SYSTEM DYNAMICS ANALYSIS OF SUGAR-SWEETENED BEVERAGE TAXING EFFECT ON SUGAR CONSUMPTION, DENTAL HEALTH SERVICE UTILIZATION AND ORAL HEALTH FOR THAI ADULTS AND ELDERLY

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การวิเคราะห์พลวัตระบบของผลกระทบมาตรการภาษีเครื่องดื่มที่มีน้ำตาลต่อการบริโภคน้ำตาล การใช้บริการทันตกรรม และสุขภาพช่องปากของประชากรไทยวัยทำงานและวัยสูงอายุ

น.ส.นิภาพร เอื้อวัณณะโชติมา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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นิภาพร เอื้อวัณณะโชติมา : การวิเคราะห์พลวัตระบบของผลกระทบมาตรการภาษีเครื่องดื่มที่มีน้ำตาลต่อการบริโภคน้ำตาล การใช้บริการทันตกรรม และสุขภาพช่องปากของประชากรไทยวัยทำงานและวัยสูงอายุ. (SYSTEM DYNAMICS ANALYSIS OF SUGAR-SWEETENED BEVERAGE TAXING EFFECT ON SUGAR CONSUMPTION, DENTAL HEALTH SERVICE UTILIZATION AND ORAL HEALTH FOR THAI ADULTS AND ELDERLY) อ.ที่ปรึกษาหลัก : ดร. นพ.ปิยะ หาญวรวงศ์ชัย, อ.ที่ปรึกษาร่วม : ผศ. ดร.จอห์น พาสเทอร์ แอนซา

โรคฟันผุเป็นปัญหาสุขภาพช่องปากที่สำคัญ โดยเฉพาะอย่างยิ่งในกลุ่มประเทศกำลังพัฒนา เกือบครึ่งหนึ่งประชากรไทยวัยทำงาน และวัยสูงอายุมีฟันผุที่ไม่ได้รับการรักษาอย่างน้อยหนึ่งซี่ โรคฟันผุนั้นก่อให้เกิดความเจ็บปวดและมีผลกระทบต่อประสิทธิภาพการทำงาน รวมถึงการดำเนินชีวิตประจำวัน การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาความสัมพันธ์ของโรคฟันผุ การบริโภคน้ำตาล และการใช้บริการทันตกรรม และพัฒนาแบบจำลองพลวัตระบบ เพื่อประมาณการผลของการใช้นโยบายการเก็บภาษีเครื่องดื่มที่มีน้ำตาลต่อการเปลี่ยนแปลงของโรคฟันผุในประชากรไทยอายุ 15 ปีขึ้นไป การศึกษานี้ใช้การสร้างแบบจำลองพลวัตระบบแบบหลายส่วน เพื่ออธิบายความสัมพันธ์ระหว่างการดำเนินโรค ความรุนแรงของโรคฟันผุ และพฤติกรรมที่เกี่ยวกับสุขภาพช่องปาก และมีการจำลองสถานการณ์สี่สถานการณ์เพื่อประมาณการเปลี่ยนแปลงผลลัพธ์ และหาจุดแทรกแซงในการลดสภาวะโรคฟันผุในประชากร โดยสถานการณ์หลักคือการเก็บภาษีเครื่องดื่มที่มีน้ำตาล ผลการศึกษาแสดงให้เห็นว่า ภาษีเครื่องดื่มที่มีน้ำตาลมีผลต่อการลดการบริโภคน้ำตาลได้เมื่อเปรียบเทียบกับสถานการณ์ก่อนใช้นโยบาย ทั้งในระยะสั้น (3.2% สำหรับประชากรที่รายได้น้อย และ 5.4% สำหรับประชากรที่รายได้ปานกลางและสูง) และในระยะยาว (5.2% สำหรับประชากรที่รายได้น้อย และ 7.5% สำหรับประชากรที่รายได้ปานกลางและสูง) อย่างไรก็ตามมาตรการภาษีดังกล่าว มีผลต่อการลดโรคฟันผุไม่เด่นชัด ทั้งนี้แบบจำลองยังแสดงให้เห็นว่าการบริโภคน้ำตาล และความชุกของโรคฟันผุจะลดลงมากขึ้น ถ้ามีการดำเนินนโยบายภาษีนี้รวมกับมาตรการอื่น ๆ ที่ไม่ใช่ภาษี เช่น โครงการสร้างเสริมสุขภาพ และการสนับสนุนให้มีผลิตภัณฑ์ เครื่องดื่มที่มีน้ำตาลน้อย นอกจากนี้การเปลี่ยนแปลงของสุขภาพช่องปากจะเด่นชัดในกลุ่มประชากรที่มีอยู่ในกลุ่มเสี่ยงต่อโรคฟันผุ หรือมีภาวะฟันผุรุนแรง การศึกษานี้เป็นตัวอย่างของการใช้แบบจำลองพลวัตระบบนี้เป็นเครื่องมือเสริมให้ผู้กำหนดนโยบายสำหรับการพิจารณาผลกระทบของนโยบาย และสนับสนุนการวางแผนนโยบายด้านสุขภาพช่องปากของประชากรไทย

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Nipaporn Urwannachotima : SYSTEM DYNAMICS ANALYSIS OF SUGAR-SWEETENED BEVERAGE TAXING EFFECT ON SUGAR CONSUMPTION, DENTAL HEALTH SERVICE UTILIZATION AND ORAL HEALTH FOR THAI ADULTS AND ELDERLY. Advisor: PIYA HANVORAVONGCHAI, M.D.,M.Sc.,S.D. Co-advisor: Asst. Prof. John Pastor Ansah, B.Sc.,M.Sc.,Ph.D.

Dental caries is a major oral health problem, particularly among developing countries. Almost half of Thai adults and elderly have at least one untreated dental caries. Dental caries can result in debilitating pain that affects work productivity and even the performance of daily activities. The objectives of this study are to develop system dynamics model addressing the relationship of dental caries, sugar consumption and dental health service utilization of Thai population aged 15 and older; and to estimate the changes of dental caries prevalence when the sugar-sweetened beverage tax is implemented. A multi-sector system dynamics model was developed to consolidate the relationship between the progression of dental caries experience and oral health related behaviors. Four hypothetical policy scenarios were simulated to investigate potential points of intervention to improve dental caries status in the population. The main scenario was the implementation of sugar-sweetened beverage tax. The study shows that the sugar-sweetened beverage tax can produce the reduction of sugar consumption compared to the base-case scenario without the policy for both short-run (3.2% for poverty population, and 5.4% for non-poverty population) and long-run (5.2% for poverty population, and 7.5% for non-poverty population). However, the impact of the sugar-sweetened beverage tax on reduction of dental caries prevalence is not pronounced. The model also shows that the combined tax policy with other non-tariff intervention such as health promotion program and the encouragement of reformulation in sugar-sweetened beverages could provide the most benefit on reduction of sugar consumption and dental caries prevalence. In addition, changes in oral health are evident in populations at high risk for dental caries. This study is an example of system dynamics model use for providing policy makers with additional insights to support their oral health policy planning for Thai population.

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LIST OF ABBREVIATION

CLD	Causal loop diagram
DMFT	Decay, Missing and Filled Teeth
GMB	Group model building
SES	Socio-economic status
SD	System dynamics
SFD	Stock and flow diagram
SSB	Sugar-sweetened beverage

CHAPTER I
INTRODUCTION

1.1 Background and rationale

Oral diseases leading to the loss of teeth are still a major health problem in Thailand. Dental caries can result in debilitating pain, affecting daily activities and work productivity.[1] Moreover, untreated dental caries has been one of the primary causes of tooth loss among Thai adults and elderly.[2] The prevalence of dental caries has increased from 85.6% in 2000 to 86.7% in 2012 among Thai adults.[3-4] For elderly (60-74 years), the prevalence of dental caries was 95.6% in 2000 and increased to 97.1% in 2012.[3-4]

Dental caries experience is commonly measured using the Decay, Missing and Filled Teeth (dmft/DMFT) Index, which is an aggregate score of the number of teeth that are either decayed, missing or filled. Each diseased tooth will contribute one count to the total dmft/DMFT score. From the year 2000 to 2012, the mean DMFT of adult (35-44 years) slightly decreased from 6.13 to 6, while the mean DMFT of elderly (60-74 years) tended to increase from 14.37 to 15.[3-4] However, the findings from recent Thailand National Oral health survey in 2012 showed that 35.7% of adults and 50.2% of elderly have at least one untreated tooth decay. Percentage of tooth loss has been increasing with age. The survey showed that the partial tooth loss and total tooth loss are 88.3% and 7.2% at age 60-74 years. In addition, the total tooth loss or edentulism was as high as 32.2% at age 80-89 years.

The proportion of the elderly is likely to increase in Thailand. According to the estimates of the Institute for Population and Social Research, Thai elderly population has increased from 10.3% in 2005 to 14% in 2015 and the risk of chronic diseases and oral health problem have increased among these population.[5] Although the proportion of the working age population has decreased slightly in the same period of time, the working-age group accounted for most of the population.[6] Moreover, they will become seniors in the future. An analysis of determinants affecting oral health shows that these groups are important for understanding the future demand for planning dental health services and policy at the population level.

Regarding dental health service utilization, the report from Health and Welfare Survey in 2015 showed that Thai adults aged 15-24 years, aged 25-59 years and elderly aged 60 years and older only 11.2%, 8.9% and 7.1% respectively had visited dentists within the past year.[7] They tended to receive dental treatment when the symptoms were severe. Therefore, treatment was often tooth extraction and complicated procedures which required long period of time. The proportion of dental health service utilization has been found to be different in each socio-economic subgroups of population.[7] The dental health service utilization rate in population was higher among women (11.1%) than among men (8.1%). People in urban area had higher rate of utilization (10.5%) than in rural area (8.9%).[7]

Despite the individual predisposition of dental caries, current evidence supports the association between high quantity and frequent sugar consumption and the prevalence of dental caries.[8-9] Sugar consumption in Thailand has increased significantly in the past 30 years.[10] Sugar-sweetened beverages (SSBs) is the most common source of added sugar in the diets of Thai population.[10-12] Sixty-four percent of Thais consumed SSBs on a weekly basis, with daily consumption in Thailand ranging from 10 grams to 34 grams per serving size. While the World Health Organization recommends daily sugar intake of about 25 grams[13], individuals in Thailand are more likely to exceed this recommended level. To determine the causes and solutions of sugar consumption problem in population, the factors underlying the behavior should be taken into an account.

Sugar-sweetened beverage (SSB) tax is one possible policy intervention that government use to reduce sugar consumption among the population. Some cities in the United States, Mexico and several European countries have implemented SSB taxes to control sugar intake and reduce the risk of obesity[14-15]. They have found that when the price of SSB increased, the demand for consumption decreased.[16] The systematic review of Escobar and colleagues showed that the increase of SSB price would reduce the prevalence of overweight and obesity in the adult population in USA.[15]

In September 2017 the Thai Excise Department implemented an excise sugar tax on certain beverages according to the Excise Tax Act B.E. 2017. This tiered tax levy, which will be adjusted every 2 years until 2023, depends on sugar content of SSBs. With this policy levy, it is expected to reduce sugar content of SSB products, which will eventually lead to healthier choice and lower sugar consumption among Thai population.[17-19] However, the effect of SSB tax on sugar consumption and dental caries is not straightforward. It is uncertain whether a tax increase will translate into lower sugar consumption and better oral health outcomes. Understanding the causal mechanism through which SSB tax will translate into lower sugar consumption and improved oral health is important in identifying a leverage point for interventions. In addition, it is vital to engage all stakeholders to develop a deeper understanding with a whole system perspective on the dynamic interactions between SSB tax, sugar consumption, and oral health outcomes.

Oral health issues can be conceptualized as a complex system which is linked to the context of multiple factors interacting with each other. The issues also involve with various stakeholders. The goal of the system is to promote the oral health of the population. In many cases, the interaction of those factors may not show cause and effect directly. The related factors influence each other in the feedback loop and make the whole system change.[20-21] The uses of traditional epidemiological approach may be limited because it may not determine the non-linear and complex relationship reflect their potential impacts on others.[20, 22]

System dynamics (SD) modeling is an analytical approach to understand the behavior of complex systems over time using structure of stocks, flows, internal feedback loops, and time delays.[23] It describes how the relationships of related components of a system contribute to the system behavior as a whole.[24] This approach has been used to analyze oral health problems in some countries, for example, the estimation of oral healthcare service system in the Netherlands[25], the analysis of participation in oral health promotion in New York[26] and the analysis of sustainable sugary drinks taxes and the uses of tax revenues to prevent obesity in children in the United States.[27] In Thailand, SD models have been used to estimate the dental personnel required for oral health service system.[28-29] However, such studies have not considered socio-economic and social determinants of the population.

Since oral diseases especially dental caries can be prevented by behavioral change interventions such as sugar consumption reduction, oral hygiene practices and utilizing dental health care services. Each behavior and related factors change can affect each other behaviors and oral health conditions through feedback relationships. To our knowledge, there has not been a study on the impact of SSB taxes on sugar consumption and oral health condition in complex relationships using SD model. This study aims to develop a simulation model using the system dynamics methodology to investigate dental caries experience progression and possible interventions to alleviate the situation among the Thai population.

1.2 Research questions

1.2.1 What is the pattern of complex relationships of sugar consumption, dental service utilization and oral health status of Thai adults and elderly with different socio-economic status?

1.2.2 How will the sugar-sweetened beverage tax policy affect the sugar consumption and oral health status of Thai adults and elderly in the long term?

1.3 Research objectives

1.3.1 To develop system dynamics model addressing the relationship of sugar consumption, dental health service utilization and oral health status of Thai adults and elderly.

1.3.2 To estimate the changes of oral health status of Thai adults and elderly when the sugar-sweetened beverage taxing policy is implemented.

1.4 Theoretical conceptual framework

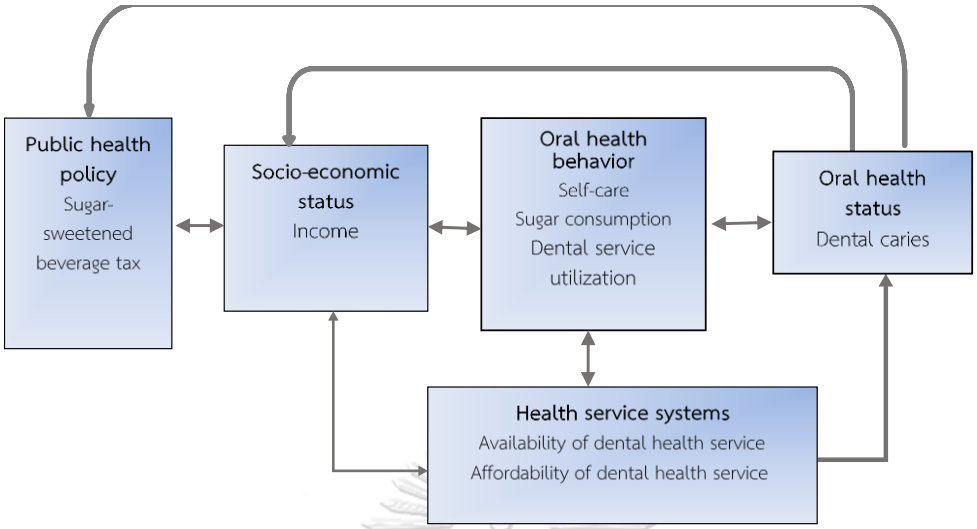


Figure 1 Theoretical conceptual framework

1.5 Operational definitions

- **Adult population**: population aged between 15-59 years in the survey year on secondary database.
- **Elderly population**: population aged 60 years and over in a survey year on secondary database.
- **Oral health problems**: dental caries assessed by the Decayed, Missing, Filled Teeth index (DMFT) for dental caries experiences
- **Dental services utilization**: the use of dental services in hospitals and dental clinics which served by licensed dentists and/or dental nurses practicing on the duty to services permitted by law, at least once in the past year before the survey.

- **Health service systems:** refer to availability of the dental healthcare services (proportion of the dental personnel per population), and affordability of the dental healthcare (people can afford the dental treatment).

- **Uptake rate of treatment**: proportion of treated population in each DMFT severity.

- **Self-care**: brushing teeth at least twice a day, using fluoride toothpaste.

- **Sugar-sweetened beverages** refer to pre-packaged non-alcoholic beverages which contain sugar ingredient such as soft drinks, tea, coffee and juices.

- **Poverty population**: population who have expenditure on consumption below the national poverty line (as of 1,555 baht/person/month in 2000 to 2,644 baht/person/month in 2015) defined by Thai National Statistical Office, The Ministry of Information and Communication Technology**.**

- **Non-poverty population**: population who have expenditure on consumption above the national poverty line

- **Very low DMFT:** the DMFT score less than 1.2 for individual aged 15-34 years old, or less than 5.0 for individual aged 35 years and older

- **Low DMFT:** the DMFT score of 1.2 – 2.6 for individual aged 15-34 years old, or 5.0 – 8.9 for individual aged 35 years and older

- **Moderate DMFT:** the DMFT score of 2.7 – 4.4 for individual aged 15-34 years old, or 9.0-13.9 for individual aged 35 years and older
- **High DMFT:** the DMFT score more than 4.4 for individual aged 15-34 years old, or more than 13.9 for individual aged 35 years and older

CHAPTER II
REVIEW OF LITERATURE

2.1 Dental caries and situation for Thai adults and elderly

The etiology of dental caries is the interaction of multiple factors over time. The three principle factors are the host factor (susceptible tooth morphology and saliva composition), the oral micro-flora and the substrate or fermentable sugar in diet; and their effects are dependent on the length of time an individual is exposed to these factors. Despite individual predispositions to dental caries, other indirect factors such as socio-behavioral and environmental factors can increase one's susceptibility to dental caries and its progression.[30-32] One such factor that is amenable to change is sugar consumption. High quantity and frequency of sugar consumption is one of the major causes of dental caries.[8] Dental caries occur when enamel and dentine are demineralized by organic acids produced from bacteria in dental plaque. These acids are the by-product from metabolic breakdown of sugar derived from diet. A longer exposure of sugars within the oral cavity due to the high frequency and quantity of sugar consumption will lead to an increase in acidity of the mouth. This causes an increase in solubility of calcium hydroxyapatite in the tooth surfaces, leading to demineralization.[8] Current evidences also support the association between high sugar consumption and prevalence of dental caries.[8-9]

In epidemiology studies, the Decay, Missing and Filled Teeth (DMFT) index is the most commonly used index to quantify dental caries experience based on the number of decayed, missing and filled teeth.[33] It has been used to measure the differences in dental caries experience among groups of population or within the same group at the different times.[34] The caries experience is calculated by aggregating the number of teeth either as decayed (D), missing due to caries (M) or filled. For the indicator age groups of children (12 years) and adults (35-44 years), World Health Organization suggested the using of DMFT to categorize the degree of dental caries experience as in Table 1.[35]

Table 1 WHO severity criteria for level of dental caries experience in permanent dentition [35]

Children 12 years of age (DMFT)	**Adult 35-44 years of age (DMFT)**
Very low < 1.2	Very low < 5.0
Low 1.2-2.6	Low 5.0-8.9
Moderate 2.7-4.4	Moderate 9.0-13.9
High 4.5-6.5	High >13.9
Very high > 6.5	

From the year 2000 to 2012, the prevalence of dental caries for adults aged 15 years, 35-44 years and 60-74 years have been slightly increasing from 62.1% to 62.4%,

85.6% to 86.7% and 95.6% to 97.1% respectively.[3-4] The mean DMFT of adult aged 15 years and 35-44 years slightly decreased from 2.11 to 1.9 and 6.1 to 6.0 respectively, while the mean DMFT of elderly aged 60-74 years tended to increase from 14.4 to 14.9.[3-4] The untreated dental caries for aged 15 years and older has also been improved for the past twenty years.[3] However, untreated dental caries is still the major oral health problem for adults and elderly. The findings from recent Thailand National Oral health survey in 2012 showed that 35.7% of adults and 50.2% of elderly still have at least one untreated tooth decay.[3] Percentage of tooth loss has been increasing with age. For the elderly, the recent survey showed that the partial tooth loss and total tooth loss are 88.3% and 7.2% at age 60-74 years. The elderly had 18.8 average remaining teeth per person. The average remaining posterior teeth was 3.2 and 1.0 pairs in 60-74 years old and 80 years old, respectively.[3]

2.2 Dental services utilization

The dental services utilization of Thai population decreases with the increasing age.[7] The trend of dental services use in population slightly increased from 7.4% in 2006 to 9.6% in 2018.[7] However, the 2017 Health and Welfare survey showed that the dental services used within the past years before the survey were only 11.2% for aged 15-24 years, 8.9% for aged 25-59 years and 7.1% for aged 60 years and older. The proportion of dental health service utilization has been found to be different in each socio-economic subgroups of the population.[7] The dental health service utilization rate in the population was higher among women (11.1%) than among men

(8.1%). People in urban area had higher rate of utilization (10.5%) than in the rural area (8.9%); and people who lived in Bangkok had the highest rate (15.8%) among other part of the country.[7]

Thai adults and elderly population tended to receive dental treatment when the symptoms were severe. The main reason for seeing the dentists was having pain or tooth sensitivity.[3] Therefore, the treatment was often tooth extraction and complicated procedures which required long period of time for treatment. On the other hand, the two main reasons for not getting dental services were having no symptom, followed by having no time for treatment even when there was the need for treatment.[3] For those who visited the dentists in the past years, the universal health coverage was the highest insurance used both for adults (70.2%) and elderly (82.8%), followed by the social health insurance in adults (15.3%) and the civil servant medical benefit in elderly (15.8%).[3]

Theories related to dental service utilization

The use of health services, including dental services, is designated as one of the factors that affect health conditions and oral health of the population.[36] In behavioral sciences, the use of health services is described as personal behavior which is a result of the unique attributes of individuals, the environment surrounding and their interactions.[37] One well known and widely used concept describing the factors involved in health service utilization is Andersen's behavioral model of health

service use.[38] The latter version of this conceptual framework includes personal and environmental factors, as well as health service system and health outcome. Moreover, the relationship are dynamics showing the feedback loop between the outcome and the related factors (Figure 2).

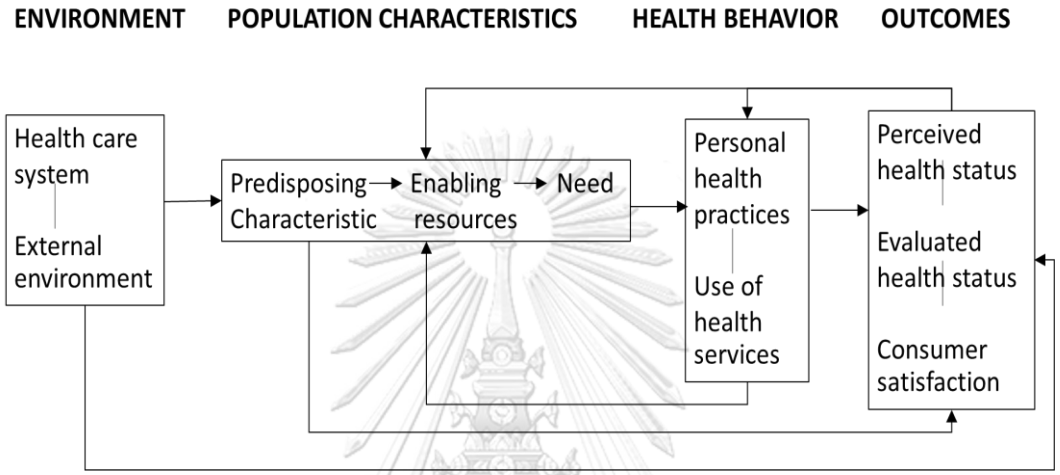


Figure 2 Andersen's behavioral model of health service use [38]

This concept describes the health outcome as a result from three factors: health behavior, population characteristics, and environment. For the population characteristics, there are three sub-factors:

1. Predisposing factors are individual factors, including age, gender, education, occupation, race and marital status. They also include health beliefs, attitudes, values and knowledge about health and health services.

2. Enabling factors are supporting factors for services use, including income and ability to pay for health services, health insurance, distribution of health service and healthcare personnel in the area.

