, gender, weight, height, income, habitual factors in food choices	Based on data from 49,127 individuals.	2021 HBS[57]
Price responsiveness	Own-price elasticity of demand: % change in consumption affected by 1% change in price of SSBs	By socioeconomic quintiles Q1: -1.58 Q2: -1.29 Q3: -1.00 Q4: -0.71 Q5: -0.42	Thai study on non-alcoholic beverages[1]. Estimate
		By food habits -0.40 for those who are influenced by an appetitive motivation toward foods	Assumption[339]. Estimate
Reformulation	Reformulation for more beverages with low sugar content (tier-based tax only)	Lower prices of SSBs with lower sugar content encouraging more of their consumption [1]	Assumption. Estimate
Duration of effect	Tax's effect duration	10 years	Assumption
Tax pass-through rate	Proportion of tax cost passed onto consumers	82% for a tier-based tax	Meta-analysis[335]
		70% for a 20% ad valorem tax	Assumption[336]
Compensation effect	Proportion of energy from SSBs consumed that was not equated to weight	90%	Thai Health-Risk Transition: a National Cohort Study[114]
Weight gain	SSB-related and non SSB-related weight gain over time	Varied by gender and age. Assuming weight develops until aged 60 years.	Thai Health-Risk Transition: a National Cohort Study[114]
Utility values	Health utility by weight categories	0.81: BMI <18.5 0.77: BMI 18.5 – <25.0 0.74: BMI 25.0 – <30.0 0.70: BMI ≥30.0	Thai study[82]

BMI = body mass index; HBS = Health Behaviour of Population Survey. Q = quintile of socioeconomic quintiles; SSB = sugar-sweetened beverages

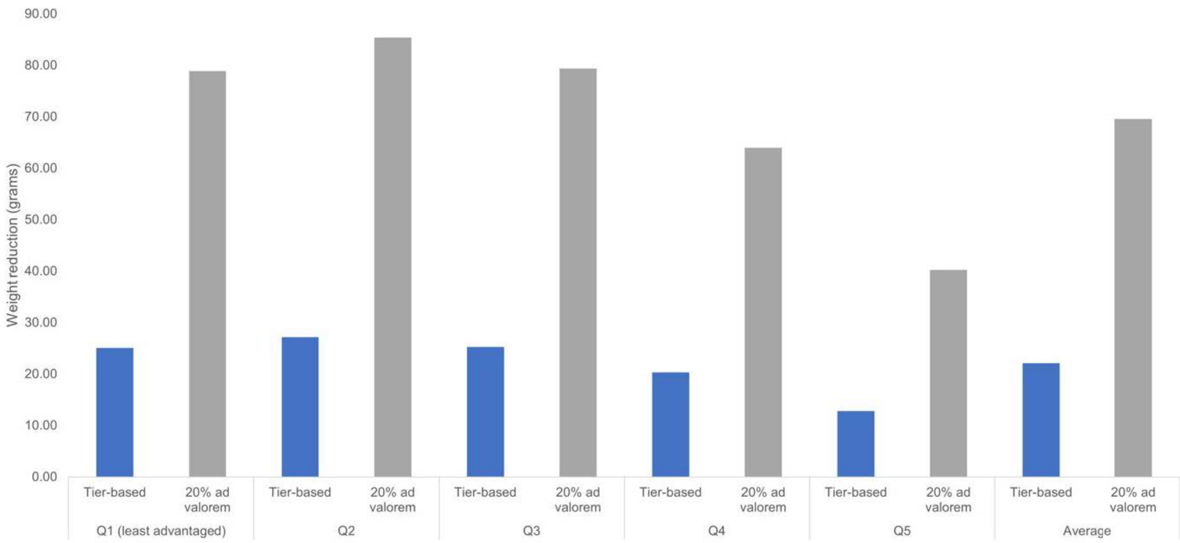
Full details in the supplementary material.

[1] the model predicted that prices of SSBs of < 10 g per 100 mL will become lower with the proposed tier-based tax.

6.7 Results

The model's projections on weight change show that the tier-based tax would, on average, prevent a weight gain of about 22 grams per individual over their lifetime with a higher effect observed among quintile 1 to quintile 3 (the low to middle socioeconomic quintiles) (Figure 6.2). In comparison, the 20% ad valorem tax is projected to prevent a weight gain of about 70 grams per individual over their lifetime.

Figure 6.2: Change in weight by socioeconomic quintiles and at the population level projected from the model



Q = quintile

In terms of the prevalence of excess weight (Table 6.3), the analysis identified distinct variations in the projected outcomes between the tier-based tax and the 20% ad valorem tax. Specifically, the tier-based tax is estimated to avert a total of 0.86 cases of excess weight in every 1,000 individuals (0.33 cases of obesity and 0.53 cases of overweight), with more cases prevented in low to middle socioeconomic quintiles than the higher quintiles. Conversely, the 20% ad valorem tax is more effective than the tier-based tax, potentially preventing approximately 2.83 cases of excess weight in every 1,000 individuals (1.18 cases of obesity and 1.65 cases of overweight). However, there is a variation from the tier-based tax where the 20% ad valorem tax is expected to prevent more excess weight within the middle socioeconomic quintiles.

For the gains in QALYs, the tier-based tax is projected to achieve an increase of 1.36 QALYs in every 1,000 individuals. This gain in QALYs is seemingly equitably distributed across quintile 1 to quintile 4, whereas the gain is expected to be lowest in quintile 5. The 20% ad valorem tax is expected to achieve an increase of approximately 4.38 QALYs in every 1,000 individuals. The distribution pattern for these gains indicates a more pronounced effect for quintile 1 to quintile 3, and a lower effect for quintile 4 and quintile 5. For every 1,000 individuals, the model predicts a reduction in the incremental costs of $712 for the tired-based tax and $2,411 for the 20% ad valorem tax. The increase in the incremental

QALYs and the decrease in the incremental costs suggest that both taxes are dominant, or cost-saving compared to the status quo.

The concentration index results of NHB are – 0.11 for the tier-based tax and – 0.12 for the 20% ad valorem tax. The negative results suggest that the gain in NHB is greater among the lower socioeconomic quintiles.

Table 6.3: Incremental outcomes and costs of the tier-based and the 20% ad valorem taxes (vs status quo)

Outcome	Q1 (lowest)	Q2	Q3	Q4	Q5	Average
Tier-based tax						
Weight[1] (mean, grams)	-25.10	-27.17	-25.25	-20.35	-12.81	-22.14
BMI[2] (mean)	-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Obesity[2] prevalence (per 1,000 individuals)	-0.41	-0.41	-0.51	-0.31	0.00	-0.33
Overweight prevalence[2] (per 1,000 individuals)	-0.61	-0.41	-0.41	-0.41	-0.31	-0.53
LYs (per 1,000 individuals)	0.97	0.95	1.02	1.03	0.40	0.87
QALYs (per 1,000 individuals)	1.63	1.46	1.60	1.51	0.59	1.36
Medical costs (USD per 1,000 individuals)	-$227	-$194	-$241	-$200	-$45	-$182
Productivity loss averted (USD per 1,000 individuals)	$555	$710	$703	$683	$463	$623
Implementation costs (USD per 1,000 individuals)						$92
Total costs	-	-	-	-	-	-$712
ICER (cost per QALY)	-	-	-	-	-	Cost-saving
NHB (QALYs per 1,000 individuals)	1.76	1.62	1.77	1.67	0.68	1.50
Concentration index – NHB	-	-	-	-	-	-0.11
20% ad valorem tax						
Weight[1] (mean, grams)	-78.89	-85.42	-79.38	-63.97	-40.26	-69.59
BMI[2] (mean)	-0.03	-0.03	-0.03	-0.02	-0.01	-0.03
Obesity[2] prevalence (per 1,000 individuals)	-1.53	-1.32	-1.53	-0.81	-0.71	-1.18
Overweight prevalence[2] (per 1,000 individuals)	-0.71	-2.24	-2.44	-2.44	-0.92	-1.65
LYs (per 1,000 individuals)	3.31	3.16	3.40	2.44	1.46	2.76
QALYs (per 1,000 individuals)	4.89	5.26	5.51	3.86	2.38	4.38
Medical costs (USD per 1,000 individuals)	-$815	-$718	-$756	-$501	-$344	-$627
Productivity loss averted (USD per 1,000 individuals)	$1,843	$2,155	$2,080	$1,905	$1,095	$1,816
Implementation costs (USD per 1,000 individuals)						$30
Total costs	-	-	-	-	-	-$2,411
ICER						Cost-saving
NHB (QALYs per 1,000 individuals)	5.42	5.83	6.07	4.33	2.66	4.86
Concentration index – NHB						-0.12

BMI = body mass index; ICER = incremental cost-effectiveness ratio; LYs = life years, NHB = net health benefit; Q = socioeconomic quintile; QALYs = quality-adjusted life years; USD = United States dollars
Note: ICER = incremental (medical costs + (-productivity loss averted) + implementation costs)/incremental QALYs
[1] accumulate per lifetime.
[2] at age 60 years.

Analysis of tax burden and economic impact

The results from the analysis of the tax and economic impacts are summarised in Table 6.4. The model predicts that the tier-based tax would account for about 0.02% of an individual's equivalised household income. However, this proportion is significantly higher in lower socioeconomic quintiles; for example, it is 0.05% in quintile 1, compared to just 0.01% in quintile 5. Comparatively, the 20% ad valorem tax imposes a heavier tax burden of 0.44% on an individual's equivalised household income. This equates to 1.00% of the equivalised household income for quintile 1 and 0.22% for the highest quintile. Given that the lower socioeconomic quintiles contribute a larger portion of their income towards these taxes, both taxes can be considered regressive[316]. When considering the total projected tax burden over the ten years of their duration of effect, the 20% ad valorem tax burden is estimated at US$2,119.30 million, much higher than the US$106.38 million estimated for the tier-based tax. Furthermore, the deadweight loss estimated for the 20% ad valorem tax is US$16.44 million, which is considerably higher than the US$0.04 million estimated for the tier-based tax.

Table 6.4: Tax burden and economic impact analysis of the tier-based and the 20% ad valorem (vs status quo)

