

**Projection of smoking prevalence and mortality averted in
Japan under the enhanced MPOWER tobacco control scenarios**

日本における MPOWER タバコ政策の強化により回避される喫煙
率と死亡に関する予測

St Luke's International University Graduate School of Public Health

Capstone Thesis for Master in Public Health 2021

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Abstract

Objective: To project the smoking prevalence and mortality averted up to 2100 should Japan implement full MPOWER tobacco control measures by 2020.

Methods: This study used a population simulation method to project the smoking prevalence and mortality for the status quo and several MPOWER policies scenarios in Japan. The simulation used 2018 smoking prevalence data as the baseline, and used projected population, cessation rates, MPOWER effect sizes, and group-specific mortality rates to project the smoking prevalence and mortality up to 2100. The simulation models were sex-and age-specific and all interventions were initiated in 2020. The mortality averted was defined as the mortality difference between the status quo and the intervention scenarios.

Results: If Japan's tobacco control status quo continues, smoking prevalence will decline from 29.6% in 2018 to 2.2% in 2100 in men and 8.3% in 2018 to 1.1% in 2100 in women. Introducing a smoke-free law is the best individual policy, and combining MPOWER measures renders smoking prevalence lower at a faster rate. Under the combined MPOWER scenario, a 50% relative reduction in prevalence can be achieved in 17 years in men and 25 years in women, and by 2100, smoking prevalence will drop to 0.7% in men and 0.4% in women. The combined MPOWER measures will avert a total of 405,910 deaths (295,048 male and 110,862 female) by 2100, of which 59,349 (14.5%) are attributable to lung cancer.

Conclusion: Properly implemented MPOWER measures will save hundreds and thousands of lives by

reducing tobacco use. It also sets the stage for legislation of tobacco control laws that are beyond the MPOWER measures to achieve a tobacco-free society in Japan.

Keywords: Japan, tobacco control, MPOWER, smoking prevalence, mortality

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Acknowledgements

I would like to express my deepest gratitude to my supervisor, Professor Stuart Gilmour. Without his guidance, this work would not be possible. Thank you for the patience you have shown whenever we encounter challenges in this work, and believing in my potential and capability when I myself have doubts. As a young researcher, I appreciate you trying to expand my collaborator network and rope me in related discussions. As an international student, I appreciate your support during the difficult times in COVID-19 period.

I would like to thank my external collaborators, Kota Katanoda and Kayo Togawa, for sharing your invaluable insights on the current status of tobacco control efforts in Japan and guidance to source for important data and references used in this work.

I am grateful for my mom, Lim Sow Mei and my siblings, Su Yin and Su Lim for always being there for me, as my emotional pillars, and showing me unconditional love and support throughout this period of work. To my dearest and my greatest supporter, Sanford Chin, thank you for your sacrifice and understanding for the time we couldn't spend together when this Master thesis work was on-going.

I am in debt to the school, all supporting staff and faculty members who provide a friendly and conducive environment for learning. I am thankful for MPH seminar course lead, Professor Kevin Urayama, and course colleagues who improved my work with constructive criticism.

Last but not least, thank you to all my MPH coursemates. The friendship that we built had opened my eyes to Japanese culture, language and wisdom. Your kindness and humility have touched me. Please allow to me express my most heartfelt gratitude to each and every one of you. “ほんとにありがとうございました。”

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List of abbreviations

DALY	Disability-adjusted life years
ENDS	Electronic nicotine delivery system
ENNDS	Electronic non-nicotine delivery system
FCTC	Framework Convention of Tobacco Control
HNB	Heat-Not-Burn
HTP	Heated tobacco products
MDG	Millennium development goal
SDG	Sustainable development goal
SHS	Secondhand smoke
WHO	World Health Organization

1. INTRODUCTION

1.1. The global tobacco epidemic

With 1.3 billion tobacco users worldwide, the tobacco epidemic is a major public health threat in the 21st century [1]. The global prevalence of adult smoking is 19.2% in 2017, with the highest prevalence recorded in high-income countries (21.6%), followed by middle-income countries (19.5%) and low-income countries (11.2%) [2]. The prevalence of global tobacco use has an encouraging downward trend, but the gains in tobacco control have not been evenly distributed globally. The net reduction in tobacco use between 2000 and 2015 was primarily a result of the tremendous progress made in the WHO regions of Americas and Europe in reducing 75.0 million smokers, followed by a smaller reduction of 3.9 million in the WHO South East-Asia region and 3.2 million in the Western Pacific region. [3]. However, this substantial decrease was also countered by the increased number of smokers in the WHO regions of African and Eastern Mediterranean (40.3 million) [3].