3. The need for health services is the experience and awareness in health status of individuals from both medical examination and self- assessment.

Environmental factors are considered in two parts: 1) external environmental factors, which include physical, political and economic factors and 2) healthcare system focusing on national health policy, provided resources and organizations changes in the health care system.

Baker[39] used Andersen's Behavioral model to analyze adults' dental service uses in the UK. The study found that the enabling factors including instructions for oral hygiene care, type of services, treatment cost and anxiety for treatment could predict the treatment needs. Then, the needs could predict dental health behavior and the service uses. These two outcomes could predict oral health status and quality of life. In addition, the predisposing factors such as social status and income indirectly affected oral health behavior and dental service uses. Therefore, the result supported Andersen's framework in describing factors associated with the use of dental services and oral health.[39]

Andersen's model has been used to analyze the use of dental services of working age and the elderly, as well as the general population and specific groups such as patients, minorities and immigrants. In working age population, Lo and colleagues[40] found that factors affecting the use of adult dental services in Guangdong, China were being female, residing in urban areas, education and dental

health knowledge. Vujicic and Nasseh[41] found a correlation between the use of dental services in the United States and the contributing factors related to the economic status, income and health insurance. For the socio-economic disadvantage population, the main factors related to dental service uses were income[42], self-assessment for treatment need[42], having symptom of oral diseases[42-43] and having routine (or regular) clinic/hospital.[44] Sohn and Ismail[45] also found that, in addition to economic factors, fear of dental treatment can be related to not regularly having dental services. From a study in Sri Lanka[46], the only two factors within the Andersen's model that related to dental services use of working age population were gender and treatment needs. The study noted that the framework had its limitations and may not be sufficient to analyze with this population.[46]

In elderly population, a review of the literature found that factors related to dental services use include age, race, education, attitude, medical history, residency area, income, health insurance and access to services and attitudes.[47] Besides the general individual characteristics, cognitive abilities[48] and community relationship by having interaction with family and neighbors affected the dental service uses among seniors living in the community.[49-50] A study in Japan also found that number of remaining teeth, tooth pain and location of the hospital were associated with the use of dental services among senior citizen.[51-52] In Thailand, the use of dental services in elderly is also related to transportation, accompanying persons, income and general health condition.[53-54]

2.3 Sugar consumption in Thai population

The Committee on Medical Aspects of Food Policy of the United Kingdom identified that Non-Milk Extrinsic Sugar (NMES) causes tooth decay or dental caries.(55) This sugar refers to all sugar added to food by the manufacturers or consumers, plus natural sugar in honey, syrups and fruit juice concentrates.[13] The amount and frequency of NMES consumption have a direct correlation to the prevalence of tooth decay.[8] The occurrence rate of dental caries is rising rapidly when the amount of sugar consumed exceeds 15 kg/person/year. The World Health Organization recommended that the consumption of added sugars in diet should not exceed 5-10 percent of the daily total energy intake.[13] Therefore, added sugar should not be consumed more than 6-8 teaspoons a day for adults who require 2,000 kcal/day and not more than 4 teaspoons a day for elderly who require 1,600 kcal/day. The Food and Agriculture Organization (FAO)'s food balance sheet data showed that total calories from sugar per capita for Thai population increased from 396 kcal/day in 2007 to 431 kcal/day in 2011.(56) This amount contributed to approximately 19.8% and 21.5%, respectively of total daily required energy of 2,000 kcal for these two periods. This showed that individuals in Thailand are likely to exceed the WHO guideline recommended level of sugar consumption.

The trend of sugar utilization in Thailand has been increasing significantly within the past decades.[10] Data from the Office of the Cane and Sugar Board showed that sugar utilization rate increased from 12.7 kg/person/year in 1983 to 33.8 kg/person/year

in 2010 (Figure 3).[10] Total sugar consumption consists of both direct and indirect sugar consumption. The direct sugar consumption referring to the amount of pure sugar sale was higher than the indirect one which referring to sugar sale for food, beverage and pharmaceutical products.[10] The trend for direct consumption was declining, while indirect consumption tended to increase (Figure 4). The beverage industry accounted for the most of indirect sugar consumption as shown in Figure 5.[10]

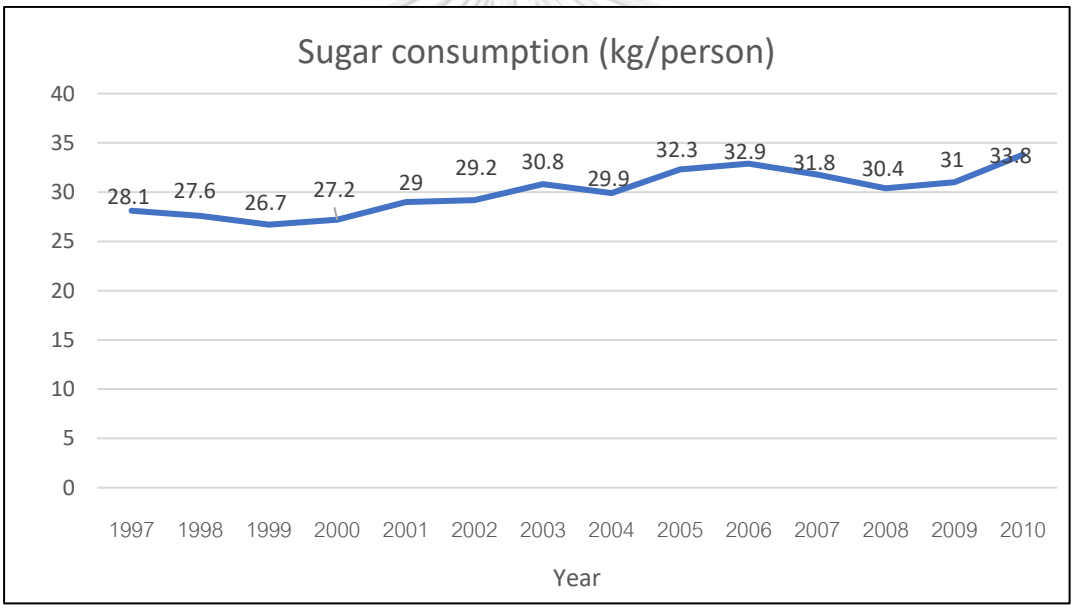


Figure 3 Indirect sugar consumption in Thailand during 1997-2010[10]

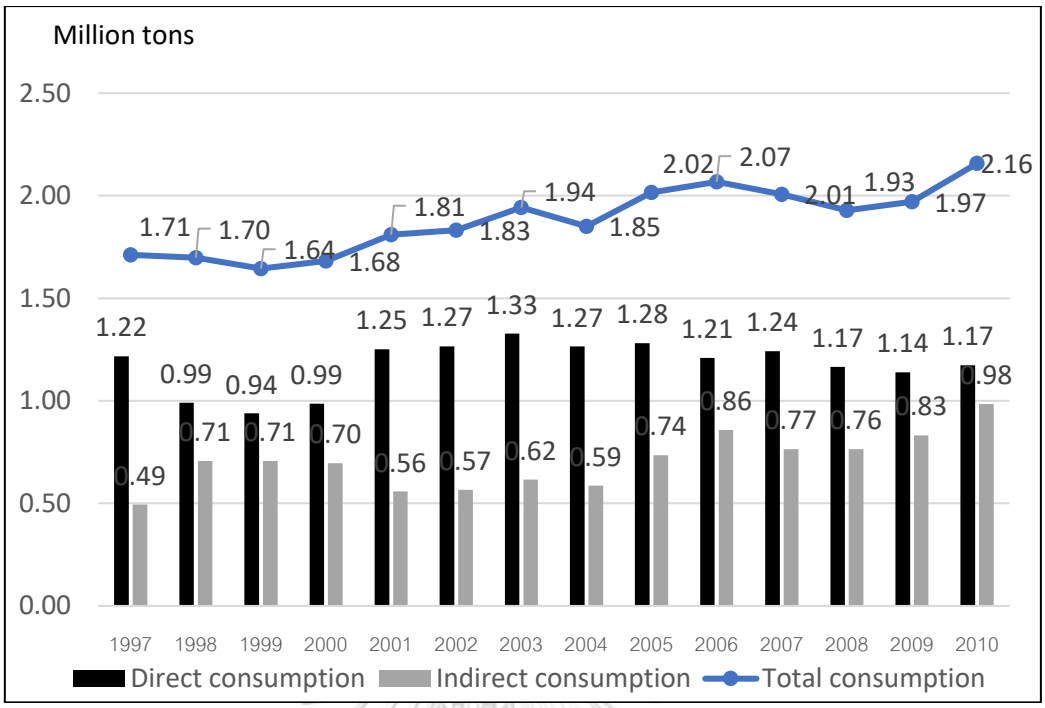


Figure 4 Direct and indirect sugar consumption of Thai population (1997-2010) [10]

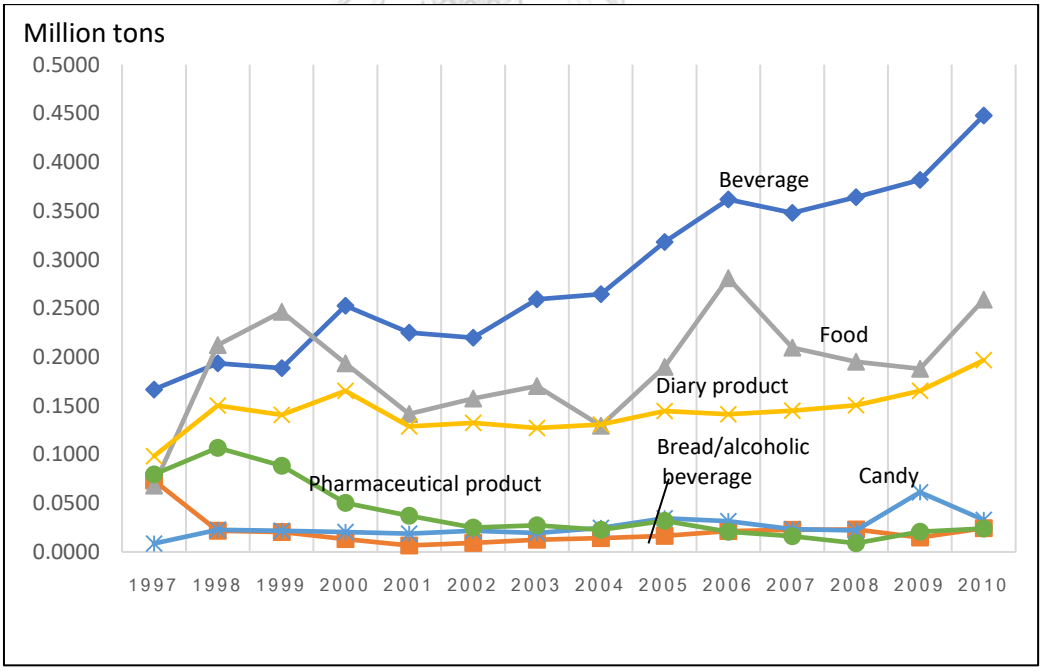


Figure 5 Indirect sugar consumption in Thailand during 1997-2010 [10]

A review from national surveys and individual studies reported that common food sources of sugar in all age groups were sweetened beverages, Thai desserts, table sugar and confectionery.[57] Among these food sources, sugar-sweetened beverage (SSB) represented the largest source of sugar consumption.[10-12] The sugar content in SSB in Thailand ranges from 10 grams per serving size in diary product and cereal drinks to 34 grams per serving size in soft drinks.[58] The 2013 national survey on food consumption behavior reported the food consumed by the population aged 6 years and over on the weekly basis as sweet non-alcohol drinks (63.6%), soft drinks (58.3%), and snacks (49.3%).[59] With the daily consumption, sweet non-alcoholic drinks were also consumed the highest as 25%, followed by soft drinks (6.5%) and snacks (6.9%).[59] Another study of Thai adults[60-61] showed that approximately 40% of males and 31% females consumed SSB weekly.

2.4 Social determinants of oral health

Social determinants of health as defined by the World Health Organization are "the conditions in which people are born, grow, live, work and age." [62] These states are determined by economic, political, and local resource allocation at national and global levels.[62] Social determinants of health are mostly responsible for inequities in health status seen within and between countries.[62] Moreover, the impacts of social determinants of health can be accumulated during the life course and alter people's health trajectories.[63] Like the concept of overall health outcomes, oral health shares the same determinants and common risk factors as several non-communicable

diseases (NCDs), such as diabetes and cardiovascular disease. Oral diseases are associated with socioeconomic status which is related to family income, educational attainment, employment, housing, physical and mental health.[64]

Oral health disparities have been reported worldwide and the most common problem included dental caries, periodontitis, tooth loss, effect on oral health-related quality of life, as well as the access to preventive treatment.[65] Earlier studies on inequality of oral health in the population have used various socio-economic indicators such as the Human Development Index (HDI), urbanization status, and Gross Domestic Product (GDP) to measure inequality in oral health in low- and middle-income countries. These indices indicate structural and mediating factors that affect oral health.[66] More recent studies focused on the process or measures to reduce the differences in oral health problems among population with different social factors.[67] The World Health Organization's Commission on Social Determinants of Health offers a framework that outlines the major determinants of oral health inequalities relate to each other (Figure 6).[68] It highlights the importance of the structural determinants which refer to the socio-economic and political contexts that generate the social gradients in society and the socio-economic position. The intermediary determinants refer to how socio-economic position then influences health through the circumstances and risk of oral diseases. Social determinant perspective helps to widen the focus on the broader social, community, environment and economic distal factors that are the underlying drivers of proximal biological and behavioral influences on oral

health inequalities.[69] In addition, the social determinants are dynamic in nature. Adverse social conditions in early life have a particularly significant effect across the life course and negatively impact health later in adult life.[70]

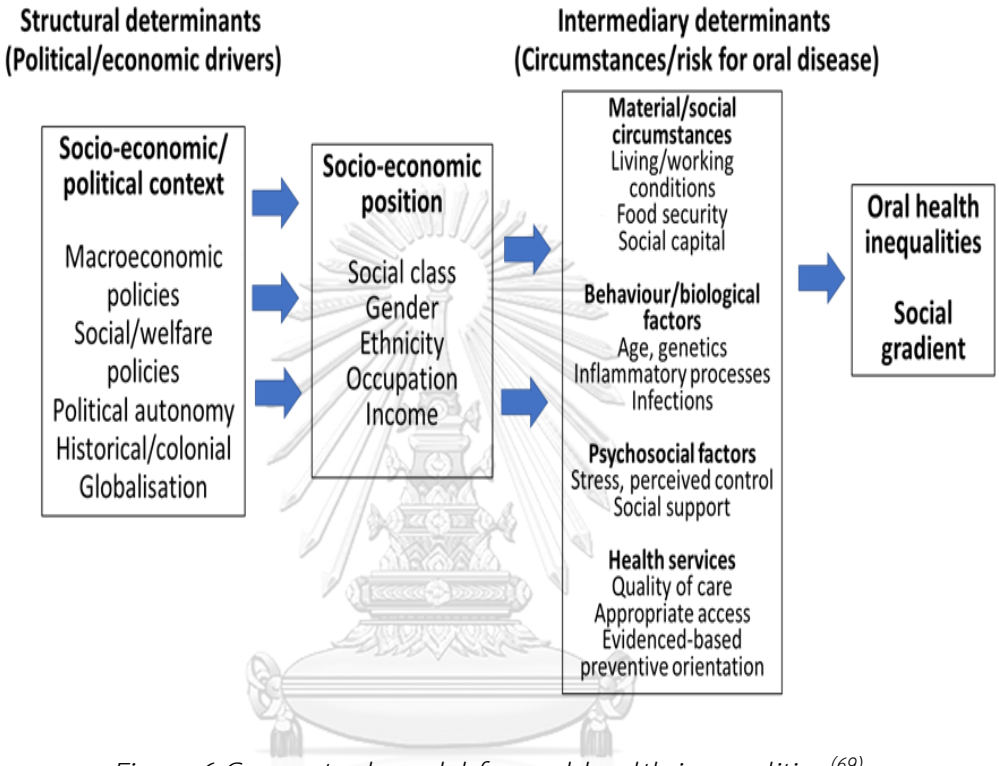


Figure 6 Conceptual model for oral health inequalities [69]

In a systematic review by Costa and colleagues[71], they presented the relationship between socioeconomic indicators and dental caries. They found that the level of education, income, occupation and the Gini coefficient were associated with higher occurrence of dental caries across 41 studies in the review. Racial and ethnic disparities are prevalent for oral health indicators, especially for untreated dental caries and periodontitis in various age groups.[72-73] Untreated dental caries in the United States were significantly higher for those living at or below the poverty level compared

with those living above the poverty level.[74] Vettore and colleagues[75] also found that low social status and low social connection were the major factors of tooth loss, perceived poor oral health and smoking in adult population. Oral health inequalities were found to vary in different age groups. An analysis of Adult Dental Health survey in England, Wales and Northern Ireland showed that there was a complex relationship of inequalities with age, rather than a uniform pattern of social gradients and oral health outcome across all adulthood. The income gradients were significant for numbers of teeth in older adults but not for the younger groups.[76]

While there have been improvement in oral health status globally, the disadvantages and vulnerable populations continue to suffer in their access to dental service.[64] The main socioeconomic factors related to dental services in these population were income and health insurance.[42] Health literacy can also affect oral healthcare use and oral health outcome. Poor oral health literacy contributes to poor access because people may not realize the susceptibility and severity of oral disease and the importance of oral healthcare. They may not know the option for accessing oral healthcare in their community.[64] Beyond the demand side, healthcare resources and dental workforce planning are also essential to provide access to oral health services.[77] Evidence from Scotland suggested that payment methods for provider affect the utilization of dental examination.[78]

2.5 Sugar-sweetened beverage tax (SSB tax)

Increasing number of governments, organizations, and advocators have proposed taxes on unhealthy food and drinks to improve nutrition and health outcome in population.[14] For example, the British Medical Association has addressed the taxes on high-sugar products.[79] The US Dietary Guidelines Advisory Committee recommended taxes to encourage the production and consumption of healthy foods and reduce unhealthy food.[80] There is a strong evidence that identify the excessive sugar consumption as contributing factor for obesity, diabetes and other metabolic health risks.[14] Sugar in beverages may be a special concern. The review examined the satiety effect of carbohydrates suggested that liquid carbohydrate, particularly sugar-sweetened beverages, produces less satiety than the solid form[81]. The individuals who consume soda and other sugar-sweetened beverages will lead to greater caloric consumption than those consuming solid-state calories.[81] Reducing liquid sugar may be particularly effective at reducing obesity and other health risks. However, the most efficient approach would be to tax sugar contents in all food and drink in order to reduce sugar consumption in population; in practice policymakers often choose the narrow target for taxing such as sugar-sweetened beverages.

Nutrition taxes can be designed into three main categories: focusing on content, volume, or sales.[14] Taxing sugar content could produce the biggest effect among those three types. The tax would increase the price of SSB, encouraging consumers to consume less and the industries to promote less sugar alternative products or

reformulation their product ingredients.[14] Table 2 illustrates the three types of tax designs to reduce consumption of added sugar in sweetened beverage.

Table 2 SSB tax designs and their possible effects [14]

	Tax Base		
	Sugar content (per gram	Volume (per liter)	Sales value (percent of retail price)
Consumers cut back on sugar drinks	✓	✓	✓
Business develop and promote zero-sugar drinks	✓	✓	✓
Consumers cannot avoid tax by buying cheaper drinks	✓	✓	X
Consumers shift to lower sugar drinks	✓	X	X
Businesses develop and promote lower sugar drinks	✓	X	X

In several countries, SSB tax policies have been implemented in different forms and rates. In 2011, Hungary used the tax rate of 0.02 USD per liter for the beverages with sugar content exceeding 8 grams per 100 milliliters.[82] In 2014, Mexico used the rate of 0.05 USD per liter, and found that the retail prices of such drinks increased 10-12 percent. Early reports show that the purchases of soft drinks in the country decreased by 10 per cent.[83] In 2015, the SSB tax was implemented at the rate of 1 cent per ounce in Berkeley, California, the United States but the retail prices increased less than half of the tax.[84] With the limitation in empirical evidences, several studies

use mathematical simulation to study the possible outcome of SSB tax. Several modeling studies suggested that it will lead to a reduction in sugar consumption, average daily calorie intake and BMI.[85-87] However, these results depend on assumptions about how consumers would adjust their consumption behaviors. There are many factors associated with the impact of a tax on consumption, such as changes in prices and demand, effect of taxes on retail prices, strategies of the manufacturing sector and the response of consumers. These factors may influence the results of the tax and cause unpredicted consequences.[14]

SSB tax may cause people to switch to other beverages like fruit juice, milk and alcohol drinks.[87-89] When the substitute drinks with high sugar content are increasingly consumed, the net sugar consumption would not reduce as the SSB tax policy intended. Several studies found these substitution effect and the result in reduced consumption ranging from little to moderate effect.[87, 89] Another unintended consequence may include the consumers' abilities to buy the targeted products without paying tax such as purchasing from illegal market and other countries or cities like the case of soda tax in city of Berkeley, California.[84] Moreover, one major concern for taxing unhealthy foods and drinks is how the tax burden would be shared across society. Households with lower incomes and less education may be the larger consumers of sugar-sweetened drinks. Thus, SSB tax will be regressive by imposing a larger financial burden on the disadvantage consumers than the higher income counterparts.[14]

Thai National Reform Steering Assembly's committee on public health and environment proposed an introduction of SSB tax, to be included as part of the Excise Tax Act B.E. 2017. This proposal was then passed by the legislature and enacted in September 16, 2017.[18] Sugar-sweetened beverages subject to the new excise tax include mineral water and carbonated soft drinks with added sugar, fruit and vegetable juices, coffee, tea, energy drinks and beverage concentrates for vending machines. This SSB tax adopts a mix tax rate system with both *ad valorem* and specific rate. The *ad valorem* part is calculated from the suggested retail price while the specific tax depends on the sugar content of the product. The tiered tax levy will be adjusted every 2 years from September 2017 until 2023. Beverages with over 6 grams per 100 ml will be subject to the specific SSB tax. Higher sugar level in a beverage, the higher rate of tax is applied.[18] According to the tiered tax levy, the government is encouraging the beverage industry to reformulate their products by having 2 years period to adjust the rate.

With this policy levy, it is expected that sugar content of SSB products will reduce and eventually lead to healthier choice and lower sugar consumption among Thai population. A study of SSB intake among Thai people aged 10-35 years old found that 40 percent of samples (2,238 people) reported their preferences in drinking sugar beverage and almost 50 percent of them consumed more than 3 days per week. The samples also reported their opinions on SSB consumption when SSB price increased. The results showed that 8.6 percent of them would stop drinking SSB if the price

increased 25 percent. Additionally, every 25 percent of SSB price rise, the percentage of reported stop drinking increased by 50 percent.[90] Bhadrakom's study on the potential impact of SSB price changes on the consumption of Thai population[91] suggested that the 10 percent proposed tax on SSB (theoretically equal to 10 percent increase in price) would lead to the reduction in SSB demand for the whole population by 7.76 percent in short term and 9.37 percent in long term. The reductions were much higher among low income households (14.59% short term, 16.93% long term) than high income household (3.85% short term, 4.55% long term) both for short and long term period.[91]

However, the effect of SSB tax on sugar consumption and dental caries is not straightforward. It is uncertain whether a tax increase will translate into lower sugar consumption and better oral health outcomes. Understanding the causal mechanism through which SSB tax will translate into lower sugar consumption and improved oral health is important in identifying a leverage point for interventions. In addition, it is vital to engage all stakeholders to develop a deeper understanding with a whole system perspective on the dynamic interactions between SSB tax, sugar consumption, and oral health outcomes.