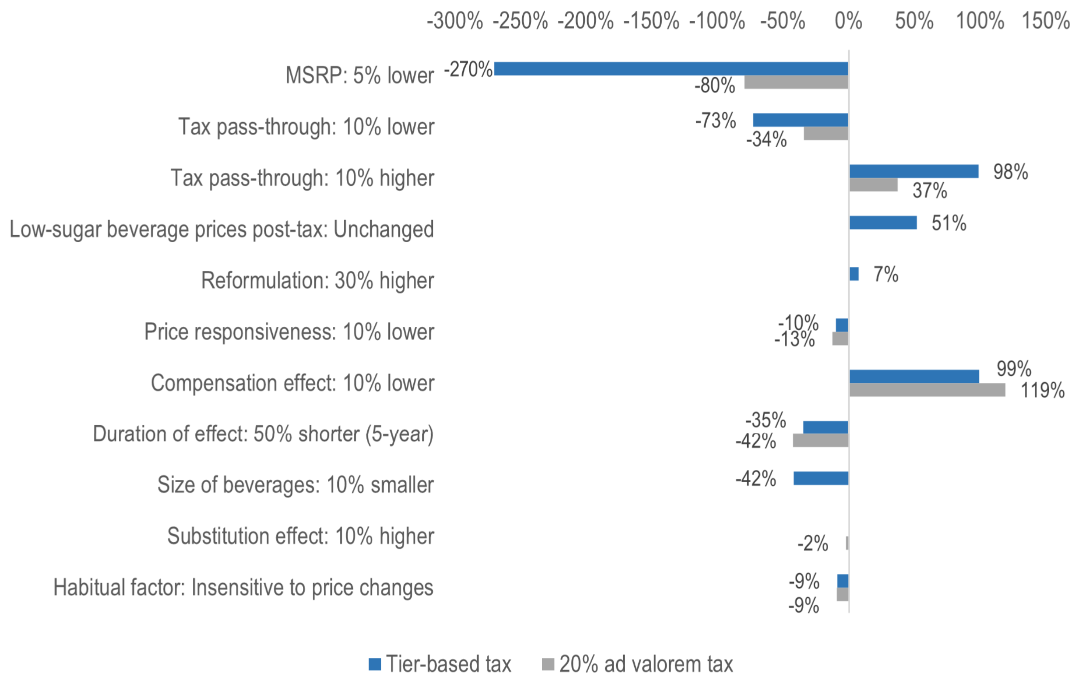
Outcome	Q1 (lowest)	Q2	Q3	Q4	Q5	Average, total[1]
Tier-based tax						
Tax burden						
Mean per person ($)	$2.04	$2.68	$3.29	$3.65	$3.57	$3.05
Tax burden per equivalised household income[2]	0.05%	0.04%	0.03%	0.02%	0.01%	0.02%
Number of people (million)	6.98	6.98	6.98	6.98	6.98	34.90
Total tax burden ($ million)	$14.26	$18.69	$22.96	$25.47	$24.95	**$106.34**
Economic impacts						
Mean deadweight loss per person ($)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Deadweight loss per equivalised household income[2]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total deadweight loss ($ million)	$0.01	$0.01	$0.01	$0.01	$0.00	**$0.04**
Total consumer surplus loss						
Mean total consumer surplus loss ($)	$2.05	$2.68	$3.29	$3.65	$3.58	$3.05
Total consumer surplus loss per household income	0.05%	0.04%	0.03%	0.02%	0.01%	0.02%
Total consumer surplus loss ($ million)	$14.27	$18.70	$22.97	$25.48	$24.96	**$106.38**
20% ad valorem tax						
Tax burden						
Mean per person ($)	$40.32	$53.08	$65.52	$72.98	$71.75	$60.75
Tax burden per equivalised household income[2]	1.03%	0.73%	0.61%	0.46%	0.22%	0.44%
Number of people (million)	6.98	6.98	6.98	6.98	6.98	34.90
Total tax burden ($ million)	$281.44	$370.45	$457.29	$509.34	$500.77	**$2,119.30**
Economic impacts						
Mean deadweight loss per person ($)	$0.54	$0.57	$0.54	$0.43	$0.28	$0.47
Deadweight loss per equivalised household income[2]	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%
Total deadweight loss ($ million)	$3.77	$4.00	$3.75	$2.99	$1.93	**$16.44**
Total consumer surplus loss						
Mean total consumer surplus loss ($)	$40.86	$53.65	$66.06	$73.41	$72.03	$61.23
Total consumer surplus loss per equivalised household income	1.05%	0.74%	0.62%	0.46%	0.22%	0.44%
Total consumer surplus loss ($ million)	$285.21	$374.45	$461.04	$512.33	$502.71	**$2,135.74**

[1] Total is in bold text
[2] Calculated as mean tax paid per year (lifetime tax/LY) divided by the equivalised household income per year in 2022.
Note: estimate for ten years (duration of effectiveness)

Sensitivity analyses

The results from the sensitivity analyses are summarised in Figure 6.3. The model is highly sensitive to the MSRP, tax pass-through rate, and compensation effect. The results are also sensitive to assuming that the industry does not reduce prices for beverages with low-sugar after the tax (tier-based), the industry decreases beverage sizes, and the effect of the taxes lasting for five years. However, the results are less sensitive to the assumption that there will be a higher proportion of low-sugar beverages due to product reformulation.

Figure 6.3: Change in net health benefits (NHB) from the sensitivity analyses



MSRP = manufacturer's suggested retail price
Reformulation: 30% higher. Assuming that a 30% reduction in the consumption of high-sugar beverages (defined as those containing 8 grams or more of sugar per 100 mL, following Briggs et al., 2017[347]). This decrease is then assumed to lead to a corresponding 30% increase in the consumption of low-sugar beverages, i.e., those containing less than 8 grams of sugar per 100 mL.
Low-sugar beverage prices post-tax. Assuming that those containing less than 8 grams of sugar per 100 mL do not become cheaper, as in the base case.

6.8 Discussion

The study presents the first economic evaluation of a tax on SSBs in Thailand. The application of a microsimulation model, as used in this study, is a rarity in Thai research. The economic model suggests that both the proposed tier-based tax and the hypothetical 20% ad valorem tax would be cost-saving policies to avoid the future prevalence of overweight and obesity in Thailand and contribute to improvement in the health outcomes of the population. In terms of the distributional impact, both taxes appear to favour the health of lower to middle socioeconomic groups while being financially regressive and disproportionately affecting those populations. Overall, the proposed tier-based tax is expected to have a lower tax burden, be less financially regressive, and cause less economic loss than the 20% ad valorem tax.

The cost saving from SSB taxes found in this study is consistent with findings from other studies in countries that either have an intermediate economic level similar to Thailand[2,25,211,218] or those with advanced economies[24,53,213-215,217]. The finding of regressivity of an SSB tax is consistent with several other studies, such as for the US[214], Australia[24] and Canada[213]. The health outcomes, which favour lower socioeconomic groups, are similar to studies in high-income countries[24,26,27,213-215]. However, these findings are inconsistent with a few studies from low- and middle-income countries that suggest lower socioeconomic groups experience less health benefits from SSB taxes[2,25]. One potential explanation is that this study's own-price elasticity applied to individuals with lower socioeconomic status was relatively high (-1.58 for quintile 1) compared to that applied to the other studies (-1.12 to -1.26 for quintile 1)[2,25].

This study predicts a markedly smaller change in weight compared to a previous study in Thailand evaluating the impact of SSB taxes on obesity[93] and other studies elsewhere, such as the Philippines[29], the US[21] and Canada. For example, the estimated weight reduction in this study ranges from around 0.02 to 0.07 kg, which is less than the 0.48 to 1.11 kg estimated in a previous Thai study[53,93]. Such lower estimates of weight change in this study can be attributed to reasons such as the low consumption of SSB and the high compensation effect applied in this study.

While it has been consistently found that SSB taxes could be cost-effective[2,24-27,53,211-218], there is less known about how various tax structures can contribute differently to health and other economic outcomes, which were examined only in a few studies[27,347]. This study adds to our knowledge on the importance of considering different tax structures when evaluating SSB taxes. When comparing a tier-based tax and a 20% ad valorem tax, this study suggests that the tier-based tax yields substantially fewer health gains than the 20% ad valorem tax. This difference arises because the model predicts the 20% ad valorem tax more effectively deters overall SSB consumption, regardless of sugar content. In contrast, the tier-based tax merely causes consumers to switch to beverages with lower sugar content due to the industry reformulation. Nevertheless, the findings of this study differ from another modelling study in the UK, indicating that a tax encouraging beverage reformulation (such as a tier-based tax) could provide larger health benefits than a tax aimed at raising prices (such as an ad valorem tax)[347]. The difference can be attributed to several factors. Specifically, compared to this study, the UK study assumed a significantly larger drop in the consumption of beverages with moderate to high sugar content under the reformulation-promoting tax scenario[347]. In contrast, it used a moderate tax pass-through rate of only 50%, compared to a higher rate of 70% in this study, in the price-raising tax scenario[347]. Furthermore, a tier-based tax was also found to yield higher health benefits compared to other tax structures, such as a volume-based tax, in a study from the USA; however, this US study did not include an ad valorem tax into its analysis[27].

The findings of this study suggest that the tier-based tax would have minimal adverse economic impacts, reflecting the distinct nature of the Thai tax on SSBs, which aims to balance health and economic interests[8,349]. Specifically, the tax was not designed to increase prices generally, but rather to tax beverages with low sugar content more lightly, providing an incentive for the industry to reformulate their products[8]. The proposed ad valorem rate of 14% is lower than the 20% under the previous excise tax. Given this structure, beverages with low sugar content are likely to experience a price drop compared to prices under the former excise tax[8]. Moreover, the proposed tier-based tax will not significantly alter the prices of beverages with high sugar content. For example, for a typical drink such as a 250 mL can of carbonated beverage containing 12 g of sugar per 100 mL, the anticipated price increase is only about 9% compared to its price under the previous excise tax. These price shifts for SSBs in Thailand are less pronounced than what is generally required to have a significant health impact, such as a change of at least 20%[20].

There are several strengths of the study. First, it offers a timely analysis of SSB taxes in Thailand, providing valuable insights for government policy. Second, the use of a microsimulation delivers a comprehensive and detailed computational approach, capturing the variability and heterogeneity in the data. This enhances the robustness of various distributional analyses, especially the assessment of equity impacts in this study[204]. Third, it integrates health behaviour into the model, aligning with recommendations that economic evaluations of public health interventions should reflect individual health behaviours[193,338].

There are limitations to this study. First, the study evaluated a simplified version of Thailand's proposed tax rather than the actual tax proposal which is complex. Second, the SSB consumption data from the HBS survey seem to be lower than previous estimates[323]. For instance, the survey indicates that the rate of daily SSB consumption among the participants is 16%, which is below the levels suggested in other surveys (40% - 70%)[323]. However, this difference might be partly arise from the inclusion of a younger population in the other survey. Younger individuals tend to consume significantly more SSBs compared to adults, the latter being the focus of this study[323]. The reduced SSB consumption could also have been influenced by the COVID-19 interruptions during the data collection period. Moreover, the survey provided incomplete information about SSBs that is essential for the model. For example, the survey does not contain information on prices or the sugar content of the SSBs consumed. The absence of data on the actual size (e.g., mL) of SSBs consumed by survey participants precluded this study from exploring a volumetric tax approach, an important tax design frequently evaluated in other countries[2,25,27,211]. Third, the model only considers health effects mediated through BMI, while there is a potential that SSB consumption has a direct link to some diseases such as diabetes. Fourth, the model was based on an analysis of a closed cohort and did not account for potential newcomers (e.g., individuals turning 25 each year) who might be affected by the tax. Last, some of the important parameters were sourced from countries with contexts different from that of Thailand. In particular, the tax pass-through rate was derived from a meta-analysis dominated by studies from high-income countries (primarily the USA), which have a different tax design (volumetric tax)[335].

Because of various uncertainties, this study's findings should not be seen as definitive predictions or outcomes. Rather, the findings should be viewed as comparative outcomes based on different hypothetical situations or scenarios. These uncertainties can be grouped into three main categories: industry response, unexplored alternative tax options, and consumer behaviour. First, consistent with a concern previously raised[52], the actual health outcomes depend largely on how the beverage industry responds to a tax. For example, similar to another study (Briggs et al., 2017)[347], the model suggests that the predicted health outcome is highly sensitive to the rate of tax pass-through to consumers; the more the tax is absorbed by the industry, the fewer health benefits are realised. Moreover, tactics from industry have posed challenges to the success of other health taxes. For example, the tobacco industry can manipulate prices at the manufacturing stage to circumvent the effects of an ad valorem tax[18]. As demonstrated in the sensitivity analysis, only a small change in the MSRP could have a high unfavourable impact on the estimated benefits from the tax. Other strategies, such as price smoothing – where changes in the prices of taxed products are managed to increase gradually rather than suddenly – were also evident following the implementation of tobacco taxes[348]. Therefore, it is important to be aware that the SSB industry may employ similar strategies in response to SSB taxes. Second, there are various other ways to design SSB taxes, and these were not explored in this analysis due to limitations such as the availability of data. For instance, a specific tax can be based on the absolute content of sugar, can be volumetric, or can be a combination of different ad valorem and specific taxes[17,350]. Further studies should explore potential differences in health outcomes from these tax design variations. Lastly, it remains important to have a better understanding of how different consumer groups respond to changes in SSB prices. This understanding should not be limited to sociodemographic factors like socioeconomic status but should also include factors like consumption choice behaviours. For example, it is important to know whether people with different food motivations react differently to changes in the price of SSBs. It is also important to understand the substitution or complementary effects that result from increasing SSB prices. In the context of Thailand, for example, consumers might opt for the large informal sector of SSBs[8], which largely bypasses the country's tax system.