Tobacco use and trends in tobacco control are also unevenly distributed in other population groups. Tobacco consumption is higher among men than women (32.7% vs 5.8%) [2]. Sex- and country income level-specific analysis showed that male smoking prevalence is highest in middle-income countries (35.3%), whereas the highest female prevalence occurred in high-income countries (16.4%) [2]. Adolescent smoking prevalence varied greatly across countries, but a global estimate from 2007-2014 data showed that 7% of youth aged 13-15 years old smoked [4]. Because tobacco is highly addictive and efforts to quit smoking often fail, this high prevalence of youth smoking means that the tobacco epidemic remains locked in for future generations, with decades of future smoking-related ill-health still guaranteed.

Tobacco use has detrimental health, social and economic consequences. Tobacco use is the second leading risk factor—after high systolic blood pressure—for premature death and disability globally, accounting for over 8 million deaths and 182 million disability-adjusted life years (DALY) lost annually [5]. Of the over 8 million deaths occurred globally per year, 7 million deaths are due to due to the direct use of tobacco and 1.2 million deaths are attributable to secondhand smoke (SHS) exposure [5]. The

top four smoking-attributable causes of death are ischemic heart disease; chronic obstructive pulmonary disease; tracheal, bronchial, and lung cancer; and stroke. These together are responsible for about 70% of all smoking-attributable deaths [5].

On the societal level, although not the same for all countries, tobacco use is disproportionately prevalent in lower-income households[6]. Tobacco use leaves poorer households in a vicious cycle of poverty, where money for basic necessities, such as food, shelter and education, are spent on tobacco [7]. Tobacco farming, usually in lower-income regions, is labour intensive and exposes tobacco farmers to occupational hazards such as pesticide poisoning and green tobacco sickness [8]. In return, farmers' wages are meagre compared to the final sale price due to the cost added along the production chain [9]. Therefore, tobacco use is not only a barrier to achieving the health-related sustainable development goal (SDG) 3.4 and 3A, it also impedes global advances to other SDGs such as SDG 10 (reduce inequality within and among countries), and SDG 8 (promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all) [10].

The tobacco epidemic also damages the global economy directly through its health impact. Smoking-attributable mortality and morbidity increased global healthcare expenditure by an estimated US\$ 422 billion in 2012, which was 5.7% of total global health expenditure [11]. The indirect cost of productivity loss from smoking-attributable death and disability was US\$ 1 trillion [11]. Altogether, the direct and indirect cost of smoking totalled US\$ 1.4 trillion, accounting for 1.8% of annual global gross domestic product [11].

1.2. Tobacco epidemic in Japan

Tobacco use remains a major public health problem in Japan. The prevalence of tobacco use in Japanese man peaked at 83.7% in 1966 before it decreased steadily by two-thirds to 25.6% in 2017, over half a century. In contrast, female smoking prevalence started lower at about 20% in 1966 but endured a slower decline to 11.2% in 2017 [3,12]. Cigarette use among Japanese adolescents is also on a declining trend [13], with lifetime prevalence of cigarette use among 15–18-year-olds of 5.1% in 2017 [14]. There were 157,800 smoking-attributable deaths in 2016, accounting for 18.3% of all deaths in

men and 4.9% of all deaths in women [15]. Despite the decline in tobacco use, due to the accumulated past exposure and Japan's rapid ageing, tobacco use plays a major role in the country's chronic disease burden. The leading smoking-attributable deaths among men are lung cancer (29%), ischemic heart disease (17%) and stroke (6%); while in women, the order is slightly different, ischemic heart disease came up first at 28%, stroke at 23% and lung cancer at 18%[16]. It has been estimated that lung cancer alone would cause 63,000 deaths in men in 2025 and 32,000 deaths in women in 2035 [17].