2.6 Complex systems and system dynamics model

Complex systems approaches have been applied to public health issues such as the outbreak of influenza[92], obesity[93], diabetes[94], AIDS and sexually transmitted

infections.[95] An important characteristic of complex systems is the interaction of various elements within the system which may be nonlinear and involve with reverse relationships (feedback loops). The results of the interaction cause the new phenomenon or emergent behaviors which are not simply the sum of the individual components, but the result of the interaction as the whole. Moreover, the systems can change (dynamic) or adapt constantly (adaptive) and some changes may not occur immediately (delay).[96]

In oral health problems, several factors including personal, social and environmental factors can influence one another in a complex relationship over time. Those factors also adapt to change as time passes.[20, 22] Most traditional studies using epidemiological approach have analyzed the factors that affect oral health in separate parts. These studies may be limited because they fail to show the nonlinear and feedback relationship and may not reflect the impact of other unintended consequences.[22] Table 3 compares the traditional to complex system approach assumption into seven domains.

Table 3 Comparison of traditional and complex systems analytic assumptions

Domain	Traditional analytic techniques	Complex systems
Functional form	Linearity	Non-linearity
Common distributions	Normality	Non-normality
Characteristics of actors	Homogeneity	Heterogeneity
Level of analysis	Single level	Multiple levels
Temporality	Static, or discretely longitudinal	Dynamic with feedback
Fundamental relationships	Among variables	Interaction of actors
Perspective	Reductionist	Holistic

There are some developed tools and methods for describing and analyzing complex systems, strategic planning and evaluating programs. The systematic review of Carey and colleagues[97] found that the application of systems-oriented approach in public health can be categorized into 4 types, 1) outlining the potential of system science concept for public health in general or specific areas, 2) using systems concepts for analysis of data collected through general methodology, 3) using system methodologies to benchmark or evaluate public health practice, and 4) using system modeling to provide insight into public health problem and how to address them. The study also suggested that soft systems modeling was useful to deploy in public health.[97] The primary methods frequently used to study complex health systems include system dynamics modeling, network analysis and agent-based modeling.[98]

System dynamics model is a mathematical model developed in the 1950s by Professor Jay W. Forrester from The Massachusetts Institute of Technology (MIT).[99] It originally arose in management and engineering sciences from the need to explicitly model non-linear processes that are characteristic of complex circumstance such as the unintended consequences, policy resistance, counterintuitive behavior of the systems.[100] Then, it was developed into an analytical tool for economic, physical, chemical, biological and ecological systems. It has also been applied to medical and public health issues.[23] System dynamics models are used to understand complex systems which have feedback relationships and change over time. It describes how the behavior and relationships of the variables contribute to the system behavior as a whole.[100]

In principle, system dynamics has two aspects: qualitative and quantitative parts. The qualitative aspect involves mapping the causal relationships between key factors in the systems and identifying feedback loops which cause certain behaviors. The primary tool used in this process is Causal Loop Diagram (CLD). CLD is used to illustrate the mental model, highlighting causality and feedback loops. It is often developed using a participatory approach with stakeholders interested in the problems. CLD consists of variables and links that aid in visualizing how different variables and concepts in a system are interrelated. Each relationship was described with an arrow and a positive or negative sign indicating the polarities of the relationship. A link with positive polarity indicates that the two variables change in the same

direction; while a negative polarity means a change in the opposite direction. A feedback loop occurs when the output of a variable in the cause-effect chain is routed back to the cause variable to form a circle. There are two types of feedback loops—reinforcing and balancing loops. Reinforcing feedback loop represents the increase or decrease of one variable and then the same effect through the relationships will return to the same variable. While in balancing feedback loop, the increase or decrease in one variable will returns a decrease or increase (opposite direction) to the same variable. Figure 7 shows the example of CLD for population dynamics.

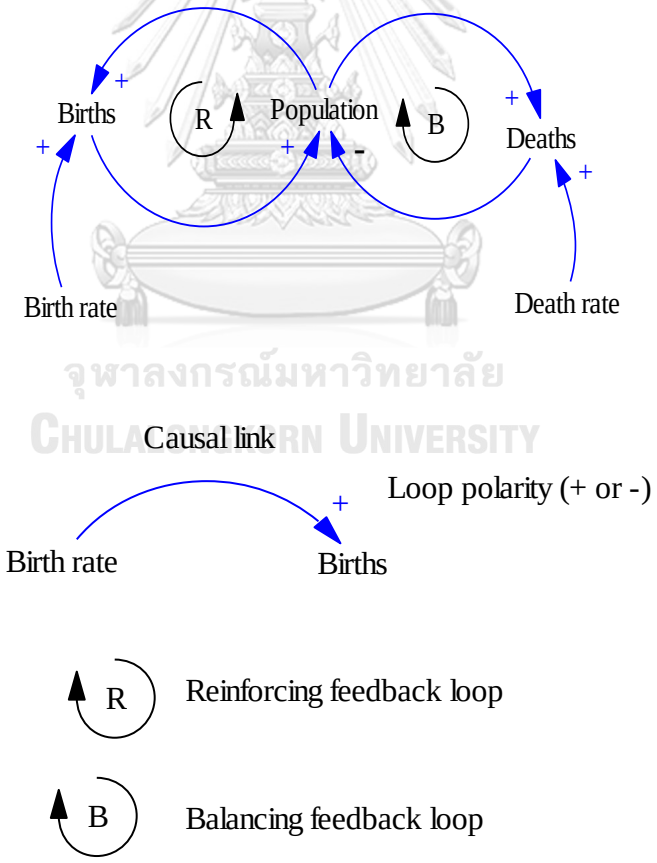
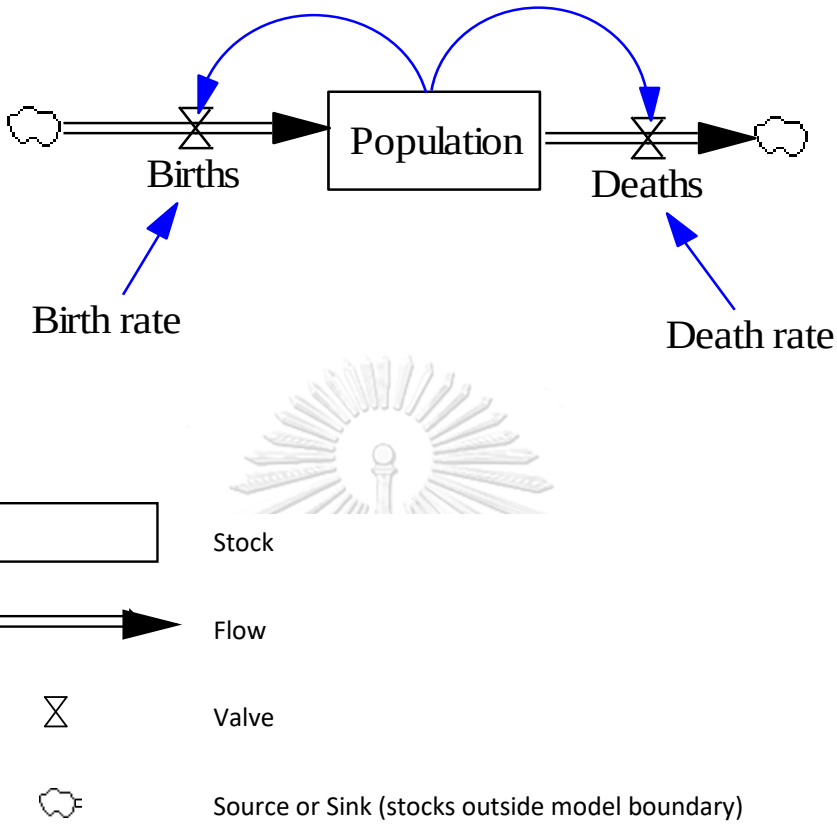


Figure 7 Example of causal loop diagram representing population dynamics

The quantitative aspect involves the development of simulation models which consist of series of differential equations representing the interaction among set of variables in the systems. The conceptual model from the qualitative part is converted into mathematical terms and executable equations to investigate the interaction and behavior of the outcome of interest. The existing policies or scenario planning related to the outcome can also be investigated using the model structure. Specialized computer software is required during this process. Examples of the core software widely used in SD modeling are iThink® and STELLA® (isee systems), Powersim Studio (Powersim Software), Vensim® and Ventity (Ventana System, Inc.). The primary tools used in this part is Stock and Flow Diagram (SFD). SFD primarily consists of three groups of variables: stocks, flows and auxiliary variables. Stocks (state variables) are accumulations over periods of time that characterize the state of the system. Flows (rates of change) are entities that make changes (increase or decrease) to the accumulations of stocks. The assumption used to build SD model is that the structure can be represented using a series of stock and flow variables.[100] Auxiliary variables are other variables (besides stocks and flows) that interact with or be influenced by flows and other variables to make the model complete. The example of SFD representing the population dynamics from the above CLD is shown in Figure 8.



Population = INTEGRAL (Births – Deaths, Population)

Births = Population * Birth rate

Deaths = Population * Death rate

Figure 8 Example of stock and flow diagram representing population dynamics

System dynamics model has been used to analyze the dental public health problems such as dental services system in the Netherlands[25], oral health problem and related factors of elderly living in urban area in the United States.[26] These studies suggested that stakeholders should communicate and be involved in the modeling process. Lui and colleagues used system dynamic modeling to study SSB tax policy

and to evaluate its sustainability and the impact versus other measures. Their study proposed the framework for policymaker to understand the system and introduced policy alternatives for obesity prevention in children in the United States.[27] Udompanich used system dynamics modeling to develop a delivery care model of dental public health in the community level in Thailand.[28] His study estimated the demand for dental personnel during the year 1995-2015. It also suggested that SD modeling could be used to generate alternative solutions for the production and allocation of dentists and dental nurses to support the decisions of policy makers at national level.[28, 101] Several factors related to dental services providing services and the treatment needs were covered. However, it did not consider the economic and social factors that are fundamental causes of oral health status. Recently, there are few studies using complex systems approaches in dental public health issues.[25-28]

CHAPTER III

RESEARCH METHODOLOGY

3.1 Research design

This study uses system dynamics modeling to study oral health problem, specifically dental caries and its complex interaction with related variables and the changes over time. The study has two aspects: qualitative and quantitative.

The qualitative aspect involves mapping the causal relationships between key factors in the system and identifying feedback loops which cause the oral health behaviors and outcomes of interest. The modeling processes in this part includes problem articulation and developing dynamics hypothesis.

The quantitative aspect involves the development of mathematical simulation models representing the interaction among set of variables related to dental caries and SSB tax policy which were identified from the qualitative part. The modeling processes include formulation of simulation model, model testing and policy analysis.

3.2 Study population

3.2.1 Target population: citizen of Thailand aged 15 years and older

3.2.2 Sample population: target population who were included in the secondary databases used in the model.

3.2.3 Unit of analysis: the whole country, divided into subgroups by age, gender and income according to variables related within the model.

3.3 Modeling process

The system dynamics modeling process consists of five primary steps. Each step is iterative which can be repeated several times after the later steps.

3.3.1 Problem articulation (Boundary selection)

- The problems to be considered including dental caries status and sugar consumption of Thai population were specified by using the data gathered from secondary data and literature review of documents/research related to oral health and SSB tax policy.
- **The stakeholder analysis** was conducted to identify stakeholders involved in SSB tax policy and its consequences (problem of interest in this study). Following the framework for stakeholder identification, assessment and prioritization, the three steps of questions were considered.

    1) Who can affect or be affected by the SSB policy?
    2) How should each stakeholder contribute to the policy? What are their potential interests in the policy?
    3) Which stakeholders should be the high priority of involvement?

    Then, identify the stakeholders with high impact on SSB policy and contact them as key informants for the interviews.

The detail stakeholder analysis matrix is shown in Appendix A.

- **The in-depth interviews** were conducted with the key informants in the groups identified by prior stakeholder analysis. The purposes of these key informant interviews were to gain an in-depth understanding of the perspectives of multi-sector stakeholders on the SSB tax policy and its possible consequences on sugar consumption and oral health outcomes.

Seven key informants were purposively selected from: Thai consumers' foundation (1); Thai association of SSB industry (1); health economist and researcher (2); the Bureau of Dental Public Health, Department of Health, the Ministry of Public Health (1); and the Excise Department, Thai Ministry of Finance (2). Each informant was interviewed for a period of 30–60 minutes at their workplaces, using a semi-structured, open-ended questionnaire. All the key informants read and signed the written informed consent prior to the interview.

The interview questions covered a broad list of issues including sugar content in SSB and sugar consumption, general and oral health outcome as a consequence of sugar consumption, and concerns on the SSB tax, as well as the expected barriers and consequences of SSB tax from the stakeholder's perspectives. The interviews were note-taken,

audio-recorded and transcribed. The questions and summary of the answers from the interview are shown in Appendix B. Transcripts from the interview were analyzed for the next process.

- **Group Model Building (GMB),** an established methodology for engaging stakeholders to gain mutual understanding of complex relationships related to the SSB tax policy, sugar consumption, dental services use, and oral health outcome, was conducted for 2 sessions in Bangkok. In boundary selection step, GMB's purpose was to determine key variables to be included in understanding the dynamics of SSB tax and oral health outcomes; the time horizon; and the reference modes of the key variables.

  GMB session 1: The participants in the GMB session 1 included 7 stakeholders from different sectors: dental public health and Thai Dental Council (4) and public health policy experts (3) of which two have expertise in systems thinking. They were purposively selected with the inclusion criteria of having at least 10 years of experience working in their respective fields. GMB session 1 consists of four activities: 1) Identifying the main outcomes of interest and time horizon, 2) Identifying key variables, 3) Identifying the reference modes of the key variables and 4) Developing causal loop diagram. The scripts for group

activities/tasks used during the sessions were developed from "scriptapedia version 4.0.6".[102] Detailed notes and audio-recording was taken by an assistant of the modeling team.

Activity 1: Identifying the main outcomes of interest and time horizon.

The main concept of system thinking and objectives of the study were introduced. Then, the participants were asked to consider a dynamic relationship between oral health outcomes and sugar consumption through a facilitator-led discussion. The discussion mainly focused on oral health outcomes that oral health intervention could influence; and the time horizon to consider for this study. Each participant articulated the oral health outcomes that policy makers should track when they implement such oral health interventions. All the responses were written on a large whiteboard. The mutually agreed time horizon and set of outcomes were proposed after the discussion and clarification of each outcome variables.

Activity 2: Identifying key variables.

The researcher led the participants to identify as many variables as possible that could affect or be affected by the outcomes identified in **Activity 1**. The summary of the key informants' interviews was also

presented to the group to provide details input from the interviews. Participants were given an opportunity to ask clarifying questions on each listed variable. The variables were added or removed until all mutually agreed by the participants. Then, the key variables were categorized into identifiable groups.

Activity 3: Identifying the reference modes of the key variables.

This activity focused on current understanding of the behavior of variables of interest by the stakeholders. First, the "behavior over time" graph or reference modes was introduced to stakeholders, then a graph of dental caries prevalence in Thailand was presented. The participants discussed the prevalence of caries and were given an opportunity to select some outcome variables and graph their behavior overtime considering: (1) past trends; (2) future trends, if current policies remain unchanged; and (3) what the behavior over time would be with different oral health interventions.

3.3.2 Formulation of dynamic hypothesis

- The focus of this process was to develop a dynamic hypothesis that explain the dynamic relationships between SSB tax, sugar consumption and oral health outcomes in the feedback structure. **Causal Loop**

Diagram (CLD) was used as a tool to capture the complex interactions or causal relationships of the key variables.

Activity 4: Developing Causal Loop Diagram.

The example of CLD were presented and explained in details to the participants. The participants were asked to collectively construct causal relationships and feedback mechanisms among key variables identified from the prior activities based on their expertise and the qualitative data from the interview. The facilitated discussion was conducted to clarify the meaning of the relationship among variables. After several rounds of discussion and adjustments, all participants agreed with the first draft of CLD. During the discussion, the draft diagram was written on the whiteboard and then was transferred into Vensim® DSS version 7.2 (Ventana Inc.) modeling software.[103]

- **GMB session 2:** This session was conducted several weeks after the first session. The session consisted of some stakeholders who participated in the first session (4) and other stakeholders from the Thai Ministry of Public Health (1) and the Fiscal Policy office (2). The aim of this session was to validate the causal loop diagram of oral health outcomes and SSB tax by verifying the variables and their relationships, as well as the assumptions underlying these interactions. After reviewing the CLD from GMB session

1, the participants were asked to identify the variables and the causal linkages that they would like to revise or/and add. The discussion then continued until the causal loop diagram could reasonably capture the dynamic interactions among oral health outcomes, sugar consumption and SSB tax in Thailand. The final CLD was presented to stakeholders for their final approval.

3.3.3 Formulation of a simulation model

- This quantitative process involved formalizing the conceptual framework (CLD) created from the prior process into mathematical model, gathering the information, setting the basic parameters in the model from literature review and/or from secondary data, and/or estimate from expert opinion. Stock and Flow Diagram (SFD) was developed for this simulation model using Vensim® DSS version 7.2 (Ventana Inc.) modeling software.

- The SFD consists of interacting sets of differential and mathematical equations developed from a broad range of relevant empirical data to capture the interrelationship of various key variables and oral health outcomes. Model structure was divided into 4 sub-models including: Population, Oral health, Sugar consumption and Oral health service utilization. The final model structure was presented in chapter IV (System dynamics model structure).

- During the model development process, oral health policy experts were consulted to verify the assumptions and the outcome measures.
- After verification, the model was parameterized using a series of empirical data. When data were not available, estimates from experts were used. Detailed parameters are shown in Appendix D. Finally, the model was simulated to generate base-case scenario to identify potential points of intervention to improve oral health.
- Main outcomes of interest in this model:
    1. Numbers of population with dental caries experiences in each severity group using DMFT score. The criteria used to categorize DMFT severity group is shown in Table 4.
    2. Proportion of population with untreated dental caries in each severity group using DMFT score
    3. SSB consumption for poverty, non-poverty group and total population.
    4. Sugar consumption from beverages for poverty, non-poverty group and total population.

Table 4 DMFT severity criteria used in this study (modified from WHO severity criteria for level of dental caries experience in permanent dentition)

DMFT severity group	Age group 15-34 years old	Age group 35 years and older
Very low	< 1.2	< 5.0
Low	1.2-2.6	5.0-8.9
Moderate	2.7-4.4	9.0-13.9
High	>4.4	>13.9

- Data sources:

    1. Thai population data was obtained from Thailand Official Statistics Registration Systems, Department of Provincial Administration, The Ministry of Interior. [104]
    2. Fertility rates were obtained from The World Bank Group.[105]
    3. Mortality rates were obtained from Thailand Public Health Statistics Report 2000, Bureau of Policy and Strategy, Ministry of Public Health.[106]
    4. The proportion of population in each DMFT severity group with treated or untreated dental caries condition, the proportion of population with regular dental visit, the proportion of population with perceived need for dental treatment and the proportion of population with oral health self-care were estimated from the Thai national oral health survey data in

2000-2001, 2006-2007 and 2012 from the Bureau of Dental Public Health, Department of Health, Ministry of Public Health.

5. Average sugar consumption of the Thai population (2000-2015) was obtained from the consumption data provided by the Thailand Office of the Cane and Sugar Board, Ministry of Industry.[107]
6. Consumption of SSB was estimated from the report of food consumption data of Thailand 2006, The National Bureau of Agriculture Commodity and Food Standards [108] and Thai National Statistical Office, Ministry of Information and Communication Technology.
7. Proportion of poverty and non-poverty population was obtained from poverty data from Thai National Statistical Office, Ministry of Information and Communication Technology.

3.3.4 Model testing

Model testing was conducted to verify the model's validity and to gain confidence in the insights and recommendations emerging from the model. This study used two primary approaches for model testing.

- **Structure-based validation** was conducted to test the validity of the structure in order to ensure whether the model is suitable for its purpose and consistent with the real situation. Part of this process was conducted

by researchers and experts in regarding the real system and the process included in the GMB session 2. The goals of structure-based validation are:

1. To test the suitability of the structure.

First, the dimensional accuracy of the model equations and unit consistency of all variables were checked. Then, the model structure was checked to ensure that the equations were reasonable on extreme conditions. Finally, the model boundary was checked to ensure that it contained all the necessary variables and feedback structure to address the purpose of the study. The model boundary also was reviewed to include additional variables important to form feedback structure and for model testing.

2. To test the consistency of the model outcomes with the real system.

The model structure and its parameters were evaluated by the researcher and experts from the GMB. The model structure was evaluated to ensure it capture the important aspects of the actual system of dental caries, SSB and sugar consumption issues. The parameters were compared with the information available.

- **Behavior-based validation** was conducted to test the accuracy of the system behavior. The simulated behaviors of main variables

(population, dental caries status, dental treatment status and sugar consumption) were compared with the historical reference data. The model output and data were also compared qualitatively for the patterns and trends of behavior. Sensitivity analysis was performed to check the robustness of the simulated behavior when the assumption changes.

Finally, the model was adjusted using model calibration and optimization function for the sensitive parameters. The model was simulated under the base case and alternative policies.

3.3.5 Policy formulation and evaluation

Four policy scenarios were developed for the purpose of this study. The main policy was the SSB tax. The other hypothetical scenarios were selected in response to the range of possibilities identified by stakeholders. All four scenarios in addition to the base-case were explored.

- **Base-case**: The base-case simulation assumes that all model parameters and key variables remain unchanged over the simulation run. This simulation serves as a reference point for comparing four scenarios mentioned below.
- **Policy 1**: This scenario assumes the SSB tax as the actual excise tax implemented in Thailand since September 2017. The changes in this

simulation started from 2018 to 2040 with the tired levy depending on sugar content in SSB (Appendix E).

- **Policy 2:** This scenario assumes the implementation of health promotion program over the time period of 2018 to 2040.
- **Policy 3:** This scenario assumes the gradually increase in intake of dental students from 933 person in 2018 to 1200 person in 2040. In addition, the proportion of the poverty population who have financial accessibility to the dental treatment is assumed to gradually increase from 40% in 2018 to 80% in 2040 with the steady rate of change each year.
- **Policy 4:** This scenario assumes the combined implementation of policy 1, policy 2 and policy 3.

Sensitivity analysis was performed on all the scenarios proposed in the study to observe the value of parameter changes would affect the main outcomes of interest (population in each DMFT group and sugar consumption). The parameters used in the sensitivity analysis are shown in Table 5. Using multivariate sensitivity analysis, the values of each parameters were varied by 20 percent on both sides, and a uniform distribution for each parameter was assumed. Then minimum and maximum values at 95 percent confidence level for each run were used to show the credible interval, in addition to the mean values. The exception is the parameter on percent reduction in SSB sugar which was calculated using a range from 10 to 50 percent to

reflect the actual situation in SSB sample products after the introduction of SSB tax as well as the range proposed by experts.

Table 5 Parameters, baseline values, and their range in sensitivity analysis

Input parameter	Baseline value	Min	Max
VL to L transition rate	0.063	0.0504	0.0756
L to M transition rate	0.066	0.0528	0.0792
M to H transition rate	0.063	0.0504	0.0756
elasticity of affordability	0.01	0.008	0.012
elasticity of capacity	0.01	0.008	0.012
elasticity of perception (Very Low DMFT)	0.8	0.64	0.96
elasticity of perception (Low DMFT)	0.05	0.04	0.06
elasticity of perception (Moderate DMFT)	0.4	0.32	0.48
elasticity of perception (High DMFT)	0.8	0.64	0.96
elasticity of sugar consumption	0.6	0.48	0.72
elasticity of price (poverty)	-1.46	-1.168	-1.752
elasticity of price (non-poverty)	-0.39	-0.312	-0.468
Percent reduce SSB sugar	0.8	0.5	0.9

3.4 Ethical Consideration

The ethical approval for this study was granted from the Institutional Review Board (IRB) of Faculty of Medicine, Chulalongkorn University. The study protocol followed 3 basis ethical principles of the Belmont Report (1979).

Respect for person: The information from the secondary data did not have to reveal the identity of an individual. In addition, the data in each variables of interest were calculated to form a relationship for the whole population. For the qualitative data collection and participatory group process, the voluntary written consents were obtained prior to the process and all participants' confidentiality were protected. The opinions and decisions of the participants were respected and the results of the study did not specify the individual's opinion.

Beneficence/Non-maleficence: The agency providing the information and the participants in the study may not be the direct beneficiaries. However, the result of this study can provide recommendation for the dental public health intervention and SSB tax which it is expected to benefit the whole population.

Justice: Both qualitative and quantitative process implemented as the principles set forth, without prejudice to the results of the study and the benefit of any agency or person. There were also no conflicts of interest with the relevant authorities and the researchers.