Some policy implications can be drawn from the findings. First, the Thai government should consider the implementation of a tier-based tax, offering a balanced approach between health benefits and economic considerations. Second, a monitoring system is essential for strategies like a tier-based tax to ensure industry compliance. This may include an additional administration system that might be needed to verify whether sugar levels align with the tax tiers, continuous surveillance to observe if industries use tactics to mitigate tax impacts on SSB prices, such as price manipulation or absorbing most of the tax, and regular reviews of the impacts of the SSB tax, both intended (such as reformulation) and unintended (such as tax regressivity). Lastly, it is necessary to protect vulnerable populations, particularly people from lower socioeconomic backgrounds who could face a greater burden from SSB taxes. If an SSB tax is initiated in Thailand, options for supportive measures, such as subsidies for healthier food options, should be explored to offset the financial impact of an additional tax on SSBs.

6.9 Conclusion

This is the first study evaluating the cost-effectiveness of SSB taxes in Thailand. The study, using microsimulation, suggests potential benefits to population-level health from either the proposed tier-based tax or a hypothetical 20% ad valorem tax. Both taxes were found to be cost-saving, distributing more health gains to lower socioeconomic groups of the population. However, both taxes were also found to be regressive, imposing a greater financial burden on lower socioeconomic groups. Furthermore, the evaluated taxes are subject to several substantial uncertainties, largely from adverse responses from the industry, that can hinder the impact of an SSB tax on health. The government may decide to implement the tier-based tax but should also consider other concurrent interventions to minimise the adverse aspects of tax regressivity. Ongoing monitoring of industry strategies and continuous modelling of other tax options are recommended.

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Chapter 7: Discussion

The primary research question in the thesis was: What are the cost-effectiveness and equity impacts of the taxation of sugar-sweetened beverages (SSBs) as an anti-obesity policy in Thailand? Specifically, this thesis has:

- Identified methodological issues in published economic evaluations of SSB taxes.
- Examined the patterns of socioeconomic inequality in obesity in Thailand and determined the role of SSBs in influencing this inequality.
- Investigated the characteristics of frequent SSB consumers in Thailand.
- Estimated the cost-effectiveness of the proposed SSB tax, including the potential long-term effects on health outcomes, economic implications, and the impact on health equity in Thailand.

This chapter discusses key findings from the four studies conducted in the thesis and presents the resulting policy implications and recommendations. It also notes the limitations and uncertainties arising from this work, as well as making recommendations for future research.

7.1 Key findings

The systematic review (Chapter 3) highlighted various methodological issues in current economic evaluations of SSB taxes. Specifically, methodological issues arose from the approaches to estimating the effect of SSBs on body weight and the impact of SSB taxes on weight outcomes. Previous evaluations have focused on the effects of SSBs on body weight, neglecting the possibility of consumers compensating for SSB consumption by reducing their consumption of other products (i.e., the compensation effect). The evaluations also inadequately addressed that when SSB prices increase, consumers might choose alternative sugary products (i.e., the substitution effect). Furthermore, there was limited investigation into the unintended adverse outcomes, especially the economic burden of SSB taxes. Health equity considerations are increasingly common, often relying on informal analyses, like subgroup health outcome evaluations based on socioeconomic status.

As identified in the systematic review, information about health inequality, particularly the disproportionate prevalence of poor health among populations with lower socioeconomic status, is crucial for integrating equity into evidence-based health planning[29]. Thus, the second study in this thesis (Chapter 4) examined health equity and found evidence of socioeconomic inequality related to obesity in Thailand. The results indicated that this inequality varied by gender, with obesity more common among men of higher socioeconomic status and women of lower socioeconomic status. Certain factors like education status, health conditions and various unhealthy behaviours played significant roles in affecting these inequalities. While SSB consumption contributed to this inequality, its impact was relatively minor and was concentrated in people of higher socioeconomic status. This indicated that policies targeting SSB reduction might have limited impact in addressing socioeconomic-based health inequity. The study also identified that a significant proportion of women of lower socioeconomic status were obese and had health issues, recommending the introduction of government action to alleviate health inequities. The results also revealed that obesity-related socioeconomic inequality varied by region within Thailand, suggesting that regional public health authorities could play a key role in reducing this disparity. Last, the study suggested that while lower socioeconomic status men did not have an excess weight problem, they might face another serious health issue due to their high smoking rates.

The third study (Chapter 5) explored the determinants of SSB consumption in Thailand. Specific demographic, socioeconomic and behavioural factors were found to significantly influence consumption patterns for SSBs. The findings from this study reinforced those of the second study that higher socioeconomic status individuals consume more SSBs. Frequent SSB consumers often exhibited other unhealthy behaviours like smoking, consuming unhealthy foods, and having low leisure-time physical activity. Moreover, the study extended our understanding of SSB consumption by showing that SSB consumers had habits mirroring those seen in addiction, as evidenced by their appetitive motivations for foods including ‘liking’ and ‘wanting’[311,312]. Additionally, the study suggested that the factors contributing to SSB consumption varied by socioeconomic status. People of higher socioeconomic status tended to pair SSB consumption with consumption of other foods regardless of whether the foods were healthy or unhealthy. Conversely, people from lower socioeconomic backgrounds associated SSB consumption with behaviours like smoking, drinking, and having low leisure-time physical activity; or habits like using appetitive motivations for foods. Given these findings, this study built on the previous one, suggesting that policies addressing SSB consumption alongside broader unhealthy behaviours might have a more pronounced effect on both health and health equity. However, the study also hinted at the potential financial strain on lower socioeconomic groups from the implementation of an SSB tax, especially those already bearing health-related taxes on tobacco and/or alcohol.

The final study (Chapter 6) of the thesis was the first to assess the cost-effectiveness of SSB taxes in Thailand. It drew together the information on methodological challenges observed in the systematic review, together with the factors affecting SSB consumption and subsequent obesity, as identified in Chapter 4 and 5 including the impact of appetitive motivations for foods, assuming they relate to less price sensitivity for SSBs. Using a bespoke microsimulation model, the study suggested potential benefits to population-level health from either a tier-based tax or a hypothetical 20% ad valorem tax. Both taxes were estimated to be dominant relative to the status quo, being both cost-saving and offering more health benefits overall. The model showed that while individuals of lower socioeconomic status consumed fewer SSBs, factors like price responsiveness (higher among them than those of higher socioeconomic status) meant they could experience greater health benefits from such taxes (by experiencing a greater reduction in SSB consumption in response to a tax) relative to those of higher socioeconomic status. However, this study also highlighted existing concerns about the regressivity of SSB taxes in that they might impose a larger financial burden on people of lower socioeconomic status. Nevertheless, the tier-based tax had milder regressivity compared to the hypothetical 20% ad valorem tax. Lastly, the study suggested several substantial uncertainties regarding the predicted consequences of a tax on SSBs, largely due to adverse industry reactions, such as reducing the proportion of a tax that is reflected in the beverage price increase (tax pass-through rate).

7.2 Policy Implications and Recommendations

When deciding on SSB taxes, policymakers need to consider various aspects of its design and possible impacts. A high tax rate on SSBs could raise revenue and reduce consumption, but it could also harm the economy and face strong resistance from the industry and consumers. On the other hand, a low tax rate on SSBs might have a negligible effect on both price and health outcomes, failing to achieve the public health goals of the policy. Therefore, policymakers should aim for a balanced approach that considers the health benefits, the economic impacts, and the tax burden, that is acceptable to the stakeholders involved. The following section on policy implications and recommendations suggests a possible SSB tax option for Thailand, discusses what to consider with respect to delivering the expected outcomes, identifies unique groups of the population that may need more attention from policymakers, and concludes with how other interventions should complement the SSB tax to improve health and equity in Thailand:

Implementation of the proposed tier-based tax for SSBs: The results in this thesis demonstrated that a tier-based tax is cost-saving, enhances health, and reduces health inequities. The tax also has a negligible economic impact and reduced tax regressivity. Its mechanism, which incentivises beverage reformulation to reduce sugar content, is pivotal in delivering health benefits without substantial adverse impact on the economy. Overall, a tier-based tax offers a balanced approach between health benefits and economic considerations.

Monitoring, enforcement, and periodic evaluations: In introducing a new tax, rigorous enforcement and adherence are crucial. A robust monitoring system is essential for strategies like a tier-based tax to ensure industry compliance. An additional administration system might be needed to verify whether sugar levels align with the tax tiers. Continuous surveillance is crucial if industries use tactics to mitigate tax impacts on SSB prices, such as price manipulation or absorbing most of the tax (i.e., a tax does not result in price rises). Additionally, regular reviews of the impacts of the SSB tax, both intended (such as reformulation) and unintended (such as tax regressivity), are necessary to refine and adapt the policy to achieve its public health objectives effectively.

Protecting vulnerable populations: People from lower socioeconomic backgrounds and groups already impacted by health-related taxes (like tobacco and alcohol) could face a greater burden from SSB taxes. If an SSB tax is initiated in Thailand, supportive measures, such as subsidies for healthier food options, should be considered to offset the financial impact of an additional tax on SSBs.

Diverse intervention strategies: Recognising obesity as a complex health issue highlights the need for a range of intervention methods. The success of anti-obesity policies could be more effective with a broader spectrum of strategies less influenced by industry responses. As well as SSB consumption, addressing other factors contributing to obesity is crucial, possibly through interventions like educational campaigns, physical activity promotion, and facilitating easier access to nutritious foods[58]. The benefits and related consequences of other possible interventions need to be evaluated in a similar fashion as SSB taxes. Additionally, according to the model, the tax may benefit women in lower socioeconomic groups in the long run. However, considering their urgent health needs, policies with immediate and more foreseeable effects should be prioritised.

Holistic approaches for enhancing health and health equity: The ultimate public health goal in Thailand is to improve health and health equity[351]. While addressing obesity and the overconsumption of certain foods is essential, greater impacts on health and health equity could be achieved by concurrently addressing other health concerns along with obesity and SSBs. As shown in the analysis in this thesis, individuals who frequently consume SSBs often have multiple unhealthy behaviours. In many individuals, merely having a normal weight does not necessarily imply good health, especially if the weight is influenced by unhealthy behaviours such as smoking. Comprehensive strategies addressing a wide range of health issues should be a government priority.

Implications for implementing a tier-based SSB tax in LMICs: This study sheds light on how a tier-based tax structure can address some of the challenges of introducing a SSB tax in LMICs with economic contexts similar to Thailand[352]. The tier-based tax encourages product reformulation by the industry while imposing a lower financial burden on consumers, making it a more viable option for LMICs (compared to ad valorem tax). It balances health benefits with economic concerns, protecting both economically and health-vulnerable populations. However, it is important to exercise caution when generalising these findings to other settings. LMICs encompass nations with significant differences in income levels and potentially distinct situations regarding obesity[70] and SSB consumption[353]. Thus, conducting evaluations that account the specific context of each country is recommended.

7.3 Challenges and Future Research Recommendations

This thesis highlights various limitations and uncertainties in assessing an SSB tax. Overall, it emphasises that the incomplete data regarding SSB consumption and the lack of key parameters for certain policy-informative subpopulations. Addressing these limitations and uncertainties, as outlined below, may assist in enriching and strengthening the evidence in the context of SSB taxes.

Ensure data comprehensiveness: Obtaining extensive and comprehensive data on demographics, socioeconomics, SSB consumption and health data such as weight and height from a single dataset is challenging in Thailand. While the dataset used in this study contained a complete set of such information, the data is limited in many ways. For example, future health surveys should include more detail on types of beverages, level of sugar content, prices of SSBs and details of SSBs sold in the informal food sector to provide a more comprehensive dataset for research on SSB consumption.