The tobacco epidemic is now made worse as the newer tobacco products, such as heated tobacco products (HTP) and electronic nicotine delivery system (ENDS), entering the market and gaining popularity. According to the National Health and Nutrition Survey 2018, about 20.3% of the smokers used HTP, of whom 8.6% of them used both conventional cigarettes and HTP, and the majority of the HTP users are aged less than 40 years. While the sales of ENDS are prohibited in Japan, electronic non-nicotine delivery system (ENNDS) is allowed. As much as 3.5% of adolescents claimed to use ENNDS in 2017, and dual users are common [14]. Ever since the launch of these new tobacco products, Japan has been claiming the largest market share for heated-tobacco products in the world [18,19]. Even as Japan's efforts to control tobacco use slowly improve, tobacco company strategies to find new ways to sell nicotine threaten to maintain the epidemic long into the future without further tobacco control efforts.

1.3. Worldwide tobacco control measures

The health and economic impact of tobacco use is huge, but unnecessary and avoidable. Although it has been 70 years since Sir Richard Doll's landmark paper that established the association between smoking exposure and lung cancer [20], and 56 years since the 1964 US Surgeon General's report that warned of the health hazards against smoking, the battle against the tobacco epidemic is far from accomplished [21]. Global effort is needed to end this epidemic and save lives. At the 2003 World Health Assembly, all World Health Organization (WHO) member states announced their commitment to curb the tobacco epidemic by unanimously adopting the Framework Convention on Tobacco Control (FCTC), and to date 182 Parties have ratified this agreement [22]. The WHO FCTC came into full force

in 2015, the same year that the United Nations Millennium Development Goals (MDGs) were replaced by the Sustainable Development Goals (SDGs) and worldwide tobacco control was embedded in SDG 3A (strengthening the implementation of the WHO FCTC) and SDG 3.4 (reducing premature mortality from non-communicable diseases by one-third) [23]. In 2017, the WHO FCTC introduced the MPOWER package, a bundle of six cost-effective and high-impact measures intended to assist countries in reversing the tobacco epidemic, and to help track national progress on tobacco elimination. The six domains of MPOWER measures are:

1. **Monitor** tobacco use and prevention policies
2. **Protect** people from tobacco exposure with smoke-free policies
3. **Offer** help to quit
4. **Warn** about the dangers of tobacco
5. **Enforce** bans on tobacco advertising, promotion and sponsorship
6. **Raise** tobacco tax

The 2019 WHO report on the global tobacco epidemic noted that 136 countries (70%, covering 5 billion population) had implemented at least one out of six MPOWER measures; 82 countries (42%, covering 3.4 billion population) have implemented at least two out of six MPOWER measures to the highest level [2]. Cessation polices (O) are the least frequently adopted measure (23 countries) at the highest level, whereas cigarette pack warnings are the most adopted measure (91 countries) [2]. In 2012, Australia became the first country to go beyond MPOWER measures to enact a tobacco plain packaging law to restrict advertising on cigarette packages and since, about 19 countries have followed suit to either mandate plain packaging or pass regulation to do so [2].

Countries progressed at a vastly different pace, some steadily improving while some are lagging behind [2,24]. So far only Turkey and Brazil have successfully implemented all MPOWER measures to the highest level; Australia, New Zealand and Ireland are very close to achieving that, with only the "E" measure remaining at the second highest level [2]. Although countries are bound by the obligation to the FCTC international treaty to end the tobacco epidemic, overall progress towards a tobacco-free world is slow. According to a global estimate, only 37 (21%) countries are on track to achieve the 2025 target of 30% relative reduction on male smoking prevalence and 88 (49%) countries are able to achieve

female smoking prevalence target[24]. The probability of countries achieving targets is shown in Figure 1.