CHAPTER IV

SYSTEM DYNAMICS MODEL STRUCTURE

4.1 Causal loop diagram

Figure 9 shows the final causal loop diagram which contain two main components: oral health care (illustrate with blue arrow in Figure 9) and SSB consumption care (illustrate with red arrow in Figure 9). This diagram serves as the dynamic hypothesis for this study. It includes eight feedback loops, which consist of seven balancing feedback loops (B1-B7) and one reinforcing feedback loop (R1). The pathways of the feedback loop are described in Table 6.

Table 6 The pathway of feedback loops identified in the causal loop diagram

Feedback loop	Paths
B1	1⟶2⟶3⟶4⟶9⟶10⟶7⟶8⟶1
B2	1⟶2⟶3⟶4⟶9⟶13⟶15⟶8⟶1
B3	1⟶4⟶5⟶1
B4	5⟶7⟶8⟶1⟶6⟶5
B5	5⟶1⟶6⟶5
B6	16⟶14⟶2⟶3⟶4⟶9⟶19⟶16
B7	20⟶19⟶25⟶20
R1	16⟶17⟶18⟶19⟶16

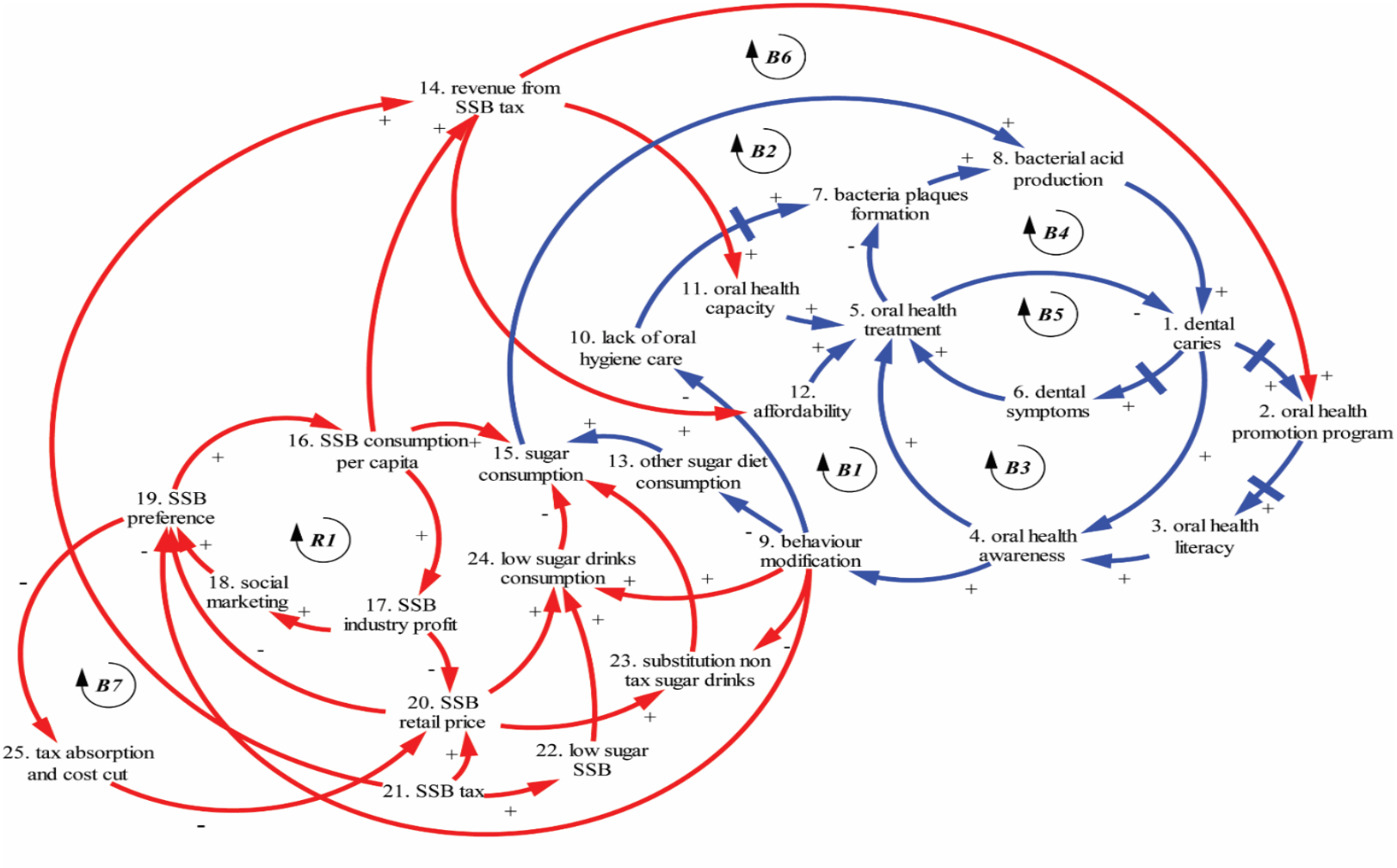


Figure 9 Causal loop diagram of dental caries, sugar consumption and SSB tax

4.1.1 Oral health care

From the perspective of the stakeholders, dental caries—the main outcomes of interest—is caused by demineralization at the tooth surface. This demineralization occurs when cariogenic bacteria in dental plaques turns consumed sugar into acid. The acid produced promotes mineral loss from the enamel. When frequent and prolonged demineralization occurs, which exceeds the capability of a tooth to absorb back the mineral or remineralization over a period of time, the enamel surface will dissolve to become cavities or dental caries. Poor oral hygiene practices and low fluoride use further contributes to more dental plaque formation, which can enhance the demineralization process.

For oral health interventions, the stakeholders identified several factors including low oral health awareness, inadequate oral health service capacity (human and infrastructure), and poor affordability of oral health services as the main reasons for low dental care services utilization. Five balancing feedback loops that slow the growth of dental caries were identified.

The feedback loop B1 postulates that as the prevalence of dental caries increases at the population level, the Ministry of Public Health will respond with an oral health promotion program nationwide to educate the population on oral health. An oral health promotion campaign is assumed to increase oral health literacy in the population, which then increases oral health

awareness and leads to behavior modification among the population, albeit with a significant delay. Behavior modification at the population level is assumed to reduce unhealthy habits, such as lack of oral hygiene care and no fluoride use. These will eventually decrease the prevalence of dental caries with a significant delay over time. While the Feedback loop B1 demonstrates that the prevalence of dental caries can be reduced by oral hygiene care and fluoride use, **the feedback loop B2** assumes that behavior modification can lead to a reduction in sugar consumption, which decreases the production of acid by cariogenic bacteria and reduces dental caries prevalence.

For **the feedback loop B3**, dental caries progression will cause pain and discomfort, which is assumed to increase oral health awareness and oral health treatment over time. When oral health treatment increases, dental caries are assumed to decrease. **The feedback loop B4** postulates that oral health treatment, such as scaling, root planning and filling, will impact bacterial plaque formation, which eventually decreases the prevalence of dental caries, dental symptoms and the need for oral health treatment. For **the feedback loop B5**, as oral health treatment increases, prevalence of dental caries is assumed to decrease, further reducing dental symptoms and treatment.

4.1.2 SSB consumption

For the purpose of this study, SSB is defined as any pre-packaged sugar sweetened beverage available to the public. In the CLD as shown in Figure 8,

sugar consumption is assumed: (1) to increase as per capita SSB consumption and other sugar consumption increases; and (2) to decrease as low-sugar-content drinks increase while decreasing high sugar content drinks. SSB consumption per capita increases herein as SSB preference among the population rises. SSB preference is determined by SSB social marketing, SSB retail price, and behavior modification programs. The stakeholders hypothesized that as SSB consumption per capita increases, SSB industry profits will increase. With increased profits, more resources are made available for social marketing, which is expected to further increase SSB preference and consumption. This dynamic relationship is captured in **the reinforcing feedback loop R1**.

For **the balancing feedback loop B7**, the stakeholders argued that as SSB tax is implemented, retail price of SSB is expected to increase. As retail price rises, population preference for SSB is assumed to decrease. As a result, the SSB consumption per capita, the SSB industry profits and the intensity of social marketing are assumed to decrease over time. The reduction in consumer's preference for SSB will lead to more tax absorption and cost cutting measures by the SSB producers to reduce SSB retail price, and to maintain the customer base for SSB.

The stakeholders agreed that if the retail price of SSB increases due to SSB tax, two outcomes can be hypothesized: (1) likely increase in consumption of low sugar content drinks; or (2) substitution of SSB for non-taxed high sugar content drinks. The stakeholders argued that, to avoid the substitution effect, SSB tax should be applied to all high sugar content products without exception. Moreover, it was hypothesized that an SSB tax could encourage the SSB industries to reformulate their SSB products to reduce the sugar content in order to avoid the SSB tax. Therefore, the availability of low sugar SSB in the market will increase, which will likely lead to an increase in low sugar drinks consumption. For **the feedback loop B6**, the implementation of an SSB tax has a potential to generate revenue, which could be used for an oral health promotion program to improve oral health capacity and/or to subsidize oral health services.

4.2 Stock and flow diagram

The stock and flow diagram serve as the quantitative simulation model in this study. The model comprises of four sub-model: population, dental caries, oral health service utilization and sugar consumption

4.2.1 Population sub-model

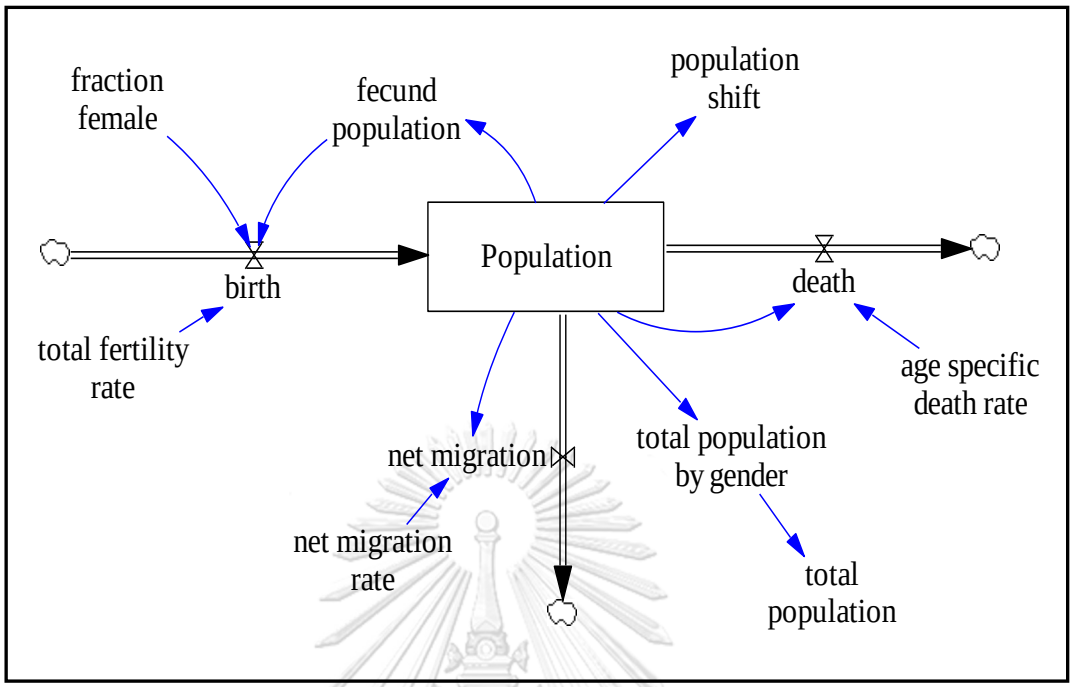


Figure 10 Stock and flow diagram: Population sub-model

The population sub-model (Figure 10) was first developed to project the population of Thailand from age 0 to age 100 and older. The base population from this sector then was used for the oral disease prevalence in target population of adults aged 15 and older.

The model structure illustrates the stock of population in Thailand with the aging process. The population stock is disaggregated by single year age cohorts (age 0—age 100 and older) and by gender (female, male).[109-110] The flow of birth is a function of total fertility rate and fecund population (sexually active female cohort) which results in an increase in population, whereas the flow of death is determined by age specific mortality rates from life tables and

number of population that serve to decrease the population. Net migration is the difference between immigration (transition from foreign labor to permanent resident status) and emigration (resident population migrating from Thailand to other countries). Net migration rate is determined through calibration.

In the aging process, birth flow into the first age cohort while the surviving population in each age cohort flows into the subsequent cohort, with the exception of the final age cohort (age 100 and older). The non-surviving contingent in each age cohort is removed via an outflow that reflects the mortality for that age cohort. The population sub-model is calibrated using national statistical data that is publicly available.[111]

4.2.2 Dental caries sub-model

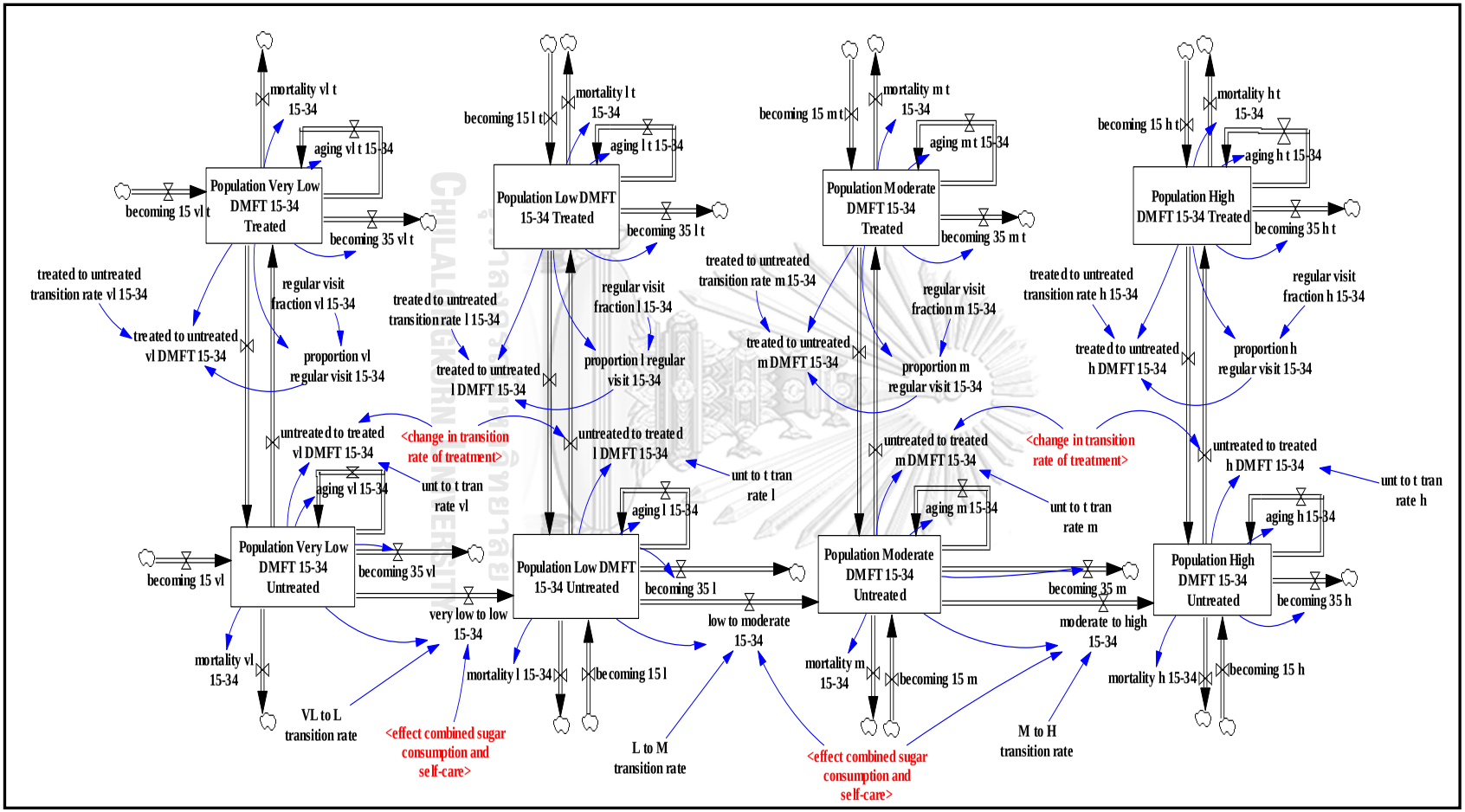


Figure 11 Stock and flow diagram: Dental caries sub-model

The dental caries sub-model is the simplified version—showing only sub-model for age 15-34 years (Figure 11). It illustrates the process of dental caries experience progression. In this sub-model, the Thai population aged 15 years and older were divided into 4 main categories: very low DMFT, low DMFT, moderate DMFT and high DMFT. The categories were defined using standards set by the World Health Organization for two representative age bands, namely 12 years and 35-44 years.[35]

In this model, for the population aged 15-34, the standard for 12 years was used and the standard for 35-44 years was applied to the population aged 35 and older. Subsequently, the very low, low, moderate and high DMFT groups were each further divided into two groups: completely treated for dental caries and untreated. Population in the treated groups were the ones with no normative treatment need and no need for a dental prosthesis, while the untreated groups included the rest who still required treatment.

The process of dental caries experience progression allows for movement of the population across the various DMFT group, from very low to low; low to moderate; and moderate to high DMFT. As DMFT scores of individuals cannot decrease over the lifetime by virtue of their definition, transitions across DMFT categories are progressive and uni-directional. Transitions across treatment status were captured in the oral health sector:

from untreated to treated and vice versa, for each DMFT category. Transition through DMFT severity group was estimated by the transition rate between each stage, modified by the effect of oral hygiene (how changes in oral hygiene modifies transition rates).

The population aged 14 (becoming 15 years) enters the model each year, and are distributed across the various DMFT groups according to their oral health status. The aging process ensures that at the end of each year, the surviving population in each age cohort transitions to the subsequent cohort except for the final age cohort (age 100 and older). The model allows the target population to transition between each state or to flow out as they die.

Transitions from untreated to treated states are influenced by the change in uptake rate of treatment, which is derived from the utilization sector. Transitions from treated to untreated states are influenced by regular dental visit fraction which was calculated from the number of the population who visited dentists in the past year prior to the national oral health survey. The dental caries prevalence from Thai national oral health survey in 2000-2001, 2006-2007 and 2012 were used in the model as the main data sources.

4.2.3 Oral health service utilization sub-model

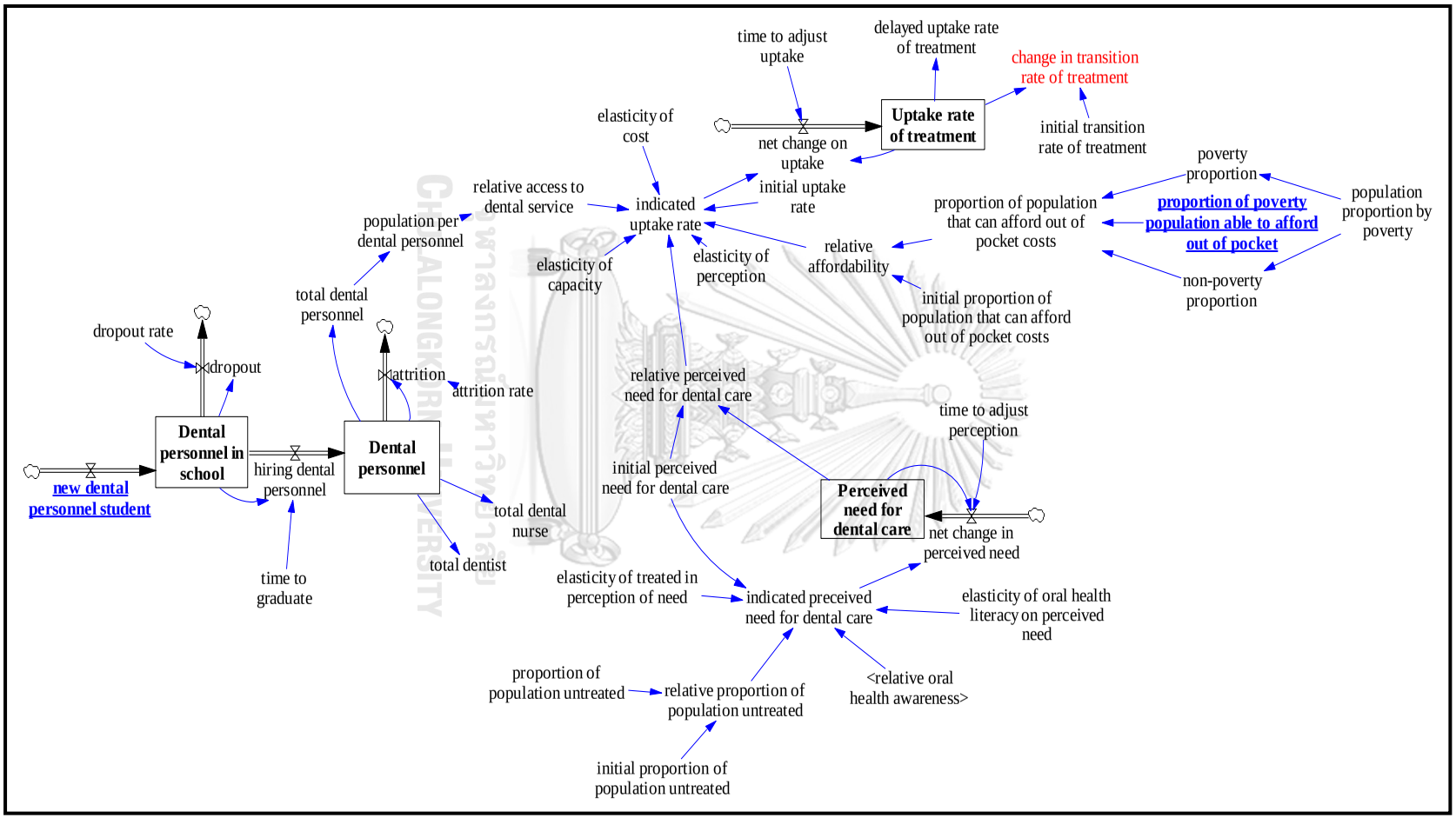


Figure 12 Stock and flow diagram: Oral health service utilization sub-model

The oral health service utilization sub-model (Figure 12) models how the use of dental services (number of individuals receiving treatment) changes over time. Three main factors were identified as key components that change the use of dental services in Thailand. These factors are 1) access to dental services, 2) perceived need for dental care and 3) affordability for dental care. An increase in rate of dental treatment was assumed to increase the transition between untreated dental caries to the treated state in the dental caries sector.

Population per dental personnel (dentists and dental nurses) ratio was used as a proxy of access to dental services. The supply of dental personnel is affected by the training pipeline of dental personnel and increases as a result of hiring graduates from dental personnel in school, and decreases due to attrition of dental personnel. Dental personnel in dental school increases with increasing intake of dental personnel and decreases with dropouts. Data on dental personnel was obtained from Thai Bureau of Dental Public Health, Ministry of Public Health year 2000-2015.[112] It was assumed that an increased access to dental care would increase the treatment uptake rate.

Perceived need for dental care is assumed to be affected by both the level of oral health awareness, dental caries untreated status from the dental caries model sector, and population affluence, represented by the proportion of the population above or below the poverty line (expenditure) from Thai

National Statistical Office, Ministry of Information and Communication Technology. As the level of oral health awareness increases, the perceived need for dental care increases. Also, as the proportion of the population who have untreated dental caries increases, the perceived need for dental care is assumed to increase with the effect depending on the group of dental caries experiences (very low, low, moderate, high).

In this model, affordability of dental services is assumed to vary across socio-economic (SES) group. The model accounts for two SES groups (poverty and non-poverty, defined by the poverty line). A proportion of the poverty individuals are assumed to experience affordability issues with the out of pocket costs of dental care, whereas non-poverty individuals are assumed to have no problem.

The contribution of access to dental services, perceived need for dental care and affordability of dental services to uptake rate of dental care, modified by their elasticity (relative contribution to uptake rate of dental treatment) is multiplied by the initial uptake rate to derive the indicated uptake rate. Uptake rate of dental treatment is modeled as a stock which changes by net change in uptake. Net change in uptake is modeled as the difference between indicated uptake rate and uptake rate, adjusted by the time it takes to change uptake rate.