Understand consumer behaviours: The success of SSB taxes, grounded mainly in classical economic theory, assumes that consumers will react predictably to price changes. While the literature generally indicates that price increases can reduce SSB consumption, these findings often focus on population averages[335] or subpopulations based socioeconomic status[195]. However, one of the findings from this thesis suggest that SSB consumers, especially those exhibiting addictive-like behaviours, might not always act in predictable ways. There is also limited understanding about price responsiveness of other specific policy-relevant subpopulations such as those differentiated by gender or age. Availability of such information would permit more nuanced analysis in equity-based economic evaluations. This area warrants further research. Also, the evidence for the substitution or complementary effects of SSB taxes is unclear[1,195,354,355]. In Thailand, a potential concern is the large informal SSB industry, which largely avoids the official tax system[123]. The actual behaviour of individuals after the implementation of the tax should also be examined.

Monitor industry response: The success of an SSB tax is heavily affected by how the beverage industry reacts. For instance, if beverage manufacturers absorb the tax or manipulate the manufacturing price, the expected outcomes from the tax can change dramatically. Drawing on the tobacco industry's tactics to evade taxes, the beverage industry might employ a range of foreseen and unforeseen strategies, such as shifts in marketing practices and using various pricing strategies (e.g., managing manufacturing prices, price smoothing, or reducing size of product)[348,356]. The response of the beverage industry following tax implementation remains poorly explored[341]. Further research is needed to examine industry responses to tax changes.

Explore alternative unexplored tax structures: While SSB taxes have been repeatedly shown to be cost-effective in numerous countries[2,24-27], there is less clarity about the effectiveness and outcome of different tax structures. Instead of questioning the cost-effectiveness of SSB taxes, the focus should shift to determining which tax structures are more cost-effective than others. Future research should examine a broader array of tax structures and aim to replicate real-world tax implementations more closely in evaluations.

Reconsider impact between SSBs and body weight: Estimating the impact of SSB consumption and SSB taxes on body weight remains a challenge[341]. Using estimates to predict health outcomes introduces uncertainty. Future evaluations should consider focusing on the direct effects of SSBs or sugar consumption on health, bypassing the intermediate step of body weight estimation.

R*e-evaluate measurement of obesity*: A body mass index (BMI) is a widely accepted surrogate measure of obesity, primarily due to its ease of collection. However, other metrics might offer a more accurate representation of obesity, providing a better prediction of obesity-related diseases[357]. For example, waist-to-height ratio has been demonstrated to be better than BMI in predicting mortality and cardiovascular disease[358]. Nevertheless, this study could not employ other obesity measurements due to the absence of supporting data from the 2021 Health Behaviour of Population Survey (HBS) survey (i.e., only weight and height are available). Researchers should consider incorporating a variety of obesity metrics in future studies.

Refine approach addressing health inequity: The perspective of the impact of the tax on health inequity in this thesis is derived from an informal analysis of health benefits across socioeconomic groups. This is just one of several approaches to address the issue[204]. Integrating equity into efficiency analysis, such as cost-effectiveness, is a complex issue that may demand a more refined methodology. One emerging approach worth considering for future evaluations is distributional cost-effectiveness analysis (DCEA)[330]. However, this method typically demands more detailed data on equity-related characteristics of interest, which is not readily available in Thailand. Specifically, it requires future research to obtain data such as health-related quality of life (HRQoL) as a function of sex, age and socioeconomic status[359], as well as data on the social distribution of health opportunity costs of healthcare expenditure[360].

7.4 Concluding Remarks

This thesis investigates the potential impacts of an SSB tax in Thailand and contributes to a deeper understanding of the potential impacts of an SSB tax on obesity in Thailand. The results suggest that the proposed tier-based tax could potentially offer benefits to public health. Specifically, the tax could enhance health outcomes and reduce health care expenditure, making it a cost-saving strategy, as well as improve health equity by narrowing the health inequality across socioeconomic groups.

Additionally, the results of this thesis suggest that there are no substantial negative economic consequences (deadweight loss) arising from the proposed SSB tax. However, the tax also has some drawbacks and challenges that policymakers need to consider. Particularly, the tax could be regressive, disproportionately affecting lower-socioeconomic individuals. In addition, potential adverse reactions from the beverage industry could profoundly hinder the potential benefits of the tax. This thesis, therefore, suggests a robust monitoring system to ensure the industry's compliance and observe its use of tactics to mitigate tax impacts on SSB consumption. This would allow the government to respond appropriately to any industry reactions.

The results in this thesis also indicate an urgent need to examine further gender-specific policies, especially those targeting the health of women with lower socioeconomic status. The SSB tax should not be viewed as a standalone solution. Instead, policymakers in the country should prioritise exploring and evaluating comprehensive strategies that address a wide range of health issues coexisting with SSB consumption as well as a range of interventions addressing obesity. This might include supportive measures, such as subsidies for healthier food options, to alleviate the financial impact on vulnerable populations, such as those of lower socioeconomic status.

Supplementary Appendix

Table 8.1: Details of proposed taxes on SSBs in Thailand (Chapter 2)

SSB groups	Sugar per 100 mL (grams)	Pre-existing general excise tax (choose 1, high value)		Proposed taxes on SSBs (choose both ad valorem and specific)							
				Oct 2017		Oct 2019		Oct 2023		Oct 2025	
		Ad valorem (%)	Specific (THB/L)	Ad valorem (%)	Specific (THB/L)	Ad valorem (%)	Specific (THB/L)	Ad valorem (%)	Specific (THB/L)	Ad valorem (%)	Specific (THB/L)
Mineral water and soft drinks containing sugar or sweetening agents or additives and other beverages (e.g., carbonated drinks, energy drinks, and mineral drinks) (0202 group)	0 – ≤6	20	0.45	14	0.0	14	0.0	14	0.0	14	0.0
	> 6 – 8	20	0.45	14	0.1	14	0.1	14	**0.3**	14	**1.0**
	> 8 – 10	20	0.45	14	0.3	14	0.3	14	**1.0**	14	**3.0**
	> 10 – 14	20	0.45	14	0.5	14	**1.0**	14	**3.0**	14	**5.0**
	> 14 – 18	20	0.45	14	1.0	14	**3.0**	14	**5.0**	14	5.0
	> 18	20	0.45	14	1.0	14	**5.0**	14	5.0	14	5.0
Non-fermented and non-alcoholic fruit juice (including grape must) and vegetable juice, regardless of whether sugar or other sweetening agent is added or not, such as tea, coffee (0203(1) group)	0 – ≤6	20	0.45	10	0.0	10	0.0	10	0.0	10	0.0
	> 6 – 8	20	0.45	10	0.1	10	0.1	10	**0.3**	10	**1.0**
	> 8 – 10	20	0.45	10	0.3	10	0.3	10	**1.0**	10	**3.0**
	> 10 – 14	20	0.45	10	0.5	10	**1.0**	10	**3.0**	10	**5.0**
	> 14 – 18	20	0.45	10	1.0	10	**3.0**	10	**5.0**	10	5.0
	> 18	20	0.45	10	1.0	10	**5.0**	10	5.0	10	5.0
Non-fermented and non-alcoholic fruit juice (including grape must) and vegetable juice, regardless of whether sugar or other sweetening agent is added or not, in accordance with the rules, procedures and conditions prescribed by the Director-General, such as fruit juice, vegetable juice (0203(2) group)	0 – ≤6	20	0.45	0	0.0	0	0.0	0	0.0	0	0.0
	> 6 – 8	20	0.45	0	0.1	0	0.1	0	**0.3**	0	**1.0**
	> 8 – 10	20	0.45	0	0.3	0	0.3	0	**1.0**	0	**3.0**
	> 10 – 14	20	0.45	0	0.5	0	**1.0**	0	**3.0**	0	**5.0**
	> 14 – 18	20	0.45	0	1.0	0	**3.0**	0	**5.0**	0	5.0
	> 18	20	0.45	0	1.0	0	**5.0**	0	5.0	0	5.0
Instant powder drinks or concentrated drinks that contain sugar and can be soluble (16.90 group)	0 – ≤6	50	0	0	0.0	0	0.0	0	0.0	0	0.0
	> 6 – 8	50	0	0	0.1	0	0.1	0	**0.3**	0	**1.0**
	> 8 – 10	50	0	0	0.3	0	0.3	0	**1.0**	0	**3.0**
	> 10 – 14	50	0	0	0.5	0	**1.0**	0	**3.0**	0	**5.0**
	> 14 – 18	50	0	0	1.0	0	**3.0**	0	**5.0**	0	5.0
	> 18	50	0	0	1.0	0	**5.0**	0	5.0	0	5.0

Source: Markchange et al., 2019[91]; Osornprasop et al., 2018[8]

Note: Beverages in 0202 group include mineral water and soft drink containing sugar or sweetening agents or additives and other such as carbonated drink, energy drink, mineral drinks.

Exchange rate of 35 THB = 1 USD in 2022[124]

Table 8.2: Data extraction form for the systematic review of economic evaluations of SSB taxes (Chapter 3)

Data	Study No (Authors, year)
<u>Rational</u>	
How study established a relationship between SSB consumption and obesity (this should come from introduction section of study e.g. explicit statement for relationship between SSB and obesity/obesity related issues)	
Provide reference(s) used for the above statement/relationship	
<u>Baseline clinical data</u>	
Evidence used to estimate baseline effect between SSBs consumption and obesity (e.g. weight, BMI)	
Whether account for overconsumption (e.g. more than 20 g if sugar drink per day considered as overconsumption rather than consumption?) [Yes, No, Likely, Unlikely]	
Whether physical activity considered? [Yes, No, Likely, Unlikely]	
Whether overall consumption of other foods considered? [Yes, No, Likely, Unlikely] (e.g. this could be a compensation effect).	
SSB Consumption by informative subpopulation e.g. socioeconomics (SES) [Yes, No, Likely, Unlikely] and if Yes or Likely, please describe more related details.	
Whether the study mentioned (or any data presented) that consumption of SSBs higher in those less advantage group e.g. lower socioeconomics	
Please justify, is that valid?	
<u>Effectiveness</u>	
Use of own-price elasticity of demand?	
If so, value (or range of value of state where it is if many values used)	
Source (reference, state if meta-analysis)	
If not price-elasticity of demand what effect used?	
Whether price elasticity of demand (or other effects used) varied by informative subgroups.	
Duration applied [number of years, unclear/not stated]	
Substitution for other consumption applied (e.g. cross-price elasticity of demand) Note: using of cross-price can represent compensation effect as well	
<u>Outcomes of interest</u>	
Key outcomes of interest	
Whether non-health outcome include? (e.g. education improvement)	
How surrogate outcomes were translated to long term outcome?	
Source of parameters	
<u>Costs</u>	
Perspective	
What costs included?	
Non-health costs included?	
If so, what costs (e.g. deadweight loss) whether ‘consumer surplus losses’ accounted.	
<u>Equity analysis</u>	
Included any form of health equity consideration?	
If so, if what basis (e.g. health outcome analysis by SES)	
Whether ‘how’ to assess ‘equity’ was specified in method section	
Tool	
Outcomes	
Decision rule (how to decide if the intervention improve inequity)	