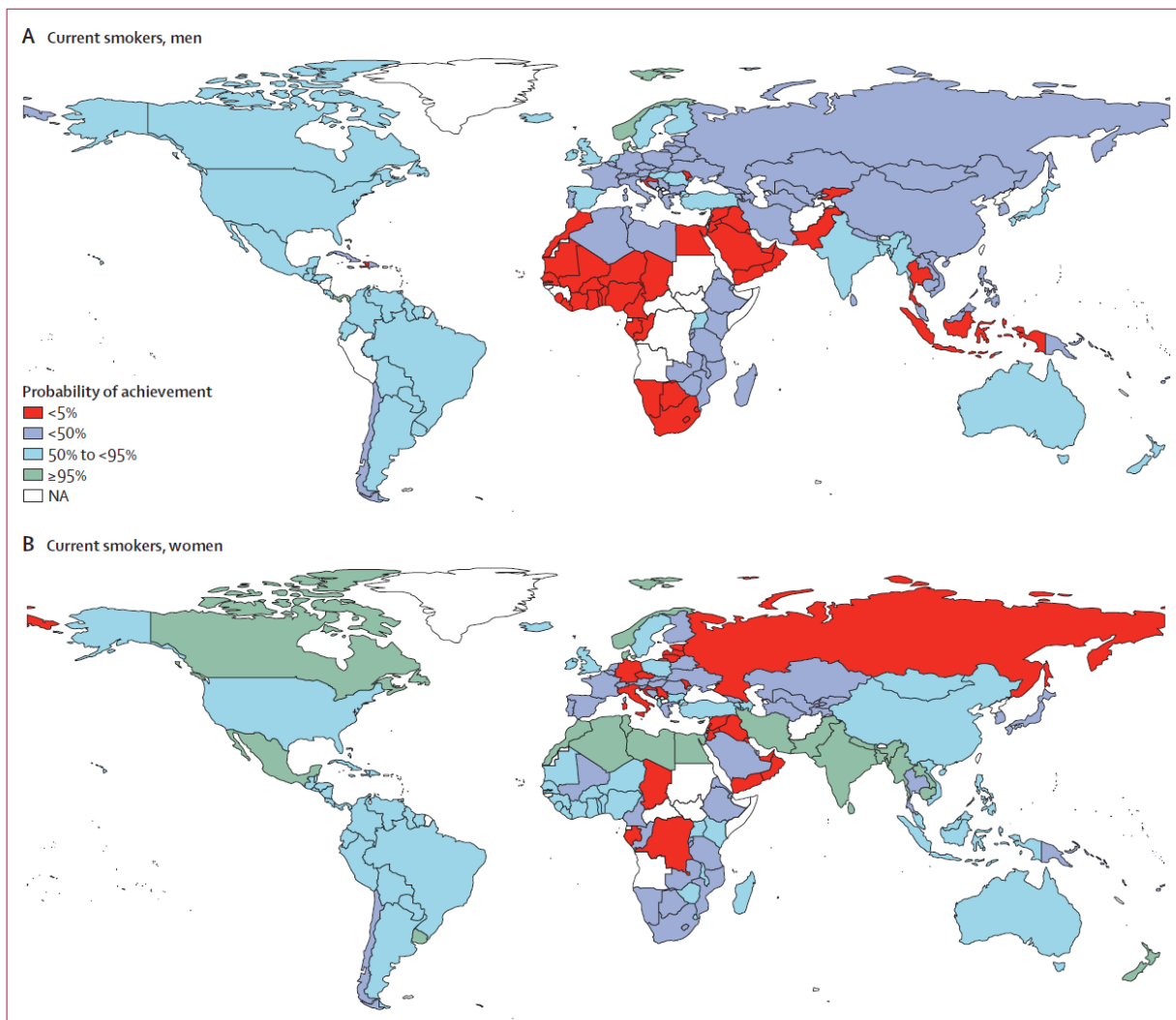


Figure 1: The probability of countries achieving 30% relative reduction on smoking prevalence by 2025. Source [24].

Countermeasures by the tobacco industry pose a major barrier to ending the tobacco epidemic is the [25]. Tobacco companies have launched several legal challenges to countries' legislative bodies in the past, and filed disputes against tobacco control laws with the World Trade Organization (WTO) [26]. Although these efforts to undermine tobacco control policies have not been fruitful, the decade-long lawsuits managed to delay policy implementation in countries and put more people at risk of tobacco-related ill health and death [27]. A more recently strategy from the tobacco industry is the attempt to disguise themselves as a worthy public health partner by claiming to help people quit conventional

smoking through newer tobacco products [2]. Tobacco companies fund research that promotes newer tobacco products as a "risk-reduction" tool and ruthlessly misinform the public on unproven health claims regarding these products, with the aim to convert current tobacco users and recruit new users [2]. For instance, Japan Tobacco International markets Ploom® and Logic® as modern lifestyle products with a sleek design that appeals to customers who want an "upgrade" from cigarette smoking. Constant action is required for governments to remain ahead of tobacco companies' efforts to find new ways to market their products, and this action is especially difficult in countries like Japan where tobacco control measures lag those of their international peers.