4.2.4 Sugar consumption sub-model

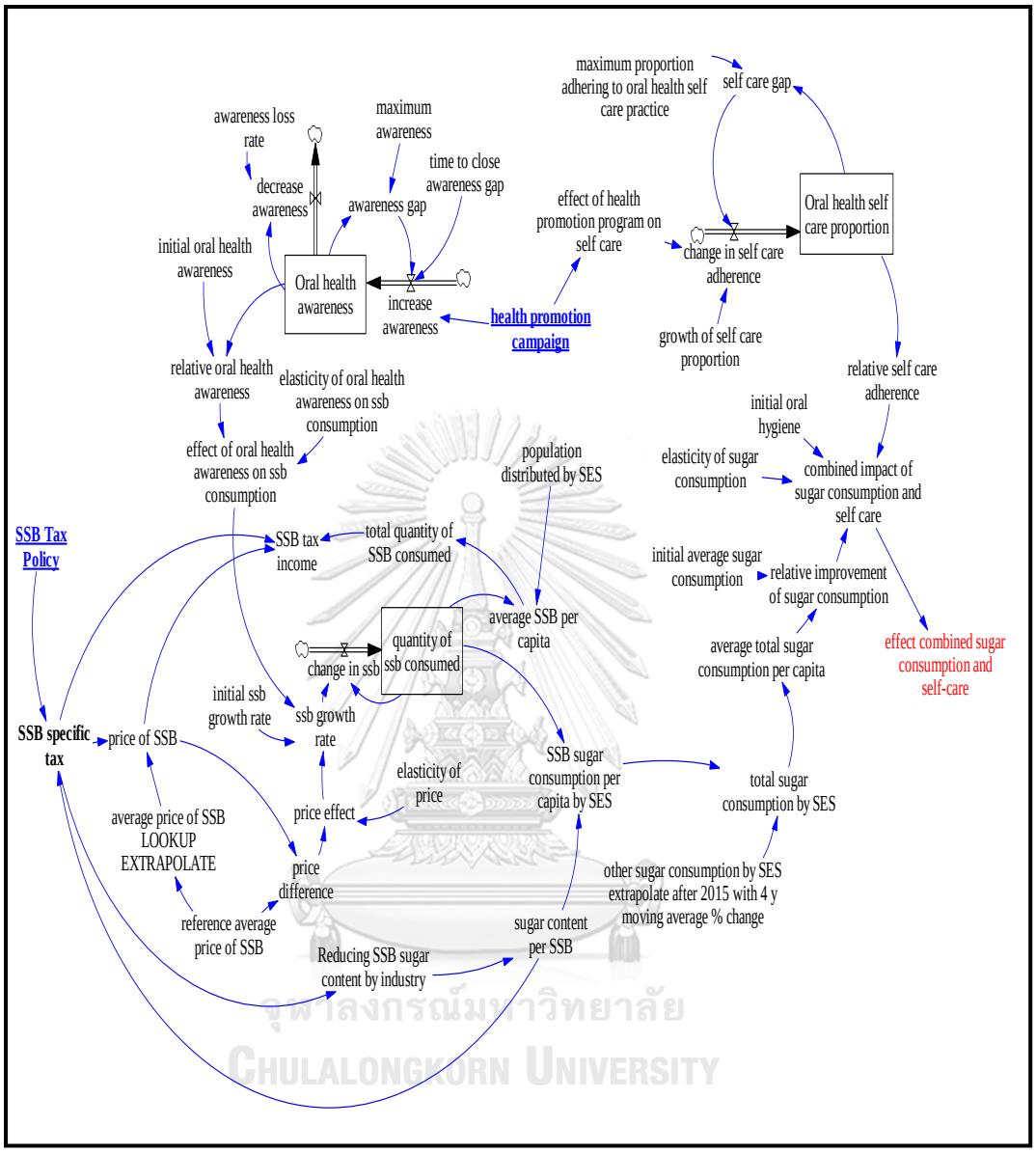


Figure 13 Stock and flow diagram: Sugar consumption sub-model

The sugar consumption sub-model (Figure 13) models the effect of sugar consumption, oral health awareness and oral self-care practice of the population on oral health outcomes. On sugar consumption, for simplicity, sugar consumed was divided into two types: sugar consumed from sugar

sweetened beverages (SSB), and other sugar. Other sugar comprises of sugar consumed from desserts and other food items. Quantity of SSB consumption is modeled as a stock and divided into 2 sub-groups by the population SES. In addition, based on evidence from other studies, SSB tax is postulated to have less impact on non-poverty group compared to the poverty group.

To estimate the quantity of sugar intake from SSB, the quantity of SSB consumed was multiplied by the average sugar content per SSB. To estimate the change in sugar consumption, current sugar consumption was compared to initial sugar consumption to derive relative sugar consumption.

Awareness of oral health is modeled here in as a stock. To simplify the model structure for oral health awareness, a maximum level of awareness was set as a level that is likely to be achieved in a population and it is compared with current awareness to determine an awareness gap. Any gap in oral health awareness is assumed to be closed by a health promotion campaign. Also, the model accounts for loss in oral health awareness over time—represented by loss rate of awareness.

Self-care practice of oral health is modeled as a stock which changes over time. Net change in self-care practice is determined by the gap between current self-care practice and the maximum possible proportion of the population likely to take-up self-care practice and health promotion campaign.

As health promotion campaign increases, self-care practice is assumed to increase if there is a gap between maximum self-care practice and current self-care practice.

4.2.5 Model assumptions

- The population used in this study includes only Thai nationality who have been registered in household registration from Thailand Official Statistics Registration Systems, Department of Provincial Administration, The Ministry of Interior.
- The secondary data used in the modeling of dynamic systems are representative of the population of Thailand.
- Each population subgroup is homogeneous, assuming there were no differences within the groups.
- Fertility rate is assumed to remain constant from 2010 throughout the projection timeframe (2000-2040).
- Mortality rates for a single age are assumed to be the same within the age group and the rate remains constant from 2000 to 2040.
- The proportion of population in each DMFT group and regular visit fraction are assumed to be the same for a single age for each age group. The proportions in the missing age groups are assumed to be the same as the proportion in the prior ages.

CHAPTER V

RESULTS

This chapter presents the results of the simulation model for base-case analysis with the reference data validation, policy scenario analysis, and sensitivity analysis.

5.1 Base-case analysis

5.1.1 Population sub-model

The projected total Thai population and population by age group with the reference Thai population data are presented in Figure 14. The projected population compared to the data is shown in Appendix C which show that the simulated population can replicate the historical reference data. From this simulation result, Thai population is projected to increase from 2000 until 2024 and will gradually decrease from 2024 to 2040. The trend of population decline is in infant, children and youth, while the elderly population is increasing. The adult population shows similar trend of changes with the total population.

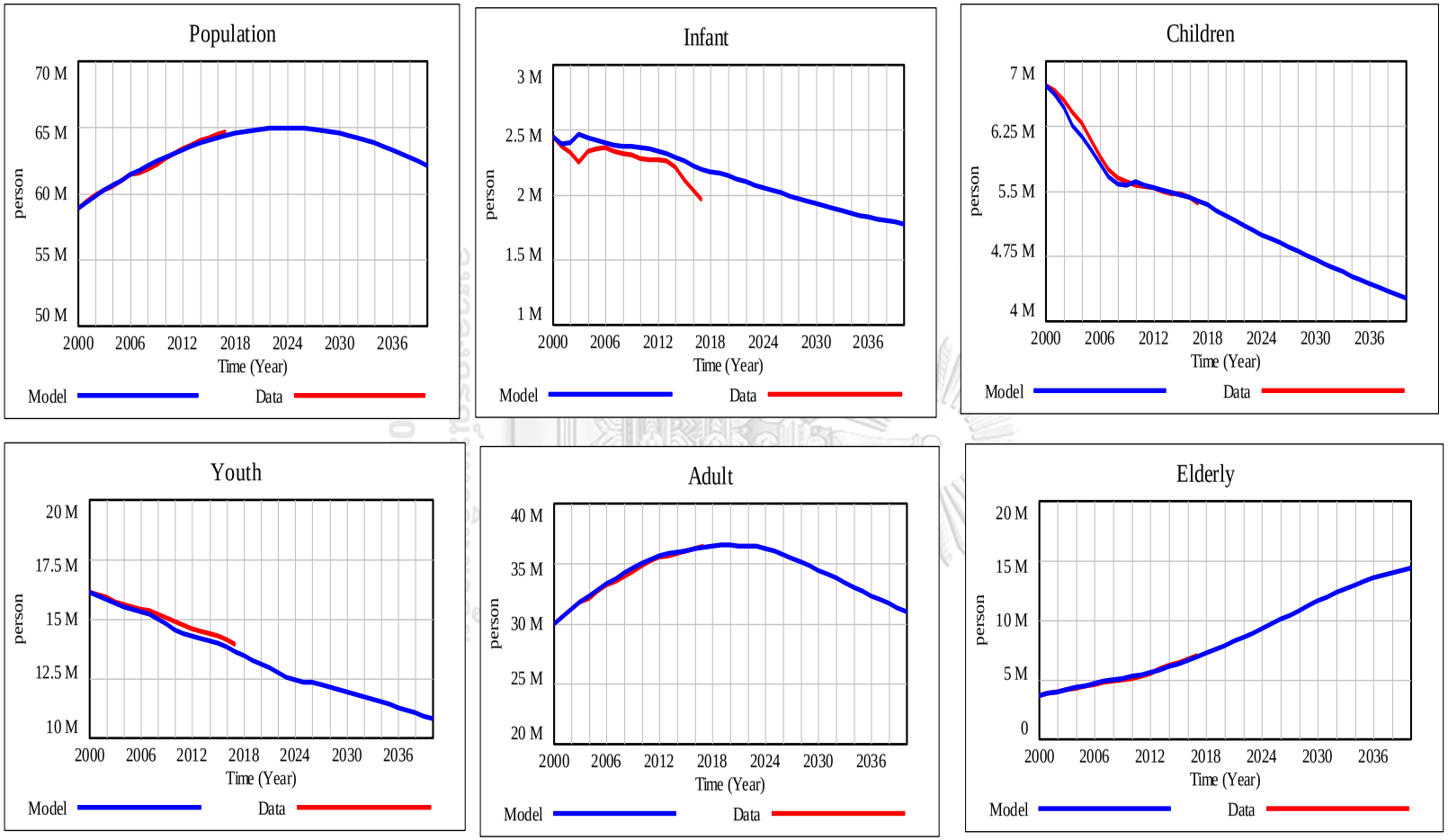


Figure 14 Projected Thai population with the reference data

5.1.2 Dental caries sub-model

The dental caries status in Thai population aged 15 and older is represented by the proportion in each DMFT severity and the proportion of untreated dental caries. Figure 15 illustrated the projected proportions of population in very low, low, moderate, and high DMFT group compared with the reference data from the Thai national oral health survey in 2000-2001, 2006-2007 and 2012. Figure 16 illustrated the projected proportions of untreated dental caries in each DMFT categories. The projected numbers of all proportions in Figure 15, 16 comparing with the reference data are shown in Appendix C.

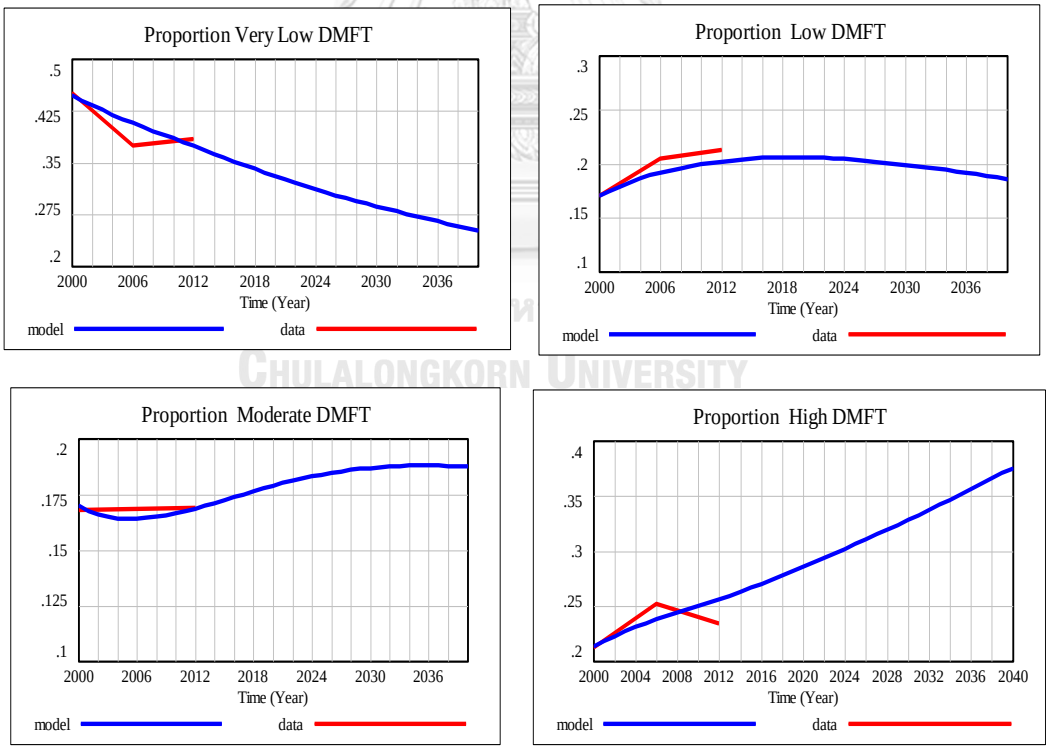


Figure 15 Projected proportion of population in each DMFT severity group with the reference data

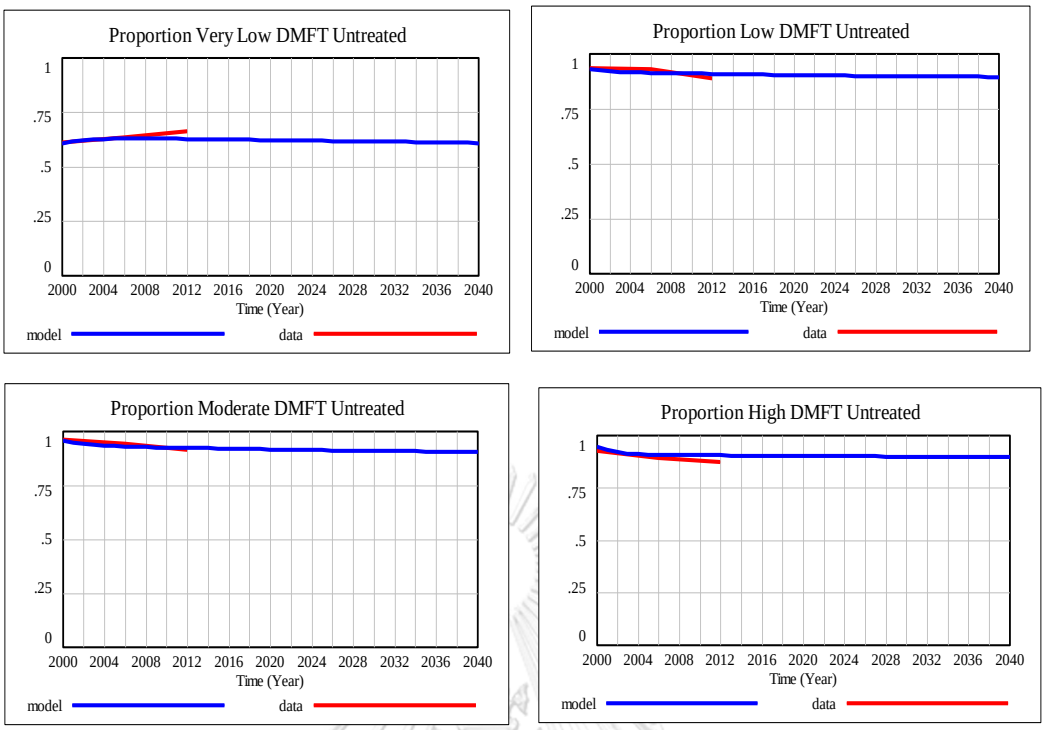


Figure 16 Projected proportion of population with untreated dental caries in each DMFT severity group with the reference data

In 2000, 44.7% of Thai population aged 15 and older had very low DMFT and the trend shows a decrease over the simulation timeframe to 25.5% in year 2040. On the other hand, the moderate and high DMFT groups (17% and 21.2% respectively in the year 2000) increase to 18.1% and 36.6% respectively by the year 2040. For the low DMFT group, the projected proportion estimated a slight increase and gradually decrease over time. The proportions of population with untreated dental caries remain very high (value close to 1) but the trend has slightly decreased for all groups, except the very low group.

5.1.3 Oral health service utilization sub-model

The projected numbers of dental personnel are illustrated in Figure 17. The trend for both numbers of dentists and dental nurses are increasing over the projected time. The projected number comparing the dental personnel and uptake rate of treatment data is shown in Appendix C. While the quantity of dental personnel is increasing, the simulated uptake rate of treatment shows the decline (Figure 18).

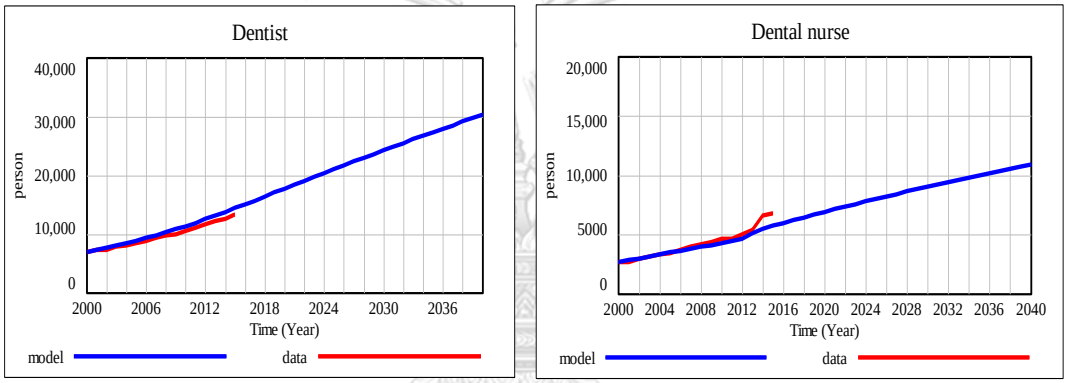


Figure 17 Projected number of dental personnel with the reference data

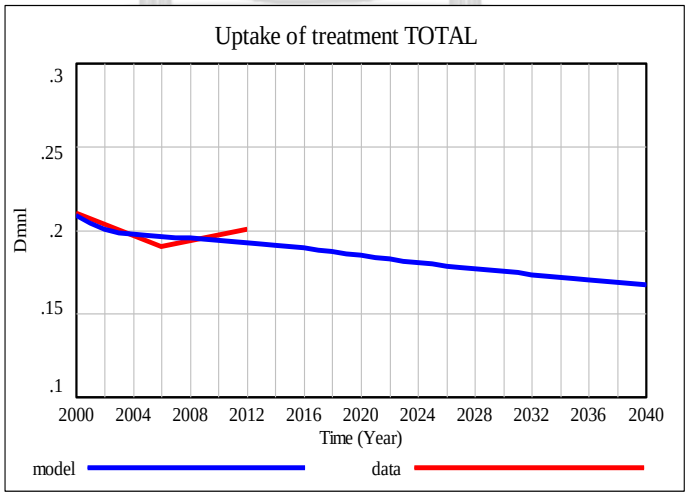


Figure 18 Projected uptake rate of dental treatment in population with the reference data

5.1.4 Sugar consumption sub-model

The average total sugar consumption among Thai population aged 15 and older is projected to increase steadily from 27.8 kg/person in 2000 to 64.1 kg/person in 2040. At the same time, SSB consumption and amount of sugar consumption from SSB have also been increasing for both poverty and non-poverty population (Figure 19, 20). The quantity of SSB sugar consumption is approximately 3 times higher for non-poverty group comparing with poverty group during the projected timeframe. From 2000 to 2040, the SSB consumption for poverty and non-poverty population have increased from 15.1 to 51.22 liter/person and 44.1 to 155.2 liter/person respectively (Appendix C).

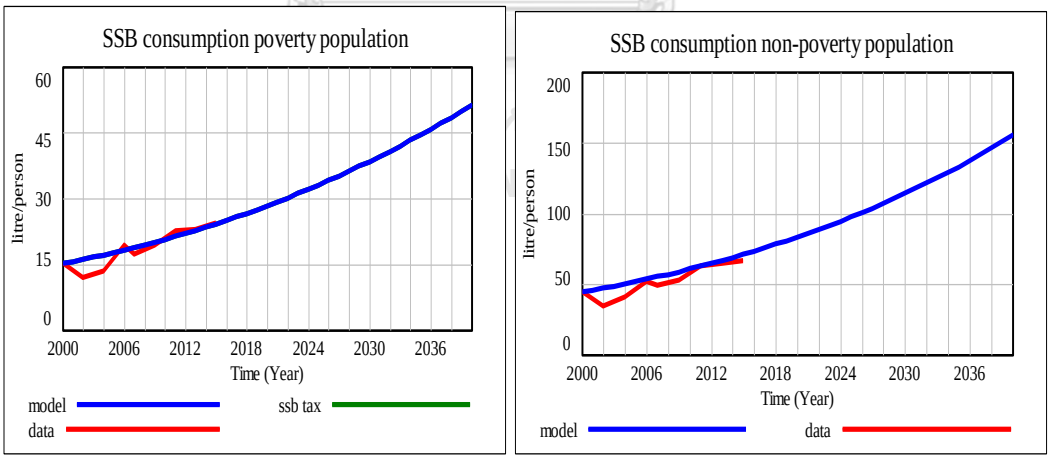
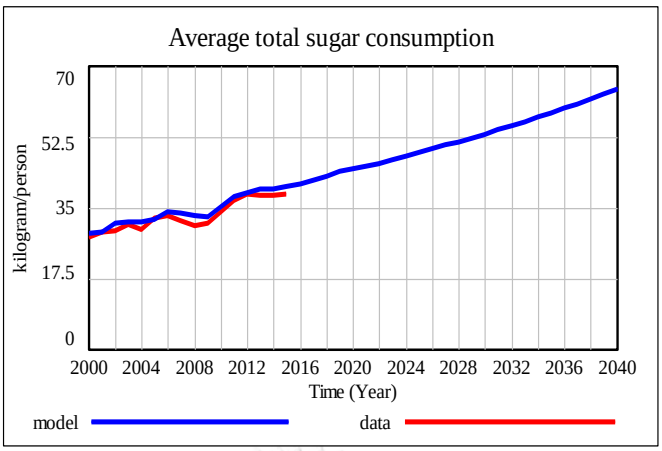
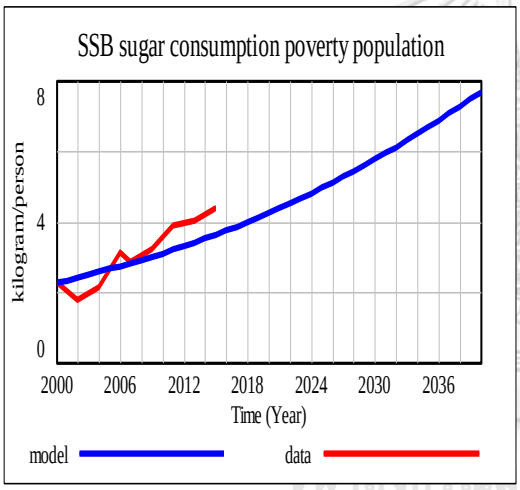


Figure 19 Projected SSB consumption in poverty and non-poverty population with the reference data





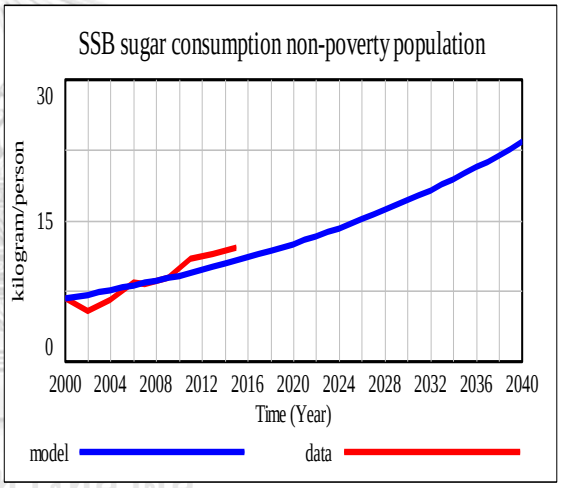


Figure 20 Projected total sugar consumption and SSB sugar consumption for poverty and non-poverty population with the reference data

5.2 Policy scenario analysis

The main outcomes for policy analysis are 1) total population in each DMFT group, 2) total population with untreated dental caries in each DMFT group, 3) SSB consumption level for non-poverty, poverty group and total population, and 4) Sugar consumption level for non-poverty, poverty group and total population.