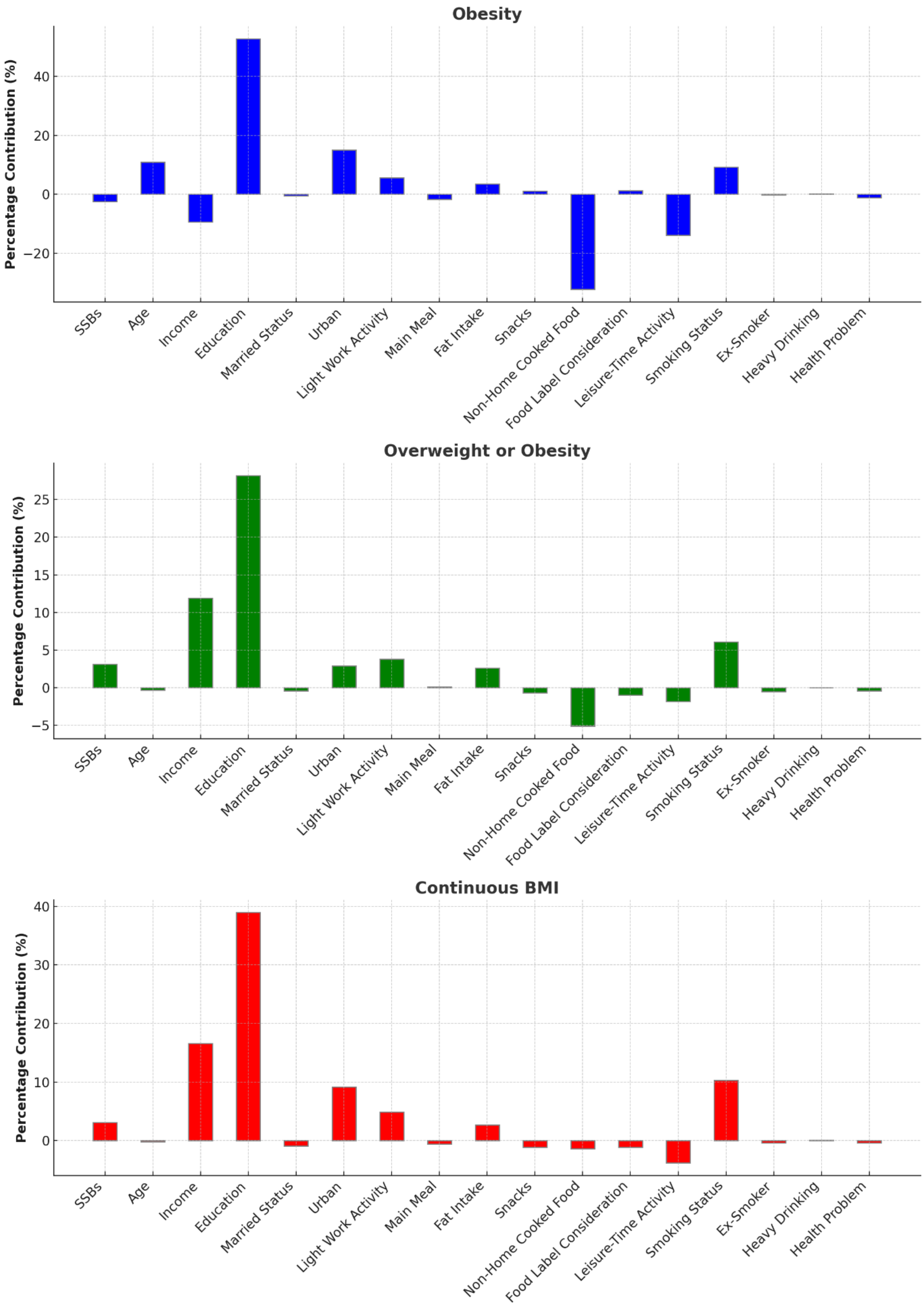
Whether the study stated that tax reduce inequity (or inequality, disparities)? If so, quote that text	
If so, in what basis?	
Any inconsistency observed (e.g. improve in equity not occur in every outcomes)?	
If so, please explain	
Whether the study relied on a single index of inequity (in this context meaning that 'absolute' and 'relative' index should be reported)	
Whether the study found that the tax is regressive?	
In case the study finding tax is regressive, how it justified equity for the tax (e.g. whether it improved health of the lower SES more).	
<u>Modelling methods / results</u>	
Type of model	
Population (age)	
Time horizon	
Country	
Intervention (tax details)	
Comparator	
Discounting (%)	
Uncertainty (e.g. PSA, univariate)	
CEA results (ICER)	
Obesity/obesity related outcomes results	
Note	

Table 8.3: Concentration index results excluding those underweight from the analysis (Chapter 4).

		Men				Women		
	N	**Obesity**	**Overweight/obesity**	**Continuous BMI**	**N**	**Obesity**	**Overweight/obesity**	**Continuous BMI**
Country	19,122	0.079***	0.091***	0.007***	27,791	-0.062***	-0.066***	-0.006***
Region								
Bangkok	876	0.096	0.037	0.005*	1,087	-0.113	-0.044	-0.007*
Central	5,918	-0.029	0.054**	0.003*	8,074	-0.125***	-0.085***	-0.008***
North	4,132	0.245***	0.138***	0.012***	5,904	-0.012	-0.033	-0.002
Northeast	4,606	-0.009	0.049*	0.004***	7,197	-0.066*	-0.068***	-0.006
South	3,590	0.072	0.099***	0.007***	5,529	-0.063*	-0.086***	-0.008***

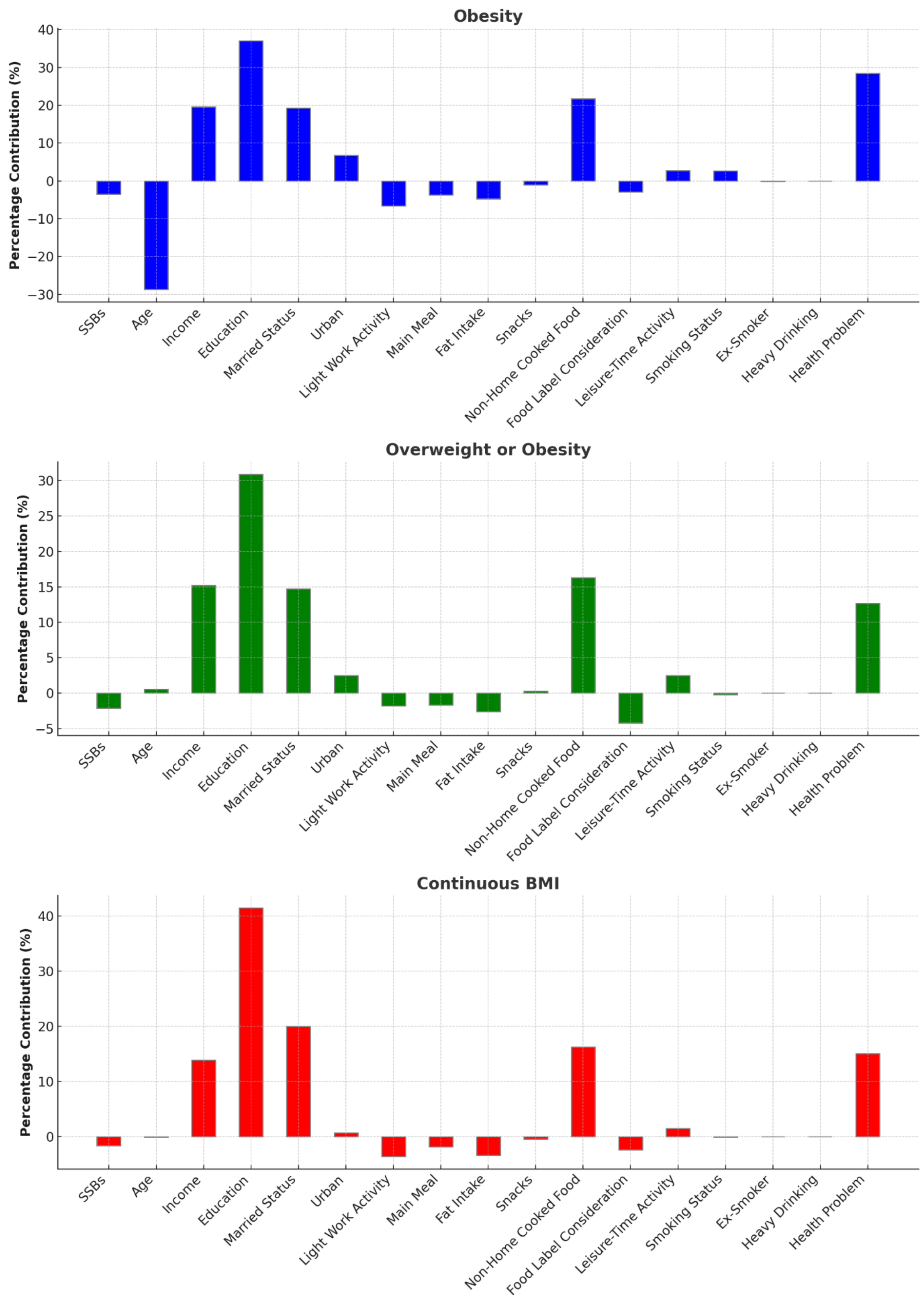
BMI = body mass index; N = number of observations
* p-value < 0.10; ** p-value < 0.05; *** p-value < 0.01
The p-value associated with the CI indicates the probability of observing the calculated concentration index under the assumption that there is no significant difference in health outcome distribution across socioeconomic groups i.e., no health inequality (i.e., the CI is zero).

Figure 8.1: Decomposition of income-related inequality in obesity among men in Thailand.



BMI = body mass index; SSBs = sugar-sweetened beverages

Figure 8.2: Decomposition of income-related inequality in obesity among women in Thailand.



BMI = body mass index; SSBs = sugar-sweetened beverages

Table 8.4: Results from the decomposition analysis of SSB consumption (with percent contribution)

Variable	C_k	E		% Contribution	
		SSB servings per month	Daily consum	SSB servings per month	Daily consumptio
Men (ref: women)	-0.009	-0.263***	-0.421***	2.8%	4.2%
Age (year)	-0.015	-0.480***	-0.173*	8.5%	2.9%
Ever-married (ref: never married)	-0.033	-0.006	0.055	0.2%	-2.0%
Education (years)	0.122	-0.031	-0.025	-4.5%	-3.4%
Socioeconomic quintiles (ref: quintile 1)					
Quintile 2	-0.476	0.026***	0.026***	-14.7%	-13.9%
Quintile 3	-0.095	0.049***	0.059***	-5.5%	-6.3%
Quintile 4	0.338	0.068***	0.066***	27.3%	25.0%
Quintile 5 (highest)	0.785	0.065***	0.063***	60.5%	55.4%
Work-related physical activity (ref: light)					
Moderate	-0.023	0.023**	0.074***	-0.6%	-1.9%
High	-0.176	0.006**	0.021***	-1.3%	-4.1%
Living in urban (ref: non-urban)	0.164	0.020*	0.055***	3.9%	10.1%
Smoking status (ref: never)					
Current	-0.085	0.028***	0.047***	-2.8%	-4.5%
Ex-smoker	0.013	0.007**	0.008*	0.1%	0.1%
Alcohol drinking status (ref: never/rarely)					
Former	-0.018	0.019***	0.027***	-0.4%	-0.5%
Occasionally	0.055	0.023***	0.018***	1.5%	1.1%
Usually	-0.059	0.010***	0.016***	-0.7%	-1.1%
Unhealthy foods for 5–7 d/w (ref: <5 d/w)	0.073	0.042***	0.072***	3.6%	5.9%
Vegetable for 5–7 d/w (ref: <5 d/w)	0.017	0.012	0.119***	0.2%	2.3%
Fruit for 5–7 d/w (ref: <5 d/w)	0.112	0.046***	0.143***	6.1%	17.9%
Main meal (number per day)	-0.004	-0.483***	-0.403***	2.3%	1.8%
Non-home cooked (ref: home-cooked)	0.219	0.071***	0.080***	18.4%	19.6%
Food choice (ref: cleanliness)					
Taste	-0.013	0.019***	-0.013	-0.3%	0.2%
Nutrition	0.120	-0.006	-0.023***	-0.9%	-3.1%
Price	-0.153	-0.001	-0.010**	0.2%	1.7%
Convenience	0.010	0.010***	0.014***	0.1%	0.2%
Liking	-0.039	0.031***	0.030***	-1.4%	-1.3%
Wanting	-0.064	0.028***	0.007	-2.1%	-0.5%
Food label consideration (ref: never/unsure)					
Seen but no impact	0.024	0.026***	0.040***	0.7%	1.1%
Seen and have impact	0.112	0.010	-0.009	1.3%	-1.1%
Leisure-time physical activity (ref: sufficient)					
Insufficient, willing to do more in 1 month	0.077	0.000	0.006	0.0%	0.5%
Insufficient, willing to do more in 6 months	0.073	0.005	0.011*	0.4%	0.9%
Insufficient, no/unclear willing to do more	-0.065	0.047	0.104**	-3.6%	-7.6%
Weight status (ref: normal)					
Underweight	-0.026	0.000	-0.003*	0.0%	0.1%
Overweight	0.007	0.022***	0.010**	0.2%	0.1%
Obese	-0.022	0.003	0.008	-0.1%	-0.2%
Health problem (ref: no health problem)	-0.052	-0.005	-0.007*	0.3%	0.4%