1.4. Tobacco control measures in Japan

Japan has been one of the signatory parties to the WHO FCTC since June 2004. Sadly, sixteen years after FCTC ratification, Japan is ranked as one of the poorest performing high-income countries in implementing MPOWER measures, predominantly due to the strong conflict of interest within the ruling government where the Finance Ministry owns a 33% share in Japan Tobacco [28]. Despite healthcare professionals, public health experts, patient groups and civil society advocating for stronger anti-tobacco policies to de-normalize smoking, the current government continues to be friendly with and allow the tobacco industry to interfere in anti-tobacco legislation [12,29,30]. As a consequence, many proven tobacco control measures have yet to be translated into public health policies. Table 1 summarizes Japan's MPOWER implementation and its limitations. The areas where Japan received "weak policy" ratings were (1) protect people from tobacco smoke (P); (2) warn about the dangers of tobacco (W); and (3) enforce restrictions on tobacco advertising, promotion and sponsorships (E) [2,31].

Table 1: MPOWER measures in Japan.

MPOWER	Current level of MPOWER implementation* and limitations
Monitor (M)	Status 【4】 Recent, representative, periodic data is available for adults and youth

Smoke-free policies (P)	<p>Status</p> <p>【2】 3 to 5 public places completely smoke-free</p> <p>Detail</p> <ol style="list-style-type: none"> 1. Provision to ban smoking completely in four public places (healthcare, education, university and government facilities) was adopted but not implemented by December 2018. 2. The <i>Industrial Safety and Health Act</i> require workplace to be smoke-free or partially smoke-free with designated smoking area (DSA). 3. There are subnational laws/ordinances in Kanagawa, Hyogo and Tokyo prefecture but with insufficient enforcement. <p>Limitations</p> <ol style="list-style-type: none"> 1. Policies are set to be effective from April 2020 [32]. 2. As per WHO FCTC standard, the definition of "complete" smoke-free environment means no ventilation and designated smoking areas (DSA) are allowed. The <i>Health Promotion Act</i> has many exemption clauses and strictly speaking, is not a complete smoke-free policy. E.g., smoking is allowed in facilities if there is a DSA and small eateries less than 100sqm are exempted.
Offer cessation (O)	<p>Status</p> <p>【3】 NRT and/or some cessation services (≥ 1 of which is cost-covered)</p> <p>Detail</p> <ol style="list-style-type: none"> 1. Nicotine replacement therapy (NRT), varenicline, behavioral modification therapy, unassisted attempt are the available smoking cessation methods. 2. NRT is available as over-the-counter items; varenicline is prescription-only medicine. <p>Limitation</p> <ol style="list-style-type: none"> 1. No national quit line. 2. NRT and varenicline are not the most popular methods to quit smoking. 3. Cost for smoking cessation service is covered under national health insurance but limits its eligibility to heavy smokers. It covers merely 1% of the smokers in Japan [33,34].
Warning labels	Status

(W, Labels)	<p>【2】 Medium size warning missing some/many appropriate characteristics</p> <p>Limitation</p> <ol style="list-style-type: none"> 1. Warning message covers 30% at the time of report. 2. Effective April 2020, it will cover 50% but still without many appropriate characteristics. 3. No pictorial warning or plain packaging [35].
Warn about the danger of tobacco thru mass media campaign (W, MM)	<p>Status</p> <p>【2】 National campaign conducted with 1 - 4 appropriate characteristics</p> <p>Limitation</p> <ol style="list-style-type: none"> 1. National campaign conducted between July 2016 and June 2018, with 2 appropriate characteristics.
Ban on advertising, promotion and sponsorships (E)	<p>Status</p> <p>【1】 Complete absence of ban, or ban that does not cover national TV, radio and print media.</p> <p>Limitation:</p> <ol style="list-style-type: none"> 1. Ban on printed media only. 2. Only focuses on restricting advertising to minors. 3. Advertising at point-of-sales, promotion to adults and tobacco company event sponsorships are allowed.
Raise tobacco tax (R)	<p>Status</p> <p>【3】 50-75% of retail price is tax.</p> <p>Detail</p> <ol style="list-style-type: none"> 1. 63.1% of retail price is tax 2. As of 2017, a standard pack of 20 cigarettes is priced at JPY430–490 (USD 4.0–4.6). If tax is increased to 75% of retail price, the selling price of a standard pack of cigarette would be JPY 636-725 (USD 6-7). <p>Limitation</p> <ol style="list-style-type: none"> 1. Cigarette price is affordable compared to other developed countries. 2. Last tax increment was in 2010.