Summary of policy scenarios (as described in Chapter 3)

Base-case	Reference point, no parameter changes
Policy 1	Introducing SSB specific tax from 2018
Policy 2	Implementation of supplement health promotion program from 2018 to 2020
Policy 3	Dental students increase by 25% from 2018 to 2040, Gradually increase proportion of the poverty population who have financial accessibility to dental treatment by 50% from 2018 to 2040
Policy 4	Combined policy 1, policy 2 and policy 3

5.2.1 Total population in each DMFT

Table 7 presents the projected Thai population aged 15 and older according to DMFT severity under each policy scenarios from 2000 to 2040. Under the base-case scenario in 2000, of the 45.2 million Thai population aged 15 years and older, 20.2 million were categorized as very low DMFT and it was projected to decrease to 13.3 million by 2040. For the same projected timeframe, individuals with low, moderate and high DMFT are projected to increase (Figure 21).

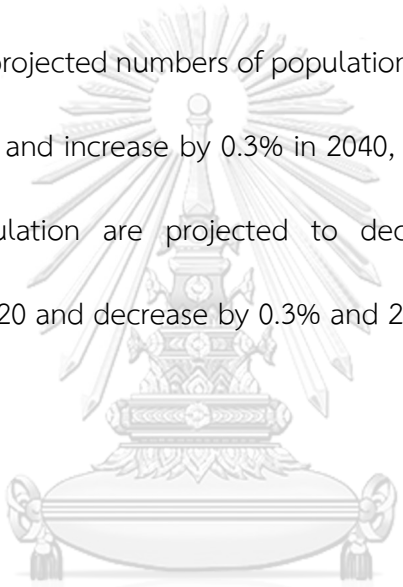
Under **the first policy —** with the introduction of actual SSB tax policy in 2018 and the hypothesized reduction of sugar content in SSB products, total numbers of individuals with very low DMFT are projected to increase from the base-case scenario by 0.02% in 2020 and 2.3% in 2040. Comparing to the base-case scenario, the projected numbers of population with low DMFT remain almost the same in 2020 and increase by 0.9% in 2040. The number of moderate DMFT population are projected to remain almost the same compared to the base-case scenario in 2020 and projected to decrease by 0.06% in 2040. The numbers of high DMFT population are projected to decrease by 0.02% in 2020 and 1.9% in 2040.

Under **the second policy—**with the implementation of supplementary health promotion program, total numbers of individuals with very low DMFT are projected to increase by 0.01% in 2020 and 1.5% in 2040 compared to the base-case. While the numbers of low, moderate and high DMFT population are expected to remain almost the same compared to the base-case scenario in 2020, the numbers of these three group are projected to decrease by 0.5%, 0.2% and 0.6% respectively in 2040 (Figure 22).

Under **the third policy—** with the increase in dental personnel and financial accessibility of poverty population, the numbers of population in all groups of DMFT are projected to be almost the same as the base-case scenario in 2020. For the projected time in 2040, the very low DMFT group is expected

to increase by 0.06%; while the low, moderate and high DMFT group is expected to slightly decrease by 0.03%, 0.02% and 0.02% respectively.

Under the **last scenario**—with the combination of the policy 1, 2 and 3, the projection shows the biggest improvement in all DMFT group compared to the base-case scenario. The numbers of individuals with very low DMFT are projected to increase from the base-case scenario by 0.02% in 2020 and 3.8% in 2040. While the projected numbers of population with low DMFT remain almost the same in 2020 and increase by 0.3% in 2040, the numbers of moderate and high DMFT population are projected to decrease by 0.01% and 0.02% respectively in 2020 and decrease by 0.3% and 2.5% respectively in 2040.



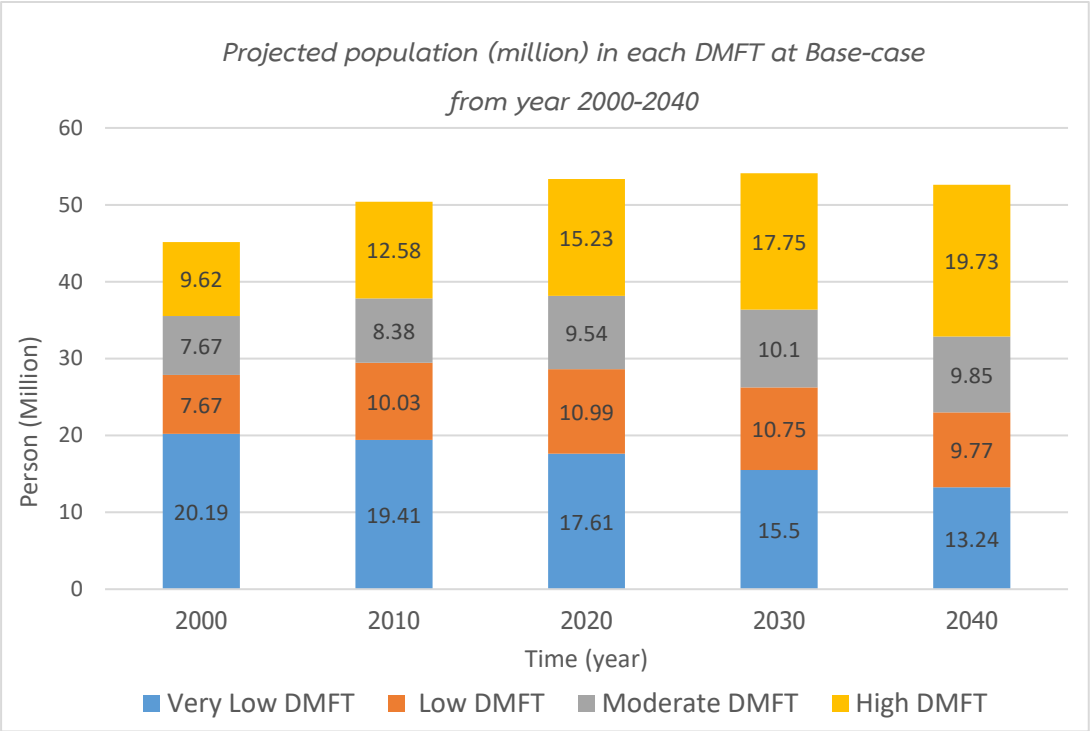


Figure 21 Projected population (million) in each DMFT at Base-case (2000-2040)

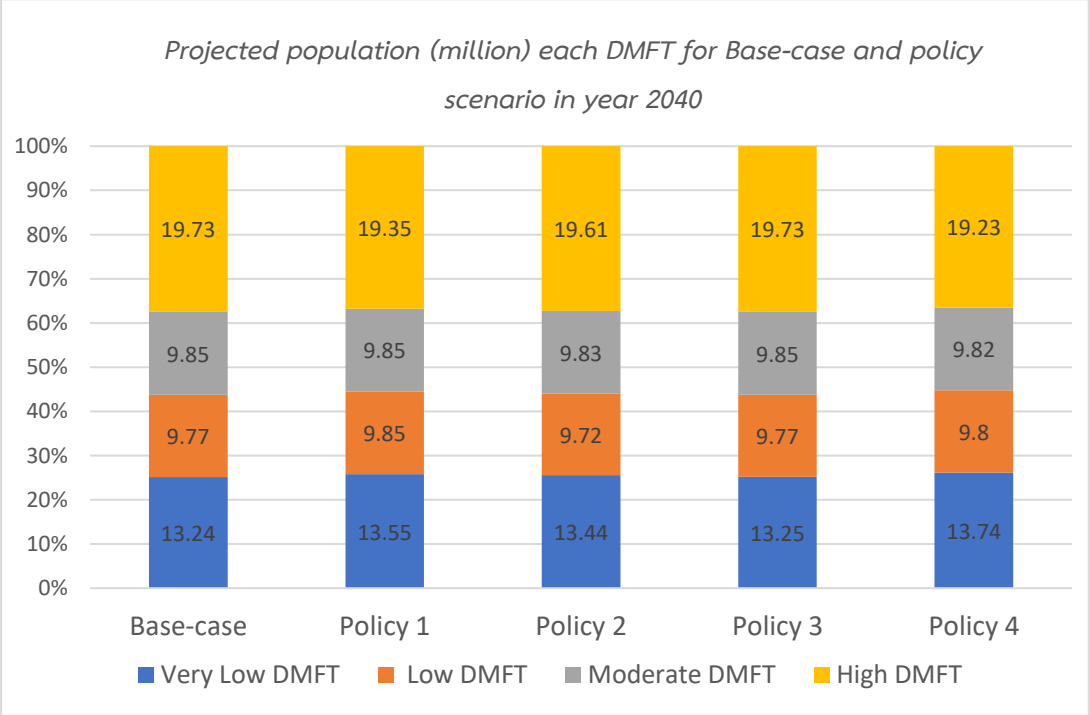


Figure 22 Projected population (million) each DMFT for Base-case and policy scenario in 2040

Table 7 Projected population (million) by DMFT severity

Time (Year)	2000	2010	2020	2030	2040	% change from 2000-2040
Very Low DMFT						
Base-case	20.19	19.41	17.61	15.50	13.24	-34.4
Policy 1	20.19	19.41	17.62	15.65	13.55	-32.9
Policy 2	20.19	19.41	17.62	15.59	13.44	-33.4
Policy 3	20.19	19.41	17.61	15.50	13.25	-34.4
Policy 4	20.19	19.41	17.62	15.74	13.74	-31.9
Low DMFT						
Base-case	7.67	10.03	10.99	10.75	9.77	27.3
Policy 1	7.67	10.03	10.99	10.76	9.85	28.4
Policy 2	7.67	10.03	10.98	10.70	9.72	26.7
Policy 3	7.67	10.03	10.99	10.74	9.77	27.3
Policy 4	7.67	10.03	10.98	10.72	9.80	27.7
Moderate DMFT						
Base-case	7.67	8.38	9.54	10.10	9.85	28.5
Policy 1	7.67	8.38	9.54	10.09	9.85	28.4
Policy 2	7.67	8.38	9.54	10.09	9.83	28.2
Policy 3	7.67	8.38	9.54	10.10	9.85	28.5
Policy 4	7.67	8.38	9.54	10.08	9.82	28.1
High DMFT						
Base-case	9.62	12.58	15.23	17.75	19.73	94.2
Policy 1	9.62	12.58	15.23	17.60	19.35	90.4
Policy 2	9.62	12.58	15.23	17.71	19.61	75.2
Policy 3	9.62	12.58	15.23	17.75	19.73	94.0
Policy 4	9.62	12.58	15.22	17.57	19.23	71.7

5.2.2 Population with untreated dental caries in each DMFT

Under the base-case scenario, the population aged 15 and older with at least one untreated dental caries (representing the unmet dental care needs) in very low, low, moderate and high DMFT group are 12.2 million, 7.1 million, 7.3 million and 9.1 million respectively in 2000. In very low DMFT group, the individuals with untreated dental caries are projected to decrease to 8.04 million in 2040; while those in low, moderate and high DMFT group are projected to increase to 8.7 million, 8.9 million and 17.7 million respectively in 2040 (Figure 23). The largest percentage increase is observed in the high DMFT untreated group (94.2%) (Table 8).

Under **the first policy**, comparing with the base-case scenario, the population with untreated conditions in very low DMFT group is projected to increase by 0.02% in 2020 and 2.5% in 2040. The numbers of untreated population in low DMFT and moderate DMFT group are projected to be close to the base-case scenario in 2020. Compared to base-case scenario in 2040, the projections continue to increase to 0.9% for low DMFT group, but decrease to 0.1% for moderate DMFT group. For the untreated population in high DMFT group is projected to decrease by 0.02% in 2020 and continue to decrease by 2% compared with the base-case scenario in 2040 (Figure 24).

Under **the second policy**, the individuals with untreated dental caries in all DMFT groups are projected to decrease compared to base-case scenario for the projected timeframe. The highest percentage of untreated dental caries decrease from the base-case scenario is among the high DMFT group (9.8%), following by the other three groups (0.6%) in 2040 (Figure 24).

Under **the third policy**, the numbers of individual with untreated dental caries in all DMFT group are projected to be close to the base-case scenario in 2020. Then the projections show the decrease from the base-case scenario by approximately for 0.1% for all DMFT groups in 2040.

Under **the last scenario**, the combination of all policies, numbers of individuals with untreated dental caries in very low and low DMFT groups are projected to increase by 1.6% and 0.2% respectively compared to the base-case scenario in 2040. On the other hand, the numbers of individuals with untreated dental caries in moderate and high DMFT groups are projected to decrease by 0.7% and 11.6% respectively compared to the base-case scenario in 2040.

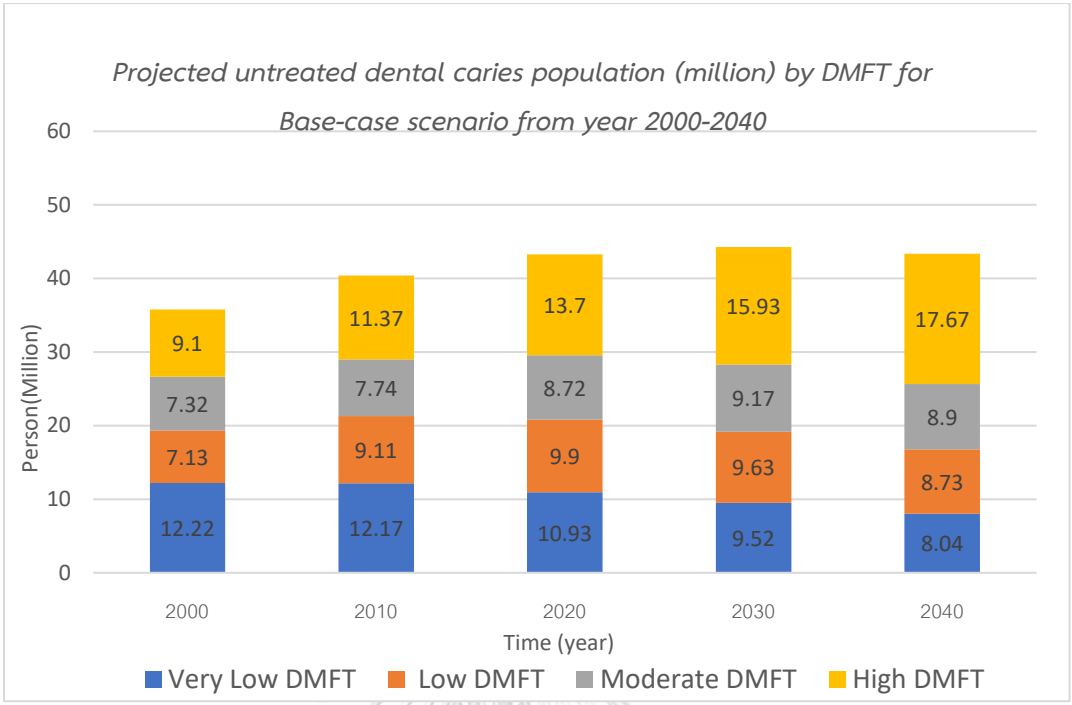


Figure 23 Projected untreated dental caries population (million) by DMFT for Base-case scenario from year 2000-2040

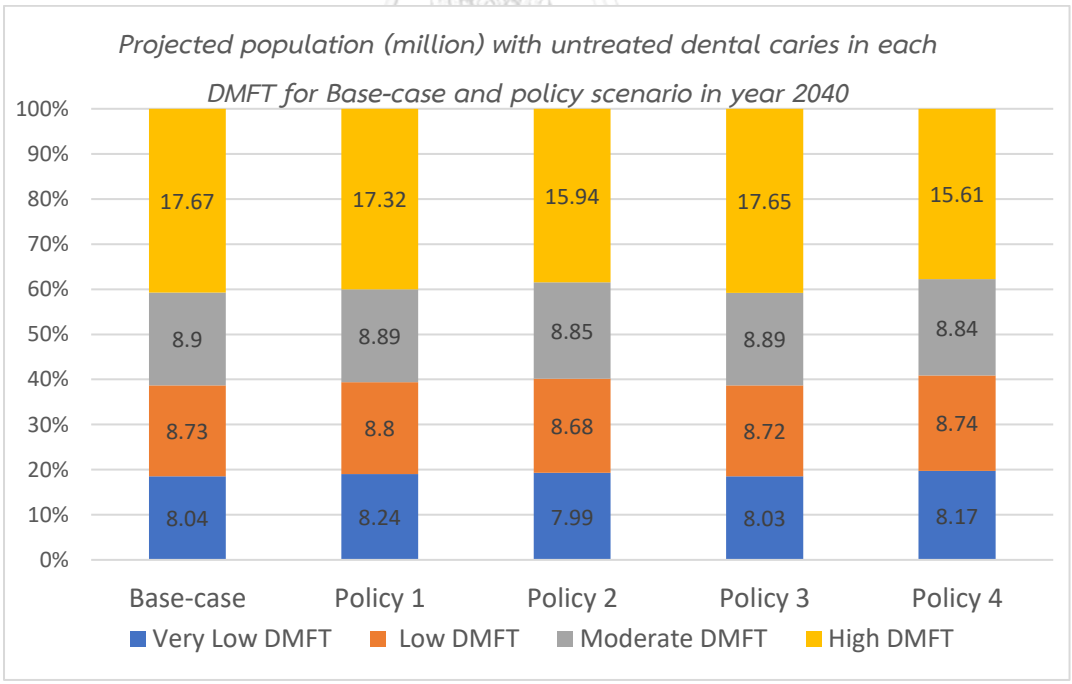


Figure 24 Projected population (million) with untreated dental caries in each DMFT for Base-case and policy scenario in year 2040

Table 8 Projected untreated dental caries population (million) by DMFT

Time (Year)	2000	2010	2020	2030	2040	%change from 2000-2040
Very Low DMFT						
Base-case	12.22	12.17	10.93	9.52	8.04	-34.2
Policy 1	12.22	12.17	10.93	9.62	8.24	-32.61
Policy 2	12.22	12.17	10.92	9.41	7.99	-34.6
Policy 3	12.22	12.17	10.93	9.51	8.03	-34.3
Policy 4	12.22	12.17	10.92	9.49	8.17	-33.1
Low DMFT						
Base-case	7.13	9.11	9.90	9.63	8.73	22.3
Policy 1	7.13	9.11	9.90	9.65	8.80	23.4
Policy 2	7.13	9.11	9.90	9.59	8.68	21.6
Policy 3	7.13	9.11	9.90	9.63	8.72	22.2
Policy 4	7.13	9.11	9.90	9.60	8.74	22.5
Moderate DMFT						
Base-case	7.32	7.74	8.72	9.17	8.90	21.5
Policy 1	7.32	7.74	8.72	9.16	8.89	21.4
Policy 2	7.32	7.74	8.72	9.14	8.85	20.8
Policy 3	7.32	7.74	8.72	9.17	8.89	21.4
Policy 4	7.32	7.74	8.72	9.12	8.84	20.6
High DMFT						
Base-case	9.10	11.37	13.70	15.93	17.67	94.2
Policy 1	9.10	11.37	13.70	15.79	17.32	90.4
Policy 2	9.10	11.37	13.64	14.70	15.94	75.2
Policy 3	9.10	11.37	13.64	15.92	17.65	94.0
Policy 4	9.10	11.37	13.64	14.57	15.61	71.7

5.2.3 Sugar-sweetened beverage consumption

In 2000, Thai population aged 15 and older consumed 31.8 liters/person of sugar-sweetened beverage (SSB). Among these population, people living in poverty and non-poverty consumed 15.1 liters/person and 44.1 liters/person of SSB respectively (Table 8). Under the base-case scenario, the projected SSB consumption for total population, among poverty and non-poverty population increase to 150 liters/person, 155.2 liters/person and 51.2 liters/person respectively in 2040 (Table 9).

Under **the first policy,** the SSB consumption level is projected to be close to the base-case scenario in the short-term projection in 2020. For the long-term period in 2040, the projected SSB consumption decrease by 5% for poverty population, 1.4% for non-poverty population and 1.4% for total population compared to base-case scenario.

Under **the second policy**, the SSB consumption level for both SES group and total population are projected to decrease at the same rate by 0.1% in 2020 and 5% in 2040 compared to base-case scenario.

Under **the third policy**—with the increase of dental personnel and financial accessibility for dental treatment. The projections of SSB consumption for both SES groups and total population do not show any differences from the base-case scenario for all the projection timeframe (Table 9).

Under **the combined policy scenario**, the SSB consumption among non-poverty and total population are projected to decrease by 0.1% in 2020 and 6% in 2040 compared to base-case scenario; while the SSB consumption of poverty population are projected to decrease by 0.1% in 2020 and 9% in 2040 compared to base-case scenario (Table 9).

Table 9 Projected SSB consumption (liter/person) for poverty, non-poverty and total population for policy analysis

Time (Year)	2000	2010	2020	2030	2040	%change from 2000-2040
Poverty population						
Base-case	15.09	20.66	28.30	38.41	51.22	239.4
Policy 1	15.09	20.66	28.30	37.67	48.66	222.5
Policy 2	15.09	20.66	28.27	37.59	48.87	223.8
Policy 3	15.09	20.66	28.30	38.41	51.22	239.4
Policy 4	15.09	20.66	28.27	36.92	46.63	209.0
Non-poverty population						
Base-case	44.11	60.55	83.13	113.84	155.17	251.7
Policy 1	44.11	60.55	83.13	113.25	153.06	247.0
Policy 2	44.11	60.55	83.03	111.34	147.67	234.8
Policy 3	44.11	60.55	83.13	113.84	155.17	251.8
Policy 4	44.11	60.55	83.03	110.81	145.83	230.6
Total population						
Base-case	31.83	54.02	79.40	109.36	149.89	371.0
Policy 1	31.83	54.02	79.40	108.76	147.78	364.4
Policy 2	31.83	54.02	79.31	106.96	142.65	348.2
Policy 3	31.83	54.02	79.40	109.36	149.89	371.0
Policy 4	31.83	54.02	79.31	106.42	140.81	342.4

5.2.4 Sugar consumption

In 2000, the population aged 15 and older who living in poverty and non-poverty consumed 20.5 kg/person and 34.4 kg/person of sugar respectively, while the average total sugar consumed was 28.5 kg/person. Under the base-case scenario, the projected sugar consumption increases to 35.4 kg/person for poverty population, 65.9 kg/person for non-poverty population and 64.1 kg/person for total population by 2040 (Table 10). For the policy analysis, policy 2 and 4 show the improvement in sugar consumption during the projection time (Figure 25).

Under **the first policy,** sugar consumption is projected to decrease by 3.2% for poverty population and 5.4% for non-poverty population in 2020, compared to the base-case scenario. The sugar consumption for total population is also projected to decrease by 5.4% in 2020. For the long-term projection, sugar consumption is projected to decrease by 5.2% for poverty population, 7.5% for non-poverty population and 7.4% for total population, compared to the base-case scenario in 2040.

Under **the second policy**, sugar consumption is projected to decrease only 0.2% for poverty population, 0.03% for non-poverty population and 0.03% for total population in 2020, compared to the base-case scenario. For the long-term projection, sugar consumption is projected to decrease by 1% for poverty

population, 1.7% for non-poverty population and 1.7% for total population, compared to the base-case scenario in 2040.