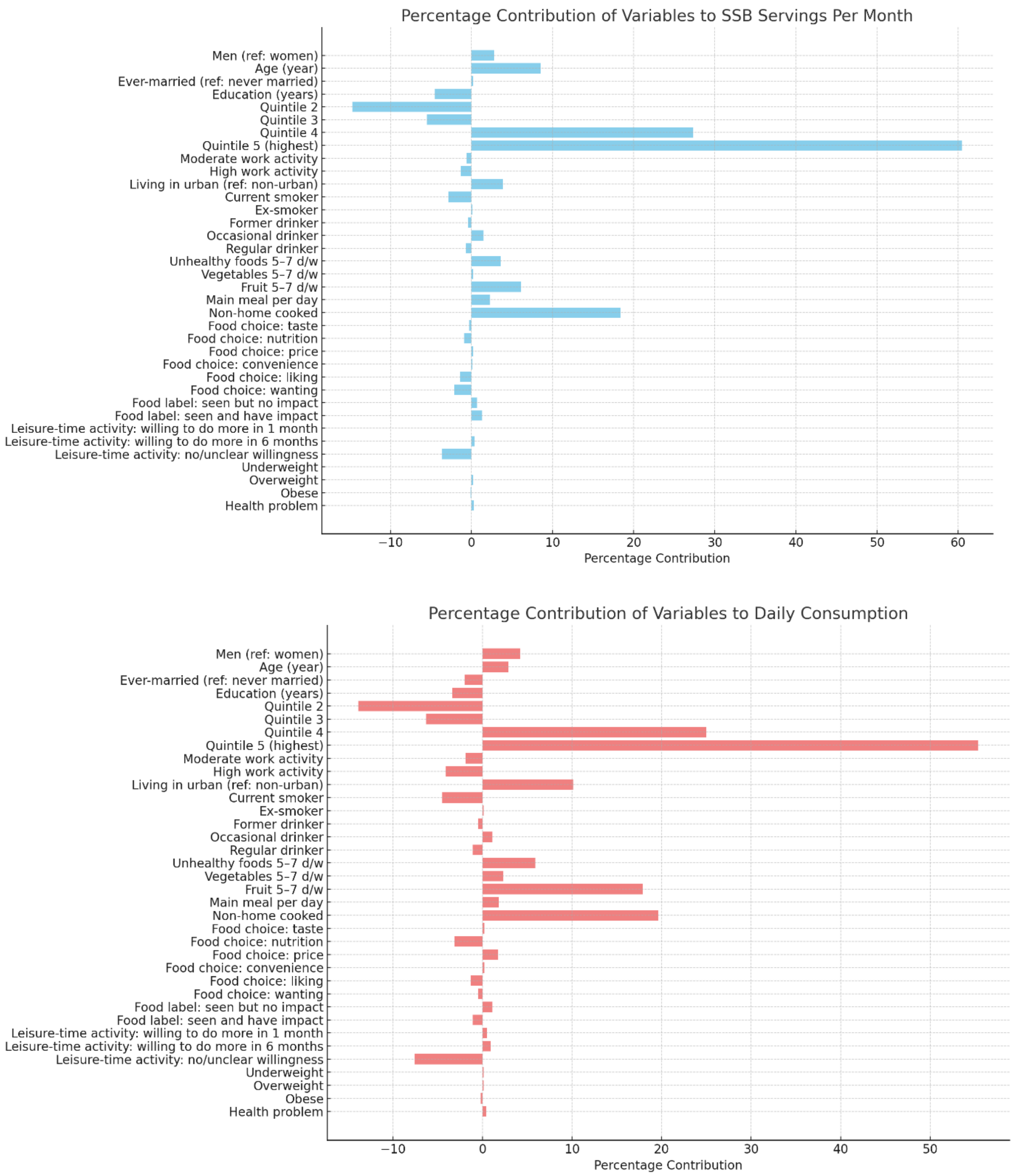
E = elasticity, the change in the outcome associated with a one-unit alteration in the explanatory variable, with a positive sign indicating an increase and a negative sign indicating a decrease in the outcome due to a positive change in the explanatory variable

C_k = the degree of concentration of the explanatory variable across socioeconomic status was denoted as Ck. A negative Ck indicates a higher prevalence of the respective variable among lower socioeconomic individuals, while a positive Ck suggests a higher prevalence among those of higher socioeconomic status)

d = day; ref = reference; SSB = sugar-sweetened beverage; w = week

*** = p-value < 0.01, ** = p-value < 0.05, * = p-value < 0.10, The p-value indicates association of explanatory variable with SSB consumption obtained from the regression coefficient from the linear regression model.

Figure 8.3: Percentage contribution of variables to SSB consumption in Thailand.



SSB = sugar-sweetened beverage

Supplementary data for the economic model (Chapter 6)

A summary of the parameters used in the economic model is presented in Table 8.5.

Table 8.5: Summary of parameters in the economic model (Chapter 6)

Parameters	Description	Value	References
Characteristics of the population	Individual level characteristics such as SSB consumption, age, gender, weight, height, income, habitual factors in food choices	Based on data from 49,127 individuals.	2021 HBS[57]
Consumption of SSBs	Mean serving per day of SSB consumption for each individual	Based on data of 49,127 individuals	2021 HBS [57]
Weight gain	SSB-related and non SSB-related weight gain over time	Varied by gender and age. Assuming weight develops until aged 60 years.	Thai Health-Risk Transition: a National Cohort Study[114] See Table S2.
Mean mL per serving of SSBs	Size of beverage	250 mL	2021 HBS [57]
Mean sugar in SSBs		12 grams per 100 mL	Phonsuk et al., 2021 [93]
Energy from sugar		16 kJ per 1 gram of sugar	P Prinz 2019 [361]
Change in energy and weight	Energy gain or loss from sugar from SSB per day per year.	1kJ per day for a year ~ 0.01 kg/year	Hall et al., 2011 [220]
Compensation effect	The proportion of energy from SSBs consumed that was not equated to weight	90%	Estimated from the Thai Health-Risk Transition: a National Cohort Study[114]
MSRP	Taxable product value	THB 2.96 per 100 mL	Assumption based on Markchang and Pongutta 2019 [91]
Distribution of SSBs by tier of sugar content		The distribution of sugar content per 100 mL is as follows: > 0 ≤ 6: 23.4% > 6-8: 15.7% > 8-10: 18.6% > 10-14: 30.6% > 14-18: 6.0% > 18: 5.7%	Markchang and Pongutta 2019 [91]
Price responsiveness	Own-price elasticity of demand: % change in consumption affected by 1% change in price of SSBs	By socioeconomic quintiles Q1: -1.58 Q2: -1.29 Q3: -1.00 Q4: -0.71 Q5: -0.42	Thai study on non-alcoholic beverages[1]. Estimate (see Box 1)
		By food habits -0.40 for those who are influenced by an appetitive motivation toward foods	Assumption[339]. Estimate
Substitution effect		0% for a tier-based tax	Assumption

		20% for a 20% hypothetical ad valorem tax	
Tax pass-through rate	Proportion of tax cost passed onto consumers	82% for a tier-based tax	Meta-analysis[335]
		70% for a 20% hypothetical ad valorem tax	Assumption[336]
Duration of effect	Tax's effect duration	10 years	Assumption
Background mortality	Rate and probability of death in the general population applied to individuals with normal weight	Values varied by age	Thai life table[340]
Mortality from obesity	Hazard ratio by weight categories in relative to normal weight	1.07: BMI 25.0 - < 27.5 1.20: BMI 27.5 - < 30.0 1.45: BMI 30.0 - < 35.0 1.94: BMI 35.0 - < 40.0 2.74: BMI 40.0 - < 60.0	The Global BMI Mortality Collaboration[66]
Utility values	Health utility by weight categories	0.81: BMI <18.5 0.77: BMI 18.5 – <25.0 0.74: BMI 25.0 – <30.0 0.70: BMI ≥30.0	Thai study[82]
Implementation costs: government		Tier-based tax: 2% of revenue's revenue	Assumption based on Du et al., 2020[206].
		20% hypothetical ad valorem: 1% for ad valorem tax (based on the tier-based tax's revenue)	Assumption, ad valorem tax is likely to cause less administrative burden[17]
Implementation costs: industry	Reformulation and compliance cost for industry (tier-based tax only)	1% of revenue predicted from a tier-based tax	Assumption [206]
Pass legislation	Parliament costs for passing legislation	One-time cost of 28,521 USD (1,000,000 THB)	Assumption
Medical costs for obesity (BMI ≥ 30)		Obese: 1,422 USD/year Probability of being obese and being ill: 2.67%	Estimated based on Thavorncharoensap, et al. 2011 [82]
Medical costs for overweight (BMI 25 - < 30)		Overweight: 145 USD/year Probability of being obese and being ill: 0.08%	Estimated based on Thavorncharoensap, et al. 2011 [82]
Productivity loss	Productivity loss from premature death	Based on Gross National Income (GNI) per capital ($7,070 in 2021)	GNI per capita in 2022 [342]
Exchange rate	USD ~ THB	35.00 exchange	Mid-year exchange value of 2022 from Bank of Thailand[124]

HBS = Health Behaviour of Population Survey; mL = millilitre; MSRP = manufacturer's suggested retail prices; SSB = sugar-sweetened beverage; THB = Thai Baht; USD = United States Dollar

Table 8.6 presents a summary of published data from a local follow-up cohort called the "Thai Health-Risk Transition: A National Cohort Study" used for estimating weight change over time[114].