Under **the third policy** scenario, the projections of sugar consumption for both SES groups and total population do not show the differences from the base-case scenario for all the projection timeframe (Table 10).

Under **the combined policy**, the sugar consumption level among poverty, non-poverty and total population are projected to decrease by 3.2%, 5.5% and 5.4% in 2020 compared to base-case scenario. For the long-term projection, sugar consumption is projected to decrease by 5.9% for poverty population, 8.8% for non-poverty population and 8.7% for total population, compared to the base-case scenario in 2040 (Table 10).

Table 10 Projected sugar consumption (kg/person) of poverty, non-poverty and total population for policy analysis

Time (Year)	2000	2010	2020	2030	2040	%change from 2000-2040
Poverty population						
Base-case	20.48	22.90	26.69	30.62	35.42	72.90
Policy 1	20.48	22.90	25.84	29.38	33.57	63.90
Policy 2	20.48	22.90	26.68	30.50	35.06	71.19
Policy 3	20.48	22.90	26.69	30.62	35.42	72.90
Policy 4	20.48	22.90	25.83	29.29	33.33	62.71
Non-poverty population						
Base-case	34.38	37.57	45.83	54.66	65.89	91.65
Policy 1	34.38	37.57	43.34	51.18	60.98	77.38
Policy 2	34.38	37.57	45.82	54.29	64.76	88.38
Policy 3	34.38	37.57	45.83	54.66	65.89	91.65
Policy 4	34.38	37.57	43.33	50.89	60.11	74.85
Total population						
Base-case	28.50	35.17	44.50	53.12	64.12	125.02
Policy 1	28.50	35.17	42.12	49.77	59.37	108.35
Policy 2	28.50	35.17	44.47	52.86	63.47	122.74
Policy 3	28.50	35.17	44.44	52.61	62.84	120.54
Policy 4	28.50	35.17	44.48	52.76	63.03	121.21

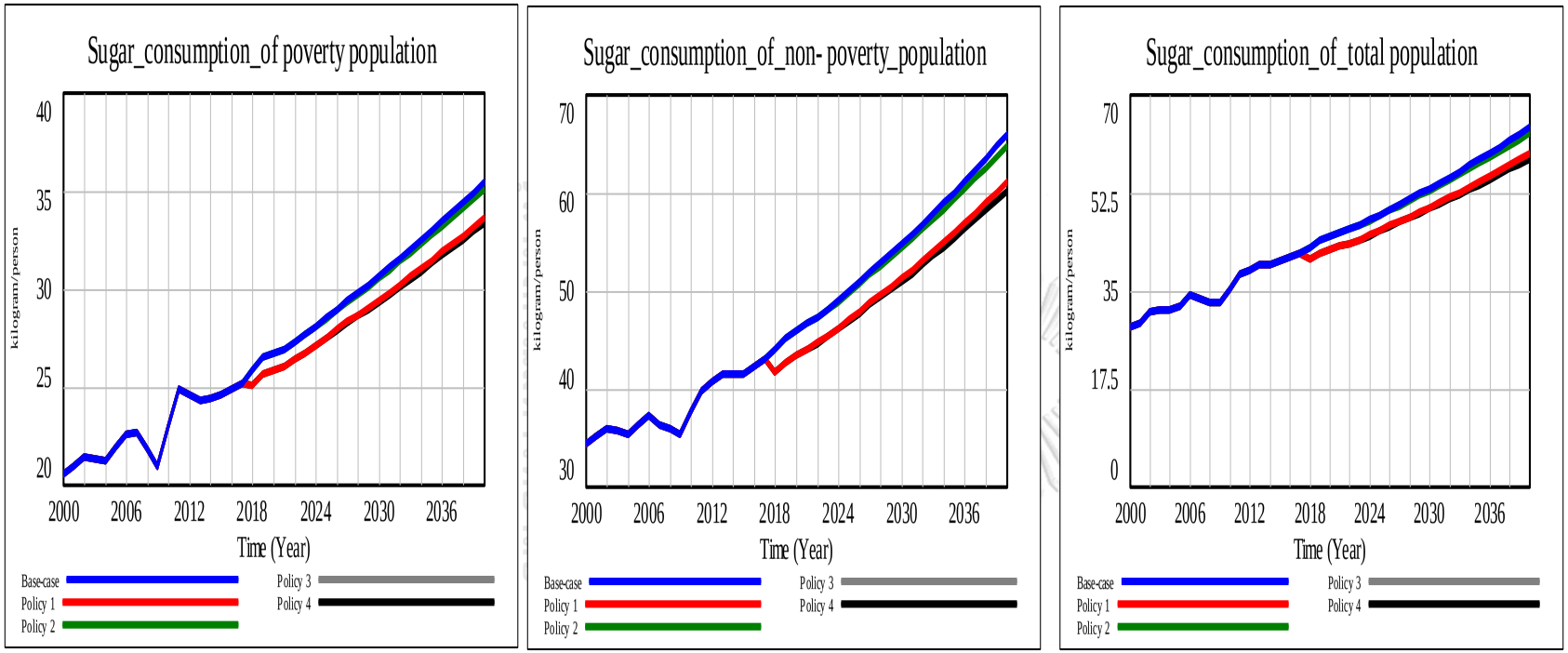


Figure 25 Projected sugar consumption (kg/person) of poverty, non-poverty and total population for policy analysis

Table 11 Summary for policy analysis results

Scenario	Effect on main outcomes compared with base-case scenario in year 2040
Policy 1 (SSB tax)	- Improve dental caries status by increasing (0.9-2.5%) very low and low DMFT group for both total population and untreated population; and decreasing (0.1-2%) the moderate and high DMFT group for total population and untreated group - Decrease the SSB consumption for poverty population by 5% and non-poverty population by 1.4% - Decrease total sugar consumption for poverty population by 5.2% and non-poverty population by 7.5%
Policy 2 (Health promotion program)	- Improve dental caries status by decreasing numbers of untreated population by 0.6%, in all DMFT group and as high as 9 % in high DMFT population; along with increasing total very low DMFT population by 1.5% - Decrease level of SSB by 0.1% and sugar consumption by 1-1.7% in all SES group
Policy 3 (Dental personnel and financial accessibility)	- Improve dental caries status by decreasing numbers of untreated population by 0.1%, in all DMFT group; along with increasing total very low DMFT population by 0.1% - No effect on SSB and sugar consumption
Policy 4 (Combined policy)	- Show the highest improvement on dental caries status and sugar consumption with the additional effect of all policies combined.

5.3 Sensitivity analysis

The parameters used in the sensitivity analysis are shown in Table 5 (Chapter 3). The outcomes of multivariate sensitivity analysis (with random uniform distribution assumed) in base-case scenario and all policies in year 2040 are presented in Table 12. The mean values with 95 percent confidence interval for each outcome confirm the robustness of the model. With the credible interval of both projected population in each DMFT group and sugar consumption for all SES group.

Table 12 Sensitivity analysis outcomes in year 2040

Outcome variables	Sensitivity analysis results for each scenario				
	Base-case	Policy1	Policy 2	Policy 3	Policy 4
Total population Very Low DMFT (person)					
mean	13393026	13835473	13649929	13401195	14086915
Lower bound (95% CI)	13221731	13666320	13478117	13229917	13917394
Upper bound (95% CI)	13564320	14004625	13821741	13572472	14256435
Total population Low DMFT (person)					
mean	9811998	9928948	9781763	9809249	9889152
Lower bound (95% CI)	9682999	9800721	9653525	9680284	9761726
Upper bound (95% CI)	9940997	10057175	9910000	9938214	10016578
Total population Moderate DMFT (person)					
mean	9893652	9879561	9871351	9891902	9854438
Lower bound (95% CI)	9780380	9768276	9758889	9778660	9743947
Upper bound (95% CI)	10006924	9990845	9983813	10005144	9964929
Total population High DMFT (person)					
mean	19497989	18952612	19293578	19494320	18766047
Lower bound (95% CI)	19295361	18756495	19092254	19291747	18571206
Upper bound (95% CI)	19700617	19148729	19494901	19696892	18960888
Sugar consumption for poverty population (kg/person)					
mean	35.42	32.94	35.07	35.42	32.72
Lower bound (95% CI)	35.41	32.82	35.06	35.41	32.61
Upper bound (95% CI)	35.43	33.06	35.07	35.43	32.83
Sugar consumption for non-poverty population (kg/person)					
mean	65.88	58.87	64.76	65.88	58.10
Lower bound (95% CI)	65.88	58.49	64.76	65.88	57.74
Upper bound (95% CI)	65.89	59.25	64.76	65.89	58.46
Sugar consumption for total population (kg/person)					
mean	64.12	57.34	63.03	64.12	56.60
Lower bound (95% CI)	64.11	56.98	63.03	64.11	56.25
Upper bound (95% CI)	64.12	57.71	63.04	64.12	56.94

CHAPTER VI
DISCUSSION

The objective of this study was to explore the relationship of sugar consumption, dental service utilization and oral health status of Thai adults and elderly. It also aimed to estimate the prevalence of dental caries among the population when the sugar-sweetened beverage tax policy is implemented using system dynamics approach. The study was divided into two part: qualitative approach and quantitative approach. The result from the qualitative part presented by the causal loop diagram and the quantitative part presented by the simulation outcomes of system dynamics model.

6.1 Causal loop diagram represented the complex relationship of SSB tax, dental caries experience, dental service utilization and sugar consumption.

The causal loop diagram developed for this study identified seven balancing feedback loops which operated to reduce the prevalence of dental caries in population through oral hygiene, behavioral modification, oral health literacy and dental treatment. The balancing loops also operated to reduce the impact of SSB tax on the consumer's consumption through industry side's strategies. Moreover, the reinforcing loop operates to maintain the share of SSB consumption among the Thai population. The results show that implementing the SSB tax cannot directly translate to sugar consumption changes and oral health status in the population.

Developing the causal loop diagram via the group model building approach in this study provide the specific context of the system responding to the specific problem of SSB tax and dental caries outcome. Moreover, the results depend on the group of stakeholders who participated in this study. Therefore, the CLD developed herein is unique in nature and to the best of my knowledge, there is no recent study that present the relationship of the oral health issues and SSB tax with the system thinking approach. However, the factors considered in this CLD are partly similar to Kum and colleagues. They used GMB to explore the oral health equity among elderly living in New York.[113] The study focused more on oral health care utilization and its related factors including accessibility, affordability, social engagement, oral health promotion, oral health literacy, financial policy and treatment cost.

The qualitative process suggested an agreement among all key informants that sugar consumption in Thailand has increased and excess sugar consumption will have adverse health impact leading to increased obesity, diabetes and dental caries. However, there were diverse opinions on the decision to implement SSB tax, which aims to reduce sugar consumption. The SSB industry and consumer representatives preferred to be more involved in designing and implementing the policy. This implies that the desirable policy should involve the participation of key stakeholders who would affect or be affected by the policy.

The insight from CLD suggests that SSB tax may likely lead to a worse substitution effect when consumers switch to other beverages or product such as non-

tax high sugar content product. This sugar consumption would not decrease because of the rise in other high sugar content products. However, the stakeholders suggested that the SSB tax has a potential to reduce sugar consumption in Thailand which is consistent with the evidence from the survey study in Thai adults.[114] The study showed that an increase in price of SSB by 20-25 percent can reduce consumption. The price increase may have limited impact given the rising income of the Thai population, and if SSB industries decide to absorb the price increase without passing it on to the consumers.

The stakeholders suggested that SSB tax alone will not be able to achieve the desired impact of reducing sugar consumption among the Thai population. It should be combined with non-tariff measures such as oral health education on the harmful effects of excessive sugar consumption, as well as increasing oral health capacity to provide needed oral health services, while improving affordability of oral health care to increase dental care utilization.

In addition, the insight of group modeling building pointed that an SSB tax has the potential to generate revenue to fund the implementation of public health. If that is the case, the tax will also give the feedback relationship to modify unhealthy behaviors, finance the development of oral health capacity or subsidies for dental care for vulnerable populations. Therefore, this would contribute to the population health.

This dynamic hypothesis can be used as a tool to inform policy planners the types of policies that will be proved to be most useful in improving oral health within the country. It is also translated into quantitative model that allows for the evaluation of the impact of SSB tax quantitatively.

6.2 Population in DMFT severity, treatment status and sugar consumption

Dental caries experiences within the Thai population aged 15 and older is expected to change over the projection timeframe from year 2000 to 2040, with the number of individuals in very low DMFT decreasing; while low, moderate and high DMFT category increasing over the years. The projected result may be due to the nature of the DMFT index which accumulate representing the dental caries experiences among the population. Moreover, the projected children population is decreasing overtime, while the elderly group is increasing. This has led to the number of individuals in the moderate and high DMFT is increasing overtime.

The sugar consumption in Thai population is projected to increase during the projection timeframe from 2000 to 2040. The total sugar consumption will increase from 28.5 kg per capita in 2000 to 64.1 kg per capita in 2040. To confirm the validity of the sugar consumption projection, the model results were validated with the sugar consumption historical data from 2000 to 2015 (see also chapter V). Moreover, the projection from this study in 2026 (49.4 kg per capita) is close to the latest FAO's projected sugar consumption of Thailand in 2026 (50.1 kg per capita) [115]. Even though, the sugar consumption projection in 2040 is as high as 64.1 kg per capita, it is still within

a feasible range of sugar consumption considering the projections in other countries e.g. FAO's projected sugar consumption of Malaysia in 2026 (at 65.5 kg per capita) [115].

To address the second objective of this study, with the implementation of Thai current SSB tax policy, the reduction of SSB consumption will only happen in long-term period (5% in poverty group and 1.4% in non-poverty group in 2040). This result may be due to low SSB tax rates in the early years and the higher rates in the later years. This result is also consistent with other economic studies[16, 116] that show higher reduction on sugar consumption level with higher tax rate.

According to economic theory, price elasticity determines the level of changes in demand when the price changes. Colchero and colleague's study in Mexico found that the price elasticity for SSB is-1. 16 which means, a 10% price increase was associated with a decrease in quantity consumed of SSB by 11.6%.[16] Prasertsom and colleague's study among Thai adults suggested the 25% SSB price increase will lead to the decision of 8.6% quit SSB drinking and additionally every 25 percent of SSB price rise will result in 50 percent increase in the percentage people reported stop SSB drinking.[90] Price elasticity of Thai population which is used in this study as suggested by Bhadrakom were -1.46 for low income household and -0.39 for high income households.[91] This different level of elasticity means stronger effect of price increase on the demand of low income household compared to high income households.

Total sugar consumption in population after the SSB tax implementation is projected to decrease from the base-case scenario for both short-term in 2020 (5.4%) and long-term in 2040 (7.4%). The SSB consumption for poverty population is projected to decrease from the base-case scenario higher than for non-poverty group. However, the percent reduction in total sugar consumption from the base-case scenario was found to be higher in non-poverty population than in poverty population. Total reduction of sugar consumption in this study is caused by the effect of SSB tax policy and the reduction trend of other sugar consumption (beside from SSB consumption). This study used historical data of other sugar consumption from 2000 to 2015 to estimate the consumption in later years until 2040 using 4 year moving average of percentage change. The higher reduction in non-poverty group is due to the higher decrease in other sugar consumption trend compared with the-poverty population.

In term of dental caries status, both number of populations in each DMFT group and the number of untreated individuals showed the improvement after the implementation of SSB tax compared to base-case scenario. In 2040, the very low and low DMFT population is projected to increase by 2.3% and 0.9% respectively; while the moderate and high DMFT population are projected to decrease by 0.1% and 2% respectively compared to the base-case scenario (before SSB tax). These results are due to the decrease of the total sugar consumption of population from both reduction of quantities of SSB consumed and the sugar content reduction in SSB product by the

industry responding to the SSB tax policy. This result is consistent to Schwendicke and colleagues' model-based study[117] which showed that 20% SSB taxation could reduce caries increment and dental treatment cost.

With the supplementary health promotion interventions, the situation in term dental caries status and sugar consumption will both improve. The highest impact is the decrease of untreated high DMFT group by almost 8% in 2040 compared to the base-case scenario. This result supports the relationship of factors presented in the conceptual framework. The model hypothesized that the health promotion program will increase oral health awareness and self-care adherence; then it will consequently reduce SSB consumption and will slow down the transition from low dental caries risk to high dental caries risk in the population. Several studies and reviews also reported positive impact of oral health education and promotion program on oral health behavior, such as tooth brushing/flossing and dental visits as well as the attitudes toward oral health.[118-120] Boles and colleagues[121] also found that health promotion campaign in mass media could influence attitudes and behavior about sugary drinks.

As the dynamic hypothesis suggests that the capacity of dental personnel and financial accessibility to dental treatment will lead to an increase in population receiving dental treatment. The third policy scenario of increasing 30% of dental students and 50% of poverty population who have financial access to dental treatment from 2018 to 2040 will result in lowering population with untreated dental

caries as shown in bigger very low and low DMFT groups and smaller moderate, high DMFT groups as well as the untreated population. However, the percentage changes from the base-case were minimal ranging from 0.02 – 0.14 percent. This result may be due to the use of only dental personnel per population ratio as a proxy of capacity for dental health service and leaving other proxies which is not included in our model boundary such as distribution of dental personnel. In addition, the increase in affordability for treatment cost showed small impact on the treatment rate in Thai population because the essential dental treatment for low-income group in Thailand have been subsidized by the universal health insurance. Moreover, it is not surprising that this scenario produces no change of sugar consumption projection.

Further, the results suggest that the combination of SSB tax with other non-tariff policies which are health promotion program, increase affordability and capacity of dental health service will provide the most benefits to improve dental caries experiences. This study's result showed the additive effect of all policies combined. However, synergistic effects from the implementation of the combined policies were not observed, which may be attributed to a multitude of factors. One potential explanation is that individuals who utilize dental services for curative treatment are more likely be the ones already engaging in positive health behaviors, and thus are more inclined to engage in preventive dental care.

6.3 Strength and limitation of the study

The inherent strength of the model proposed in this study is its comprehensive model boundary with the consideration of behavior related to dental caries progression, and its flexibility and value in comparing alternative policies within the complex oral health system. It also captures the dynamic of population and oral health determinant over time which can facilitate the holistic understanding of the problem. Moreover, the use of participatory group model building approach allowed to engage stakeholders to map the complex system interrelationships of SSB tax, sugar consumption and dental caries taking into consideration different points of views of other stakeholders. The model may be used as an additional tool to inform policy planners the design of effective policies and intervention for improving oral health in Thailand.

This study may pose a limitation of the acquisition of secondary data used in the model analysis and may not be able to use a single database for analysis. The use of proxies and estimated values in the simulation implies a certain degree of limitation to the credibility of the results. The comparison to other database both within the country or international data may be used. These can cause errors in estimation of the outcomes. However, the researcher tried to use national database that can represent the population and the reasonable proxy variables in order to reduce the potential errors. Another limitation in this study is related to the prediction of consumer behavior after the introduction of SSB tax. It is possible that the

consumers may substitute SSB with other beverages with no tax that may contain equal or higher level of sugar content. There are other studies that show that consumers switch from SSB to other beverages like fruit juice, milk and alcohol drinks.[87-89] When the substitute drinks which contain high sugar content were increasingly consumed, the net sugar consumption would not reduce as the SSB taxing propose. This substitution effect was not included in the quantitative simulation model due to the lacking of data support. However, the other sugar consumption trend was estimated by using 4-year moving average of percentage change of the historical data of other sugar consumption.

Moreover, this study also required interdisciplinary knowledge to generate the meaningful dynamic hypothesis and quantitative predictions of the model subsystems. Although this study used the GMB for this concern, there was still a lack of direct involvement of consumers and the SSB industry in the GMB process. However, we engaged Thai Consumers Foundation and SSB industry association in the interview process to contribute their input for our study.

6.4 Recommendation

6.4.1 Policy recommendation

The findings in this study would suggest the implementing an SSB tax alone will not achieve the desired impact of improving dental caries, without combining it with non-tariff interventions such as health education and promotion program, availability

of oral health capacity and affordability of oral health services. The combination of policies targeted to multiple determinants related to oral health, is vital in achieving the goal of improving oral health outcomes in Thailand. Moreover, as the current SSB tax rate alone will only has minimal impact on the reduction of SSB and sugar consumption. Besides the response of SSB industries by reformulation of their product to provide more alternative of low sugar SSB in the market.

For the most benefit to improve the population health, the government may earmark the SSB tax to use in health promotion program to target the awareness of sugar consumption, oral health care and other health issues. The effects of oral health promotion intervention tend to be observable only after a certain amount of time has passed. Thus, it is imperative that policymakers consider syncing both short-term and long-term strategies to achieve the maximum level of results desired. This may include the development of the distribution of dental personnel, while conducting oral health promotion program and preventive/curative intervention targeting the moderate to high risk group.

6.4.2 Research recommendation

For further study, the use of survey data on sugar consumption after the SSB tax implementation will be helpful to effectively evaluate the impact of the policy in Thai population. More detailed analyses by population subgroups such as by residency and socio-economic status will help policy makers identify the differential impact on

these populations. However, it may not be easy to identify existing secondary data that can support those analyses. Future studies may consider this limitation and include a plan to collect meaningful primary data to serve their objectives.

Although the effect of SSB tax on dental caries, the main interest of the study, is minimal, the study results show bigger improvement in regard to overall sugar consumption. This suggest that further study on other outcome parameters which are the direct impact from excessive sugar consumption such as obesity and diabetes should be considered. In addition, the system dynamics model used in this study can be adapted or applied to explore other outcomes of interest and to test other related policy scenarios such as the oral health problem in children or vulnerable population, tobacco policy and periodontal diseases.

APPENDIX

Appendix A: Stakeholder analysis matrix for SSB tax policy

Stakeholder group	Potential interest on SSB tax Support (+) or Oppose (-)	Level of impact	Influences on policy
Consumers and NGO advocated for consumers' rights	Increase SSB prices (-) Increase alternative beverages with low sugar content (+/-) May reduce the amount of SSB and/or sugar consumption (+/-) Benefits for health and reduce risk of disease causing by excessive sugar consumption (+)	**High**	**Low**
SSB industry	Increase the SSB production cost (-) May reduce SSB sales quantity (-) Possible to increase marketing strategies for increase sales (+) Opportunity to produce alternative/substitute product (+/-) Role for social responsibility (+)	**High**	**High**
Sugar industry	May reduce the profit from sugar sales (-)	**Medium**	**Medium**
Sugar cane farmer	May reduce the profit from sugar cane sales (-)	**Medium**	**Medium**
Ministry of Finance	Increase revenue from Tax (+) Opposition by SSB industry (-) Population health expenditure may decline (+)	**High**	**High**
Ministry of Public Health	Increase revenue from Tax (+) Opposition by SSB industry (-) Population health outcome will improve and expenditure may decline (+)	**High**	**High**

Appendix B: Interview form and summary of the key informant interview result

<u>แนวข้อคำถามสำหรับการสัมภาษณ์ผู้มีส่วนได้ส่วนเสีย</u>

เรื่อง ความคิดเห็นในเรื่องปัจจัยที่เกี่ยวข้อง แนวทางและผลที่อาจเกิดขึ้น หากมีการบังคับใช้มาตรการภาษีเครื่องดื่มที่มีน้ำตาล

คำชี้แจง

เครื่องมือสำหรับการเก็บข้อมูลเชิงคุณภาพฉบับนี้ มีจุดมุ่งหมายเพื่อที่จะวิเคราะห์ข้อมูลเชิงลึกในมุมมองของผู้มีส่วนได้ส่วนเสียในประเด็นมาตรการภาษีเครื่องดื่มที่มีน้ำตาล เพื่อเป็นข้อมูลสำหรับการพัฒนาแบบจำลองพลวัตระบบต่อไป

ผู้ให้ข้อมูล.....