Table 8.6: Weight gain by level of SSB consumption (kilogram per year) (Chapter 6)

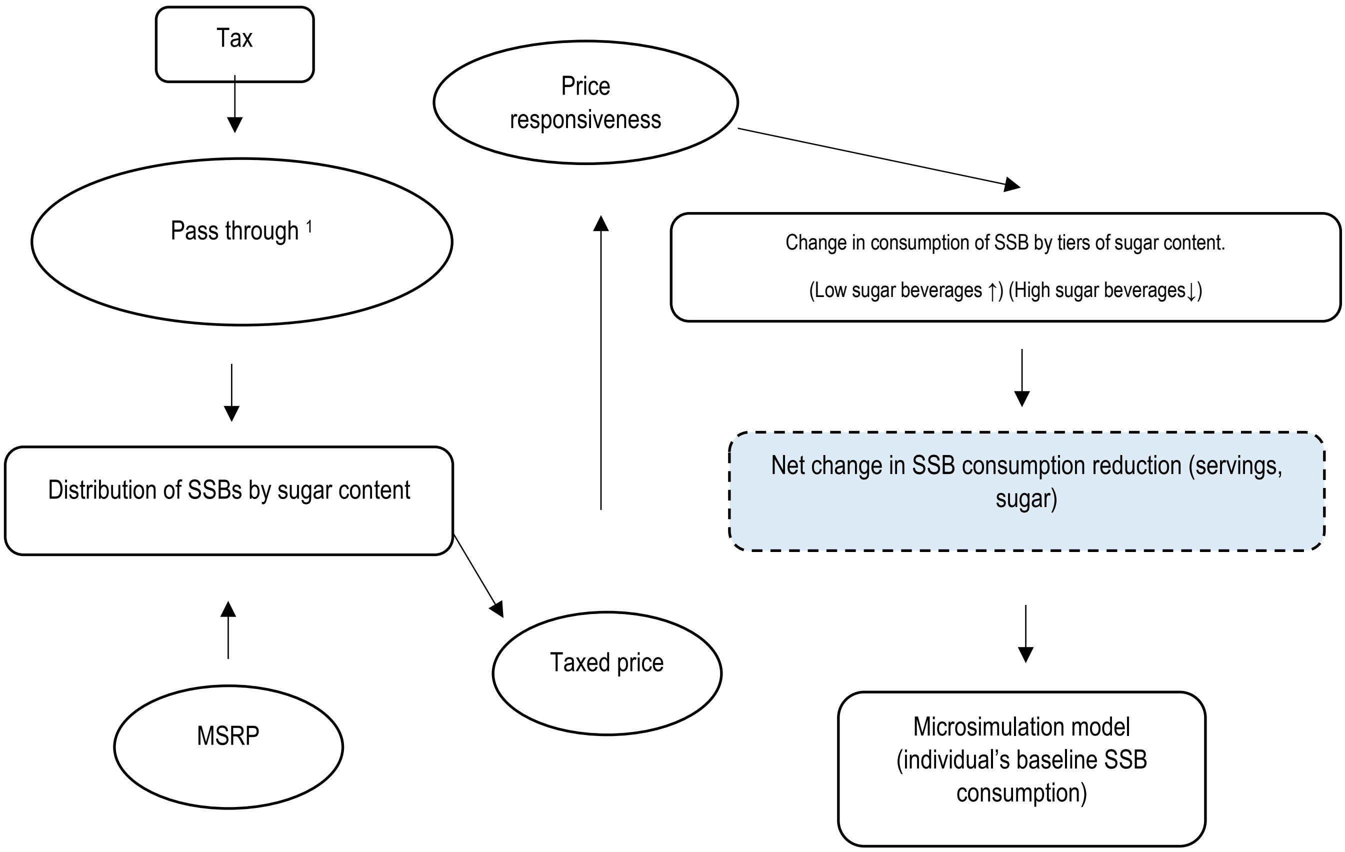
	SSB consumption - Men				SSB consumption - Women			
Age (years)	High (daily)	Moderate (3-6 days/week)	Low (< 3 days/week > 0/month)	No consumption	High (daily)	Moderate (3-6 days/week)	Low (< 3 days/week > 0/month)	No consumption
25 - 34	0.600	0.600	0.550	0.500	0.625	0.575	0.588	0.550
35 – 59	0.325	0.275	0.238	0.175	0.400	0.450	0.388	0.350
>= 60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

SSB = sugar-sweetened beverages

Effectiveness: tier-based tax.

This section presents how tax's effect on weight is estimated in the model. This involves two parts. First, the net change in SSB consumption reduction in terms of serving and sugar content is estimated. Next, that net reduction is used to estimate the change in energy intake, which later is used to estimate change in weight. A schematic diagram summarising the estimation of the net change in SSB consumption reduction in terms of serving and sugar content is presented in Figure 8.4.

Figure 8.4: Change in SSB consumption due to the tax.



MSRP = manufacturer's suggested retail prices; SSBs = sugar-sweetened beverages

[1] High-sugar beverages only (SSBs with > 8 grams of sugar per 100 mL)

Tax

In Thailand, a new sugar tax structure has been proposed, consisting of six distinct tiers based on sugar content (Table 8.1). There is a need for the definition of high and low-sugar beverages in the model. However, no such clear definition existed within the country. The model adopts the same definition as in a previous study in the UK[347]. Specifically, beverages containing over 8 grams of sugar per 100 mL are categorised as high-sugar beverages, while those with 8 grams or less are deemed low-sugar. Based on the tax structures' design, it is not anticipated that prices for low-sugar beverages will rise. Conversely, there is a likelihood of a decrease in their prices[8].

Pass-through rate

The model assumes that the industry will absorb a portion of the tax for high-sugar tier beverages. Since the tax is not expected to raise the price of low-sugar tier beverages, the model assumes that the entire tax will be passed on to consumers. A pass-through rate of 82%, derived from a recent meta-analysis[335], was applied to high-sugar tier beverages in the model. Sensitivity analyses assume a 10% increase and decrease in this rate.

Change in consumption of SSB and sugar by tiers of sugar content.

The proposed tier-based tax involves a complex process for estimating its effects. Generally, due to the design of the tax, it is expected that there will be a reduction in consumption, primarily in those high sugar beverages, whereas there will be more consumption of those with lower sugar content. The effects measured in the model involve two aspects: the net reduction in consumption and the net reduction in sugar consumption. The estimates follow a series of specific steps, as presented in Table 8.7.

Table 8.7: Calculation for net reduction in consumption (Chapter 6)

SSB	Sugar content (g per 100 mL)	Distribution [Step 1]	Change in price after tax (taxed prices) [Step 2]	Effectiveness: Reduction in consumption [Step 3]	Mean sugar (g per 100 mL) [Step 4]	Effectiveness: Reduced sugar (g) [Step 5]
Low	> 0 ≤ 6	23.4%	-5.0%	1.8%	3	0.11
Low	> 6-8	15.7%	-2.2%	0.5%	7	0.05
High	> 8-10	18.6%	3.4%	-1.0%	9	-0.12
High	> 10-14	30.6%	9.1%	-4.4%	12	-0.65
High	> 14-18	6.0%	9.1%	-0.9%	16	-0.16
High	> 18	5.7%	9.1%	-0.8%	20	-0.19
	Net	**100%**	**3.0%**	**-4.7% (used in model)**	**12** [1]	**-0.95 (used in model)**

Example for based on socioeconomic status quintile 1.
g = gram; mL = millilitre
[1] Include 2.75 g re-distribution.

Net reduction in SSB consumption.

[Step 1] Distribution of SSB prior tax. There is a need for the distribution of SSBs by sugar content according to each tier of sugar content, prior to the introduction of the tax. This was obtained from a local Thai study[91].

[Step 2] Change in price after tax (taxed price). The tax structure determines the price change of SSBs in each tier, taking into account the MSRP (taxable product value) and serving size in mL (volumetric). Based on a local Thai study[91], it is assumed that the MSRP is the same across the tiers of beverages. This results in a price change relative to the pre-existing general excise tax ranging from +9.1% (e.g., > 18 g sugar) to -5.0% (0 to ≤ 6 g sugar).

[Step 3] Consumption reduction. Change in consumption is a production of price responsiveness, i.e., own-price elasticity of demand (as explained in Box 1) and the taxed price of beverage in each sugar-content tier. As low-sugar beverages become cheaper, their consumption increases, while high-sugar beverages become more expensive, and their consumption decreases. Since the consumption data of an individual from the HBS 2021 survey do not specify levels of sugar in the beverages, the net reduction in consumption, which a sum of change in consumption of beverages across the tiers, is used in the model. This net reduction is expressed as a percentage (-4.7%).

This net reduction in consumption is estimated for each socioeconomic status group (5 quintiles) according to their differences in price responsiveness.

Box 1: Price responsiveness (own-price elasticity of demand)

Price responsiveness by socioeconomic status. Price responsiveness data is derived from a Thai study estimating a dynamic demand model for non-alcoholic beverages[1]. This study reports the own-price elasticity of demand for different groups, distinguishing them based on their income level (low vs. high) and their area of residence (urban vs. rural). Additionally, it provides both short-run and long-run own-price elasticity figures. The reported short-run and long-run own-price elasticities of demand are -1.459 and -1.693 for low-income households and -0.385 and -0.455 for high-income households, respectively. This economic model uses a mid-value of -1.576 for the lowest socioeconomic quintile (Q1) and -0.420 for the highest socioeconomic quintile (Q5). It assumes a linear relationship between price responsiveness and socioeconomic quintiles, leading to the calculated price responsiveness values of Q2 (-1.287), Q3 (-0.998), and Q4 (-0.709). This methodological approach aligns with that of a previous study[2].

Also, due to limitation of available evidence, this step has an assumption that each sugar-content tier has the same own-price elasticity.

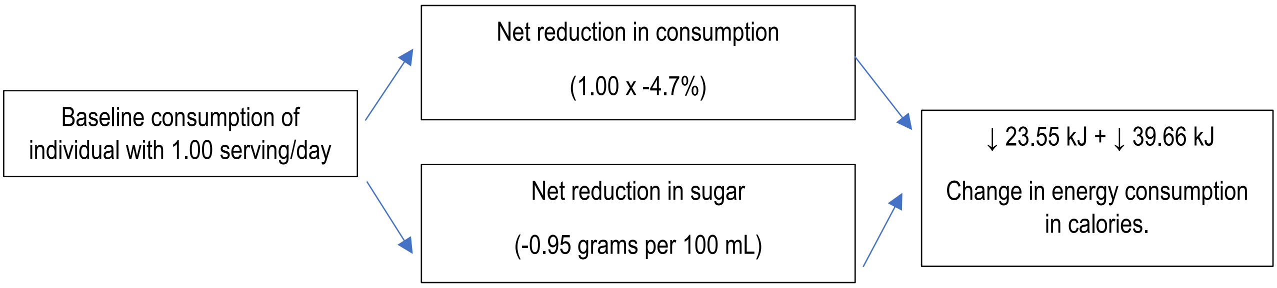
Net reduction in sugar consumption

The previous step estimates the net reduction in SSB consumption, which helps determine how reduced SSB consumption will lead to decreased sugar intake (based on the mean, i.e., net values). However, this does not account for the reduction in sugar consumption caused by the shifting distribution of beverages across the tiers. More specifically, sugar intake will change due to both the decrease in consumption of high-sugar beverages and the increase in consumption of low-sugar beverages. To capture this, a specific calculation of the net reduction in sugar consumption is required. This reduction is calculated by multiplying the average sugar content in each beverage tier [Step 4] by the net consumption reduction for that tier [Step 3]. The result is expressed in grams per 100 mL.

> Note on the average sugar content for each beverage tier: The average sugar content in each tier is determined by using the mid-value of each sugar category range (for instance, 3 grams for beverages in the 0 to ≤ 6 grams range). By factoring in these mid-values with the distribution of beverages across tiers, the resulting average is 9.25

grams of sugar per 100 mL. This is, however, lower than the level suggested in a previous study of 12 grams per 100 mL[93]. To reconcile this discrepancy and achieve the 12 gram mean, an additional 2.75 grams of sugar is allocated across each category.

Finally, the net reduction in consumption (expressed as a percentage) and the net decrease in sugar (measured in grams per 100 mL) were applied to the baseline consumption of SSBs to determine the net change in energy intake following the tax implementation. According to the survey, one serving of an SSB is equivalent to 250 mL[57]. This translates to 30 grams of sugar per serving, based on a concentration of 12 grams per 100 mL. Given that 1 gram of sugar provides an energy of 16.7 kilojoules (kJ) [361], one serving of SSB corresponds to an energy content of 501 kJ. For example, the change in energy consumption for individuals with a baseline SSB consumption of 1.00 serving per day would be:



Note: An example based on the consumption of an individual in quintile 1 consumed 1.00 serving per day.

Change in weight affected by the net change in energy consumption.