แนวข้อคำถามเชิงลึก

1. ความคิดเห็นต่อสถานการณ์การบริโภคน้ำตาลในประชาชนไทย และปัญหาสุขภาพที่เกี่ยวข้องกับการบริโภค
2. ความคิดเห็นต่อนโยบายมาตรการภาษีเครื่องดื่มที่มีน้ำตาล และ/หรือที่มา และความเป็นไปได้
3. ความคิดเห็นต่อรูปแบบ และความเป็นไปได้ของมาตรการภาษีเครื่องดื่มน้ำตาลที่เหมาะกับบริบทประเทศไทย
4. ผลกระทบที่คาดว่าจะเกิดขึ้น ในกรณีมีการกำหนดมาตรการภาษีเครื่องดื่มที่มีน้ำตาล การจัดการในภาคอุตสาหกรรม ในกรณีมีการบังคับใช้มาตรการภาษีเครื่องดื่มที่มีน้ำตาลขึ้นมาตรการภาษีเครื่องดื่มน้ำตาล

SUMMARY OF KEY INFORMANT INTERVIEW RESULT

(1) Question: What is your opinion on sugar consumption situation in Thailand and health issues related to the sugar consumption?

All key informants agreed that the sugar consumption in Thailand has increased and excessive sugar intake can cause adverse effects on health such as diabetes and tooth decay. They were concerned about the source of sugar consumption data that represent the real consumption. Most data came from the companies that produce and supply and thus may not be an actual representation (overestimation). However, the advocators attempted to use multiple data sets to support the measures and they claimed that the data of sugar consumption from the national survey could demonstrate the consumption trend in the population.

(2) Question: What is your opinion on the drive to adopt SSB taxation policy? Who have the important role to this policy process? What are the reasons and the barriers of this policy driven?

The SSB Tax policy was initiated and advocated from the health-network sector. Ministry of Public Health, the National Health Assembly, International Health Policy Program and Sweet Enough Network Thailand supported by Thai Health Promotion have cooperated to work with this policy issue. Besides the driving forces of the health outcomes expectation, the

financial problem was the main driving forces. The government tried to add more budget to the national revenue system. The key informants were concerned about the lack of other sectors' involvement in the policy process. Especially from the industry side, they argued that the government did not allow them to offer feedback from the beginning of the policy driven process and there was no mutual recognition from different sectors. As a consumers' point of view, the policy process was seen as the debate and argument between the government and industry sector instead of cooperation and mutual agreement.

(3) Question: What is your opinion about the tax measure design, and feasibility of SSB tax measures that appropriate for the context of Thailand?

The Excise Department, of the Ministry of Finance informed that the SSB tax policy design was based on the review of evidence supported by different documents, and meetings of the Board with relevant departments. The initial scheme proposed to the Reform Council was based on the sugar content in beverage. The tax exemption of sugar content would be lower than 6 grams per 100 ml. With the sugar content of 6-10 grams per 100 ml and more than 10 grams per 100 ml, a tax of 20% and 25% of the retail price should be collected. The government agreed with the use of sugar content to calculate a progressive tax rate. However, the actual rate would depend on the

Committed Board decision. Consistently with the (key informant) economist's opinion, the tax should be based on the volume and sugar content, not on sales value. There is also a suggestion of taxing other sugar containing drinks such as 3 in 1 coffee/tea mix and other powder drinks in order to prevent a consumers' substitution effect and fairness in industry side. The industry requested that the tax exemption threshold should not be set too low. Additionally, they also asked for a transition period to adjust their drink formula.

(4) Question: What is your opinion about the impact on sugar consumption of Thai population and the expected change process and outcome if the SSB tax measures has been launched?

Based on the literature review from national and international studies, the policy advocators were quite confident in a benefit of sugar consumption reduction. A previous study in Thai adults showed that at least 20-25% price increase would change consumption by Thai people. Also, the policy would promote the social norm of less sweet or sugar consumption concern among the population. The representative from health economic side added that consumption may show a minimal decrease because Thai people have the habit of consuming especially sweet-tooth norm. Moreover, price changes are not likely to significantly affect consumption of the people with a high income. The industry responded that the changes in beverage product prices and consumption depend on several factors such as tax rate and design, market

share of beverage informal sector who do not pay excise tax and the adaptation to tax measures of business sector. Therefore, how much of the changes occurred would still be problematic.

(5) Question: Do you think there are other policies that are likely to affect the change in sugar consumption of the Thai population? And please explain the possibility of the policies.

All parties agreed on the adoption of non-tariff measures to address the problem of excessive sugar consumption by the Thai population. For example, education and information on the harmful effects of (excessive) sugar consumption is likely to raise health awareness and may reduce the consumption. Food labeling indicates healthy versus unhealthy food and makes it easier for consumers to understand, such as traffic lights for sugar content (red for unhealthy and green for healthy). Communication technology such as smartphone applications would help consumers to identify healthy food and snack. The manufacturers should also adjust their beverage formula to reduce sugar content or provide alternative products with low sugar content. All strategies require intensive collaboration of both public and private sectors. In addition, there was also a need for systematic evaluation of all measures to assess their effectiveness. The government sector concluded that the tax and non-tax policy should be implemented simultaneously. While the industry sector suggested that the non-tax policy should be implement first and

evaluated the outcome. Then, the consideration of tax measure could be followed.

Appendix C: Detail result and reference data for base-case analysis

Table 13 Projected number of population (person) with the reference data

Year	Population		Children		Youth		Adult		Elderly	
	Projected	Reference	Projected	Reference	Projected	Reference	Projected	Reference	Projected	Reference
2000	58875950	58875950	6707933	6707933	16114206	16114206	29994370	29994370	3619097	3619097
2001	59342860	59362288	6618655	6656657	15966743	15986552	30567982	30555334	3799274	3799291
2002	59789528	59887912	6461168	6540448	15806019	15868392	31161860	31181999	3966208	3973241
2003	60214600	60203927	6244728	6408418	15632063	15672264	31724740	31725766	4148139	4149343
2004	60619744	60549324	6127322	6274418	15506198	15566230	32227042	32094968	4321692	4281681
2005	61007264	60991000	5976537	6093939	15382437	15469151	32758340	32643068	4476148	4437704
2006	61379000	61395496	5814499	5897346	15265283	15399902	33275240	33158169	4628688	4580511
2007	61735540	61540020	5664259	5746864	15155672	15312226	33724804	33440860	4808534	4710969
2008	62078424	61828099	5581627	5649968	14976711	15175038	34212812	33893077	4934100	4795097
2009	62406976	62194564	5557768	5603427	14773849	15015318	34610752	34336120	5098468	4938049
2010	62719216	62579932	5606505	5564129	14526028	14888471	34994896	34784554	5233816	5070591
2011	63015524	62951504	5564683	5550178	14377268	14709722	35323760	35184472	5402583	5244520
2012	63294624	63337198	5529898	5533599	14264864	14572052	35569168	35510755	5597589	5455094
2013	63552152	63650593	5500465	5498600	14175824	14452208	35757112	35595435	5804511	5849348
2014	63788240	63954350	5475167	5467377	14076356	14359162	35897648	35795991	6050039	6123509
2015	63997528	64219585	5449832	5465284	13955072	14242330	36016764	36007672	6320660	6398580
2016	64184152	64417145	5420014	5421066	13791606	14081743	36171048	36228386	6582013	6656953
2017	64356344	64627465	5382587	5354592	13614536	13914026	36295936	36434515	6870323	6965569
R^2	0.994		0.985		0.995		0.998		0.989	

Table 14 Projected number of population (person) with the reference data (continued)

Year	Population		Children		Youth		Adult		Elderly	
	Projected	Reference	Projected	Reference	Projected	Reference	Projected	Reference	Projected	Reference
2018	64510336		5332678		13431206		36400000		7170010	
2019	64641964		5274390		13262462		36482976		7459660	
2020	64750768		5218781		13099074		36473592		7816702	
2025	64936400		4947656		12321221		35997872		9639784	
2030	64529808		4702793		11914744		34427792		11552620	
2035	63554828		4472758		11386088		32655576		13200282	
2040	62109200		4264800		10800081		30964786		14305206	

Table 15 Projected proportion of population with the reference data

Year	Proportion of DMFT group							
	Very Low		Low		Moderate		High	
	Projected	Reference	Projected	Reference	Projected	Reference	Projected	Reference
2000	0.447	0.450	0.170	0.170	0.170	0.168	0.212	0.212
2006	0.407	0.362	0.193	0.188	0.162	0.170	0.238	0.280
2012	0.374	0.384	0.205	0.213	0.165	0.169	0.256	0.234
2013	0.368		0.207		0.166		0.260	
2014	0.362		0.208		0.167		0.263	
2015	0.357		0.209		0.168		0.266	
2016	0.351		0.210		0.169		0.270	
2017	0.346		0.211		0.170		0.273	
2018	0.341		0.212		0.171		0.276	
2019	0.335		0.212		0.172		0.280	
2020	0.330		0.212		0.173		0.284	
2021	0.325		0.212		0.174		0.287	
2022	0.320		0.212		0.175		0.291	
2023	0.315		0.212		0.176		0.295	
2024	0.311		0.212		0.177		0.299	
2025	0.307		0.211		0.178		0.303	
2026	0.302		0.211		0.179		0.307	
2027	0.298		0.210		0.179		0.311	
2028	0.294		0.209		0.180		0.315	
2029	0.290		0.209		0.180		0.319	
2030	0.287		0.208		0.181		0.323	
2031	0.283		0.207		0.181		0.328	
2032	0.279		0.206		0.181		0.332	
2033	0.275		0.205		0.181		0.336	
2034	0.272		0.204		0.182		0.340	
2035	0.268		0.203		0.182		0.345	
2036	0.265		0.202		0.182		0.349	
2037	0.261		0.201		0.182		0.353	
2038	0.258		0.200		0.182		0.357	
2039	0.255		0.198		0.182		0.362	
2040	0.252		0.197		0.181		0.366	
R^2	**0.577**		**0.930**		**0.992**		**0.171**	

Table 16 Projected proportion of population with untreated dental caries in each DMFT group with the reference data

Year	Proportion of population with untreated dental caries in each DMFT group							
	Very Low		Low		Moderate		High	
	Projected	Reference	Projected	Reference	Projected	Reference	Projected	eference
2000	0.605	0.616	0.930	0.934	0.955	0.959	0.945	0.925
2006	0.632	0.635	0.881	0.920	0.945	0.936	0.883	0.885
2012	0.636	0.746	0.871	0.903	0.945	0.925	0.885	0.877
2013	0.636		0.870		0.945		0.885	
2014	0.637		0.869		0.944		0.885	
2015	0.637		0.868		0.944		0.884	
2016	0.637		0.867		0.944		0.884	
2017	0.637		0.866		0.944		0.885	
2018	0.637		0.865		0.944		0.885	
2019	0.637		0.864		0.944		0.885	
2020	0.637		0.863		0.944		0.885	
2025	0.637		0.860		0.943		0.885	
2030	0.636		0.858		0.943		0.885	
2035	0.635		0.856		0.943		0.884	
2040	0.633		0.855		0.943		0.884	
R^2	**0.481**		**0.830**		0.909		0.971	

Table 17 Projected number of dental personnel with the reference data

Year	Dentist (person)		Dental nurse (person)		Uptake rate	
	Projected	Reference	Projected	Reference	Projected	Reference
2000	6795	6795	2636	2636	0.209	0.21
2001	7223	7175	2808	2701	0.204	
2002	7642	7216	2977	2930	0.200	
2003	8054	7828	3144	3102	0.198	
2004	8458	8076	3308	3307	0.197	
2005	8863	8443	3471	3456	0.197	
2006	9296	8809	3632	3697	0.196	0.19
2007	9762	9334	3791	3996	0.196	
2008	10254	9646	3948	4164	0.195	
2009	10768	9926	4104	4313	0.194	
2010	11304	10515	4259	4664	0.194	
2011	11869	11070	4411	4670	0.193	
2012	12461	11607	4643	4992	0.192	0.2
2013	13074	12089	5089	5360	0.191	
2014	13704	12600	5429	6613	0.190	
2015	14346	13215	5706	6819	0.190	
2016	14997		5958		0.189	
2017	15656		6203		0.188	
2018	16319		6441		0.187	
2019	16985		6674		0.186	
2020	17651		6903		0.185	
2025	20966		7992		0.179	
2030	24188		9014		0.175	
2035	27282		9983		0.171	
2040	30237		10903		0.167	
R^2	**0.998**		**0.980**		**0.533**	

Table 18 Projected sugar and SSB consumption with the reference data

Year	Total sugar consumption (kg/person)		SSB sugar consumption poverty (kg/person)		SSB sugar consumption non-poverty (kg/person)		SSB consumption poverty (liter/person)		SSB consumption Non-poverty (liter/person	
	Projected	Reference	Projected	Reference	Projected	Reference	Projected	Reference	Projected	Reference
2000	28.496	27.808	2.26	2.26	6.62	6.62	15.090	15.091	44.110	44.110
2001	29.040	29.048	2.34		6.83		15.575		45.533	
2002	31.205	29.165	2.41	1.79	7.05	5.22	16.079	11.877	47.003	34.716
2003	31.313	30.875	2.49		7.28		16.599		48.521	
2004	31.528	29.608	2.57	2.13	7.51	6.41	17.129	13.457	50.083	40.489
2005	32.003	32.305	2.65		7.75		17.676		51.695	
2006	33.997	32.906	2.74	3.13	8.00	8.38	18.244	19.433	53.362	51.976
2007	33.503	31.844	2.82	2.85	8.26	8.17	18.829	17.247	55.082	49.376
2008	32.938	30.437	2.91		8.53		19.428		56.852	
2009	32.800	31.039	3.00	3.22	8.80	8.79	20.033	19.319	58.670	52.721
2010	35.167	33.777	3.10		9.08		20.658		60.548	
2011	37.794	36.606	3.20	3.90	9.37	10.84	21.317	22.576	62.496	62.700
2012	38.564	38.195	3.30		9.68		22.000		64.510	
2013	39.548	37.954	3.41	4.04	9.99	11.31	22.707	22.945	66.590	64.293
2014	39.615	37.862	3.52		10.31		23.442		68.741	
2015	40.181	38.213	3.63	4.37	10.64	11.97	24.196	24.375	70.958	66.679
2020	44.498		4.25		12.47		28.301		83.127	
2025	48.441		4.96		14.60		33.043		97.337	
2030	53.119		5.76		17.08		38.410		113.841	
2035	58.327		6.67		19.95		44.451		132.986	
2040	64.120		7.68		23.28		51.216		155.169	
R^2	0.956		0.908		0.917		0.740		0.746	

Appendix D: Model parameters

Table 19 Model parameters

Parameter	Initial value		Unit	Sources
		Population sector		
Fraction female	0.51		Dimensionless	Thailand Official Statistics Registration Systems, Department of Provincial Administration, The Ministry of Interior
Total fertility rate	(2017,0.1)],(2000,0.0477),(2001,0.0469),(2002,0.0462),(2003,0.0456),(2004,0.0451),(2005,0.0448),(2006,0.0446),(2007,0.0445),(2008,0.0444),(2009,0.0443),(2010,0.0442),(2011,0.0441),(2012,0.0438),(2013,0.0435),(2014,0.0432),(2015,0.0428),(2016,0.0431),(2017,0.0434)		Dimensionless/year	Bureau of Policy and Strategy, Ministry of Public Health
Net migration rate	0.00015381		Dimensionless/year	World bank 2002; and optimization
Age specific death rate	Value by age0-100 and gender		Dimensionless/year	The Public Health Statistics Report 2000, Bureau of Policy and Strategy, Ministry of Public Health
		Dental caries sector		
Parameter	**Initial value**		**Unit**	**Sources**
	Age 15-34	Age 35 and older		
Regular visit fraction very low [female]	0.229	0.148	Dimensionless	National oral health survey data in 2000; Bureau of Dental Health, Department of Health, Ministry of Public Health, Thailand
Regular visit fraction very low[male]	0.191	0.170	Dimensionless	
Regular visit fraction low [female]	0.306	0.357	Dimensionless	

Regular visit fraction low [male]	0.308	0.385	Dimensionless	
Regular visit fraction moderate 15-34[female]	0.521	0.643	Dimensionless	
Regular visit fraction moderate [male]	0.462	0.333	Dimensionless	
Regular visit fraction high [female]	0.571	0.332	Dimensionless	
Regular visit fraction high [male]	0.583	0.215	Dimensionless	
Treated to untreated transition rate very low	0.4	0.7	Dimensionless/year	Expert's estimation with optimization
Treated to untreated transition rate low	0.78	0.58	Dimensionless/year	
Treated to untreated transition rate moderate	0.78	0.34	Dimensionless/year	
Treated to untreated transition rate high	0.7	0.75	Dimensionless/year	
VeryLowToLow transition rate	0.063		Dimensionless/year	
LowToModerate transition rate	0.066		Dimensionless/year	
ModerateToHigh transition rate	0.063		Dimensionless/year	
Utilization sector				
New dental student	(2000,500),(2001,500),(2002,500),(2003,500),(2004,500),(2005,793),(2006,793),(2007,793),(2008,813),(2009,813),(2010,933),(2011,933),(2012,933),(2013,933),(2014,933),(2015,933),(2018,933)		Person/year	Report of dental personnel 2000-2015. Bureau of Dental Health, Department of Health, Ministry of Public health, Thailand

Parameter	Initial value	Unit	Sources
New dental nurse student	(2000,200),(2001,200),(2002,200),(2003,200),(2004,200),(2005,200),(2006,200),(2007,200),(2008,200),(2009,200),(2010,200),(2011,200),(2012,1500),(2013,300),(2014,354),(2015,300)	Person/year	
Initial dental personnel in school[dentist]	3000	Person	Average number of dental personnel in school, 2000
Initial dental personnel in school[nurse]	4000	Person	
Dropout rate[dentist]	0.01	Dimensionless/year	Estimated from dental personnel in school intake and graduated data
Dropout rate[nurse]	0.01	Dimensionless/year	
Time to graduate[dentist]	6	Year	The Dental Council of Thailand Number of dentist and dental nurse, 2000
Time to graduate[nurse]	2,4	Year	
Initial dental personnel[dentist]	6795	Person	The Dental Council of Thailand Number of dentist and dental nurse, 2000 Expert's estimation
Initial dental personnel[nurse]	2636	Person	
Attrition rate[dentist]	0.01	Dimensionless/year	
Attrition rate[nurse]	0.01	Dimensionless/year	
Elasticity of capacity	0.1	Dimensionless	Expert's estimation National oral health survey data in 2000; Bureau of Dental Health, Department of Health, Ministry of Public Health, Thailand
Time to adjust uptake	1	Year	
Initial uptake rate[verylow]	0.384	Dimensionless/year	
Initial uptake rate[low]	0.066	Dimensionless/year	
Initial uptake rate[moderate]	0.041	Dimensionless/year	National oral health survey data in 2000; Bureau of Dental Health, Department of
Initial uptake rate[high]	0.075	Dimensionless/year	

Elasticity of affordability	0.1	Dimensionless	Health, Ministry of Public Health, Thailand Expert's estimation
Proportion of low SES able to afford out of pocket costs	0.4	Dimensionless	
Elasticity of perception of need	VL 0.8, L 0.05, M 0.4, H 0.8	Dimensionless	Expert's estimation National oral health survey data in 2000; Bureau of Dental Health, Department of Health, Ministry of Public Health, Thailand
Elasticity of treated in perception of need	VL 1, L 0.5, M 0.4, H 0.8	Dimensionless	
Time to adjust perception	1	Year	
Initial perceived need for dental care[verylow]	0.584	Dimensionless/year	
Initial perceived need for dental care[low]	0.071	Dimensionless/year	
Initial perceived need for dental care[moderate]	0.733	Dimensionless/year	National oral health survey data in 2000; Bureau of Dental Health, Department of Health, Ministry of Public Health, Thailand
Initial perceived need for dental care[high]	0.681	Dimensionless/year	
Population proportion below poverty line	(2000,0.4233),(2002,0.3244),(2004,0.2676),(2006,0.2194),(2007,0.2004),(2008,0.2043),(2009,0.1788),(2010,0.1637),(2011,0.1322),(2012,0.1264),(2013,0.1094),(2014,0.1053)	Dimensionless	
Sugar consumption sector			Thai National Statistical Office, Ministry of Information and Communication Technology
Reference average price of SSB	(2000,63.7867),(2001,64.1267),(2002,63.5795),(2003,64.0933),(2004,64.4933),(2005,64.9733),(2006,	Baht/litre	estimation

	64.9361),(2007,65.4755),(2008,66.3511),(2009,68.7451),(2010,69.2458),(2011,69.7695),(2012,69.9324),(2013,70.2214),(2014,69.6652),(2015,70.6322),(2016,71.4583),(2017,72.6111),(2018,72.8889)		
Demand price elasticity	Low income -15.09 High income -44.11	Dimensionless	Bureau of Trade and Economic Indices, Ministry of commerce Dr.Chayada Bhadakom, Economic analysis of overnutrition in Thailand, March 2014
Average sugar content per SSB	0.128	Kg/litre/year	Thai National Statistical Office, Ministry of Information and Communication Technology
Other sugar consumption by SES[lowincome]	(2000,18.2197),(2002,18.9535),(2004,18.6345),(2006,19.797),(2007,19.8437),(2009,17.9316),(2011,21.6663),(2013,20.8415),(2015,20.9157),(2017,21.3204),(2019,22.3497),(2021,22.5348),(2023,22.9825),(2025,23.5328),(2027,24.1233),(2029,24.5888),(2031,25.131),(2033,25.6988),(2035,26.2708),(2037,26.837),(2039,27.4304),(2041,28.0375)	Kg/person/year	Bureau of Food and Nutrition, Ministry of Public Health, Thailand
Other sugar consumption by SES[highincome]	(2000,27.7606),(2002,28.8786),(2004,27.7879),(2006,29.2149),(2007,27.9568),(2009,26.5831),(2011,30.3893),(2013,31.4391),(2015,30.7522),(2017,31.5729),(2019,33.0139),(2021,33.7156),(2023,34.3202),(2025,35.277),(2027,36.271),(2029,37.1347),(2031,38.0426),(2033,39.0347),(2035,40.0352),(2037,41.0358),(2039,42.0735),(2041,43.1462)	Kg/person/year	Thailand Office of the Cane and Sugar Board, Ministry of Industry and Thai National Statistical Office, Ministry of

			Information and Communication Technology With extrapolation after 2015 from 4y % change moving average
Initial self-care adherence	0.529	Dimensionless	Bureau of Food and Nutrition, Ministry of Public Health, Thailand
Elasticity of sugar consumption	0.6	Dimensionless	National oral health survey data in 2000; Bureau of Dental Health, Department of Health, Ministry of Public Health, Thailand
Elasticity of oral hygiene on teeth	-1	Dimensionless	
Time to close self-care adherence gap	40	Year	

Appendix E: Excise tax policy for sugar-sweetened beverage

Table 20 Excise tax for sugar sweetened beverage in Thailand

Type	Sugar Content (g/100 ml)	16 Sep 2017- 30 Sep 2019		1 Oct 2019- 30 Sep 2021		1 Oct 2021- 30 Sep 2023		From 1 Oct 2023	
		By retail price (%)	By volume (Baht/liter)	By retail price (%)	By volume (Baht/liter)	By retail price (%)	By volume (Baht/liter)	By retail price (%)	By volume (Baht/liter)
Soda and other sweet drink	0-5.99	14	0	14	0	14	0	14	0
(tea, coffee, energy drink)	6.0-8.0	14	0.1	14	0.1	14	0.3	14	1
	8.01-10.00	14	0.3	14	0.3	14	1	14	3
	10.01-14.00	14	0.5	14	1	14	3	14	5
	14.01-18.00	14	1	14	3	14	5	14	5
	more than 18.00	14	1	14	5	14	5	14	5
Fruit/Veg juice (low produce content)	0-5.99	10	0	10	0	10	0	10	0
	6.0-8.0	10	0.1	10	0.1	10	0.3	10	1
	8.01-10.00	10	0.3	10	0.3	10	1	10	3
	10.01-14.00	10	0.5	10	1	10	3	10	5
	14.01-18.00	10	1	10	3	10	5	10	5
	more than 18.00	10	1	10	5	10	5	10	5
Fruit/Veg juice (high produce content)	0-5.99	0	0	0	0	0	0	0	0
	6.0-8.0	0	0.1	0	0.1	0	0.3	0	1
	8.01-10.00	0	0.3	0	0.3	0	1	0	3
	10.01-14.00	0	0.5	0	1	0	3	0	5
	14.01-18.00	0	1	0	3	0	5	0	5
	more than 18.00	0	1	0	5	0	5	0	5

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