Changes in SSB consumption lead to shifts in energy intake measured in kJ. To translate this change in energy intake to weight, the equation specifying the effect of energy imbalance on body weight, as presented by Hall et al., 2011, is employed. According to this equation, a change of 1kJ per day over a year equates to a 0.01 kg over three-year weight change within that year (50% of the weight adjustment is realised within one year and 100% within three years)[220]. However, the model assumed that such a change would occur within a year to simplify calculations. Moreover, taking into account the associated compensation effect, the model assumes that only a certain part of the energy intake translates to weight. The base case presumes a compensation effect rate of 90%, in line with findings from a local study[114].

This means that 90% of energy derived from SSBs offsets other consumption, and thus, only 10% of energy from SSBs constitutes excess energy, which then contributes to weight gain.

Effectiveness: 20% hypothetical ad valorem tax

The estimate for the effects of the 20% hypothetical ad valorem tax is similar but less complicated than the tier-based tax. Specifically, the 20% hypothetical ad valorem tax applies a lower tax-pass through, involves no net reduction in sugar consumption, and applies a substitution effect.

- Tax-pass through rate: A marginally reduced pass-through rate of 70% was assumed, compared to 82% in the tier-based tax. This is based on evidence from alcohol taxes, which suggests that the pass-through rate for ad valorem taxes tends to be lower than for specific taxes (e.g., taxes on alcoholic beverages)[336].
- No net reduction in sugar consumption: The 20% hypothetical ad valorem tax is unlikely to incentivise reformulation and, therefore will not lead to a shifting distribution of beverages across different sugar tiers.
- Substitution effects: In economics terms, these effects are discussed in the context of cross-price elasticity. Cross-price elasticity suggests that when the price of SSBs rises, it can either increase or reduce the consumption of other products. If the consumption of other products increases, these products are deemed substitutes. Conversely, if their consumption drops, they are viewed as complementary products. The empirical evidence on this topic presents a mixed picture. For instance, a study in Mexico revealed increased sugar consumption after the imposition of an SSB tax (indicating substitution), while there was reduced consumption of items such as candies and snacks[355]. Generally, there is a higher likelihood that an ad valorem tax (relative to a specific tax) may lead consumers to opt for other similar, untaxed items[17]. Given this, the model conservatively assumes a 20% substitution effect under the 20% hypothetical ad valorem tax. This is performed in the model by assuming that a 20% reduction in energy from lower consumption of SSBs does not lead to a reduction in weight.

Costs

Medical costs for treating individuals with overweight and obesity used in the model were estimated based on the results of the cost-of-illness report for obesity in Thailand in 2009[82] (Table 8.8). The study estimated the cost of treating obesity-related diseases, including colon and colorectal cancer, breast cancer, endometrial cancer, hyperlipidaemia, diabetes mellitus, depression, hypertension, ischemic heart disease, pulmonary embolism, stroke, gall bladder disease, and osteoarthritis. The report suggests that in 2009, the total direct medical costs consisting of IPD and OPD were $US5,583,834,371.

Several steps were employed to transform this number for use in the economic model, as detailed in Table 8.8. The total number of individuals with obesity and overweight used in that estimate was used to divide the total costs to achieve the direct medical costs per patient. The direct medical costs for obesity and overweight were distinguished using information suggesting that 91% of the medical costs were attributed to obesity and 9% to overweight. All costs were adjusted to the year 2023 using the Thai consumer price index. The chance of being obese (or overweight) and receiving any medical treatment was calculated based on the proportion of obese (or overweight) individuals receiving treatment per the report divided by the number of total obese (overweight) individuals in that year. The report also presents an indirect medical cost of absenteeism from work due to illness. This was also included in the model.

Table 8.8: Steps in calculating medical costs from (Chapter 6)

Data	Value	Source
Estimate for costs		
Total IPD cost per year	THB4,733,605,555	Table 19 of Thavorncharoensap, et al. 2011 [82]
Total OPD cost per year	THB850,228,816	Table 18 of Thavorncharoensap, et al. 2011 [82]
Total IPD and OPD costs per year	THB5,583,834,371	Sum above
Number of patients (A)	128,684	Table 18 and Table 19 of Thavorncharoensap, et al. 2011 [82]
Direct medical cost per patient	THB43,392	
Proportion of direct medical cost for obese patient vs overweight (B)	91% vs 9%	Estimated from Table 30 of Thavorncharoensap, et al. 2011 [82]
CPI 2009 vs CPI 2023	85.5% vs 108.2%	Ministry of Commerce [343]
Exchange rate THB vs USD	35.06	Bank of Thailand
Direct medical cost for an individual with obesity per year	$1,422	Based on above data
Direct medical cost for an individual with overweight per year	$145	Based on above data
Estimate of the probability of receiving treatment		

Estimated number individuals with obesity having treatment (C)	116,800	Estimated from (A) and (B)
Total number of individuals with obesity in 2009 (D)	4,822,478	Data from the report (Thavorncharoensap, et al. 2011 [82]) and World Bank data (population demographics by age)[a,b]
Probability of being obese and incurring medical cost	2.42%	(C)/(D)
Estimated number of individuals with overweight having treatment (E)	11,884	Estimated from (A) and (B)
Total number of individuals with overweight in 2009 (F)	14,031,801	Data from the report (Thavorncharoensap, et al. 2011 [82]) and World Bank data (population demographics by age)[a,b]
Probability of being obese and incur medical cost	0.08%	(E)/(F)

Note:
[a] https://data.worldbank.org/indicator/SP.POP.TOTL?locations=TH
[b] https://data.worldbank.org/indicator/SP.POP.0014.TO.ZS?locations=TH

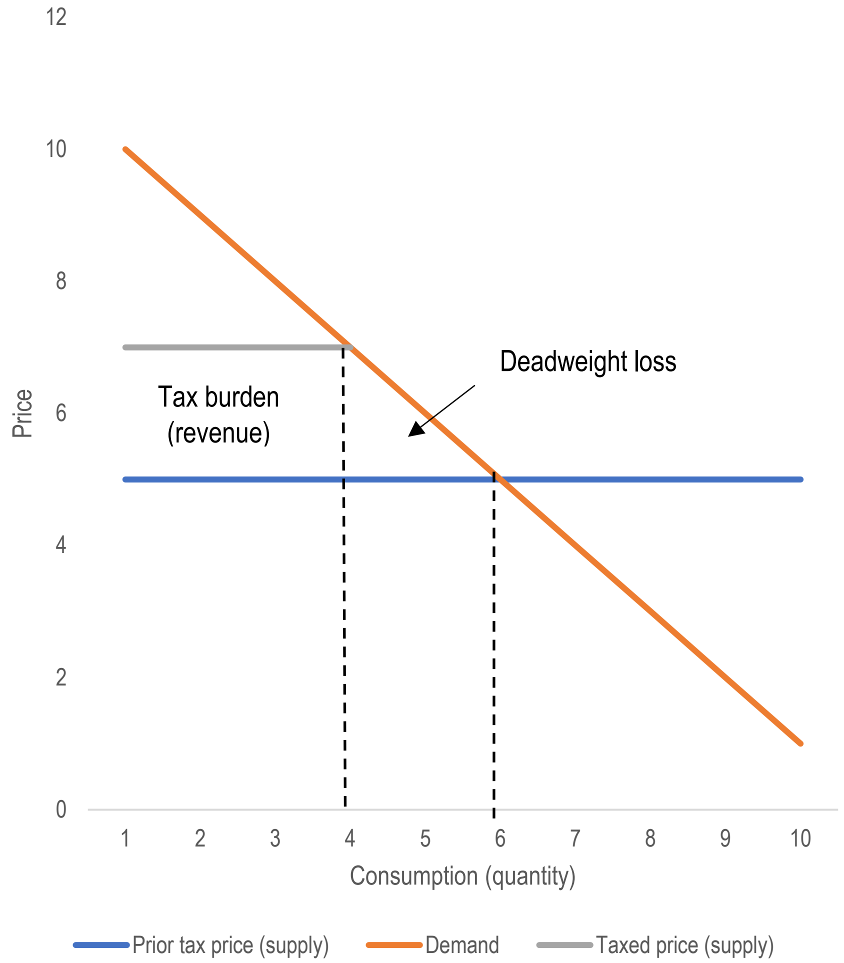
Utility

Quality of life by weight categories was obtained from a study in Thailand. The study is a cross-sectional survey conducted on 766 participants from five provinces across Thailand Bangkok, Chiang Mai, Ubonratchatanee, Songkla, and Nakhonpathom) using the EQ-5D measurement tool to assess the impact of obesity on quality of life. The results confirmed a significant negative impact of obesity on overall quality of life. Compared to individuals with a normal weight, those with overweight and obesity were more likely to experience difficulties in mobility and pain domains. Furthermore, individuals with overweight had a significantly lower utility score (0.74), and individuals with obesity had an even lower score (0.70) in comparison to individuals with a normal weight (0.77). Importantly, this significant difference remained even after controlling for confounding factors.

Tax burden and deadweight loss

The calculation of tax burden and deadweight loss (economic impact) is similar to a previous study[24], and this is illustrated in Figure 8.5.

Figure 8.5: Tax burden and deadweight loss estimated in the model.



Concentration index

The concentration index used in the study was expressed as[271]:

$$Concentration\ index = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{h_i}{h}(2R_i^y - 1)\right]$$

where h denotes health (NHB) and y is a socioeconomic quintile and R_i^y is the fractional rank of each socioeconomic quintile *(i)* according to any chosen socioeconomic variable (i.e., here five levels of equivalised household income).

CHEERS 2022 Checklist

Reporting in this manuscript followed the guidelines of the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement 2022 Checklist, which is summarised in Table 8.9.

Table 8.9: Relevant sections in the manuscript per the CHEERS 2022 Checklist (Chapter 6)

	Item	Guidance for Reporting	Reported in section
TITLE			
Title	1	Identify the study as an economic evaluation and specify the interventions being compared.	*Title*
ABSTRACT			
Abstract	2	Provide a structured summary that highlights context, key methods, results and alternative analyses.	*Abstract*
INTRODUCTION			
Background and objectives	3	Give the context for the study, the study question and its practical relevance for decision making in policy or practice.	*Introduction*
METHODS			
Health economic analysis plan	4	Indicate whether a health economic analysis plan was developed and where available.	*Not applicable* [1]
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	*Study population*
Setting and location	6	Provide relevant contextual information that may influence findings.	*SSB tax options*
Comparators	7	Describe the interventions or strategies being compared and why chosen.	*SSB tax options*
Perspective	8	State the perspective(s) adopted by the study and why chosen.	*Costs*
Time horizon	9	State the time horizon for the study and why appropriate.	*Cost-effectiveness analysis*
Discount rate	10	Report the discount rate(s) and reason chosen.	*Cost-effectiveness analysis*
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	*Outcomes*
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	*Outcomes*
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	*Outcomes*
Measurement and valuation of resources and costs	14	Describe how costs were valued.	*Costs*
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	*Costs*
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	*Model structure*
Analytics and assumption s	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	*Table 2, supplementary material*
Characterizing heterogeneity	18	Describe any methods used for estimating how the results of the study vary for sub-groups.	*Effectiveness of an SSB tax*
Characterizing distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	*Effectiveness of an SSB tax*
Characterizing uncertainty	20	Describe methods to characterize any sources of uncertainty in the analysis.	*Sensitivity analyses*
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communitie5s, or stakeholders (e.g., clinicians or payers) in the design of the study.	*NA*
RESULTS			
Study parameters	22	Report all analytic inputs (e.g., values, ranges, references) including uncertainty or distributional assumptions.	*Table 2, supplementary*

			material
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	*Results*
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable.	*Results*
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	*Results*
DISCUSSION			
Study findings, limitations, generalizability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could impact patients, policy, or practice.	*Discussion*
OTHER RELEVANT INFORMATION			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	*Acknowledge ment*
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	*Declaration*

[1] This is a new criterion from the 2022 CHEERS version. However, this research was initially developed before the new checklist became available.

https://www.bmj.com/content/376/bmj-2021-067975

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