*Country MPOWER status in June 2018, as reported in *WHO report on the global tobacco epidemic 2019*. MPOWER implementation are rated in 5 levels: 0, no data; 1, no policy; 2 minimal policy; 3, moderate policy; 4, complete policy.

The guidelines for implementation of WHO FCTC Article 8 recommend that comprehensive smoke-free policies be put in place within five years of entry into force of the Convention for that Party [36]. In July 2010, which is about five years after Japan's entry into force, the International Olympic Committee (IOC) agreed with WHO to promote the Olympics as a smoke-free event where every host country must comply to legislate a smoke-free policy throughout the Olympic games [37]. However, it was not until 2018 that the cabinet of the Japanese government, in anticipation of the Tokyo 2020 Olympics, finally passed a long-delayed, watered-down bill to prohibit smoking in all restaurants and bars with floor size more than 100m² in Tokyo [38]. This Prevention Ordinance commenced in April 2020 and allowed the Tokyo Metropolitan government to impose penalties on any facilities that violate the rule. However, this new policy is still far from meeting the requirement of FCTC Article 8, which mandates a complete smoking ban in all public and indoor places nationwide.

The evidence is clear that Japan lags behind many countries in its tobacco control measures, and there are a lot of opportunities for improvement.

1.5. Knowledge gap and study objectives

Tobacco use kills, MPOWER works. Japan lags behind in its implementation despite public health experts have criticized the inadequacy and advocated for immediate implementation of stricter MPOWER package in Japan [12,39]. Many countries conducted modelling analysis [40–42] on the potential impact of MPOWER measures on prevalence and mortality but there is no similar study conducted in Japan despite the utility of such country-specific analysis to motivate and advocate for better anti-smoking legislation. A few Japanese studies looked at how hypothetical changes in smoking prevalence [43], dynamic changes in the ageing population [17], and implementation of a single enhanced MPOWER measure [44] would affect the number of deaths from smoking-related diseases.

None of these studies considered to assess the potential impact of full MPOWER package using the effect size of each MPOWER measure in their estimation models. It is against this backdrop that my research aims to assess the impact of full MPOWER measures in Japan.

My study objectives are:

1. To project the smoking prevalence and mortality of current, former and never smokers up to 2100 under the status quo scenario representing current tobacco control measures.
2. To project the smoking prevalence and mortality of current, former and never smokers up to 2100 under enhanced MPOWER scenarios.
3. Using the status quo scenario as the baseline, to estimate the mortality averted in enhanced MPOWER scenarios.

My research will highlight the importance of anti-tobacco measures in reducing unnecessary deaths and I hope this will consolidate the scientific evidence to advocate for stricter tobacco control policies in Japan.

2. METHODS

A simulation model was used to project the number of smokers, smoking prevalence, and mortality from current, former, and never smokers. The model was run for eight different scenarios: one for the status quo, one for each MPOWER intervention, and one for combined MPOWER interventions, each time inputting the corresponding cessation rate. Youth smoking prevalence was not considered in this model; the age variable was organized into six 10-year age groups (20-29, 30-39, 40-49, 50-59, 60-69, and 70+). Models were run separately for men and women. The number of deaths averted from each intervention was defined as the excess mortality in the status quo compared to the intervention scenario.

2.1. Simulation model

The model started with the number of current and former smokers at the baseline year 2018. The number of smokers was obtained by multiplying the population projection by the age-specific smoking prevalence from the National Health and Nutrition Survey (NHNS) 2018. First, net cessation rate and current smokers' all-cause mortality rate (μ_c) were applied to determine the number of smokers who became former smokers and mortality among smokers. Net cessation rate is different for each scenario and is the key driver to different outcomes. Next, having calculated changes in the distribution of current, former and never smokers due to cessation and mortality, the population matured by one year, and 10% of the remaining population in each 10-year age group was shifted to the next age group while 90% remained in the same age group. At the end of each year, the number of smokers was converted to prevalence. The former smoker population was simulated using similar dynamics. Using 2018 as the base year, we projected the model up to 2100, and all interventions were set to begin from 2020. The process is described in Figure 2.

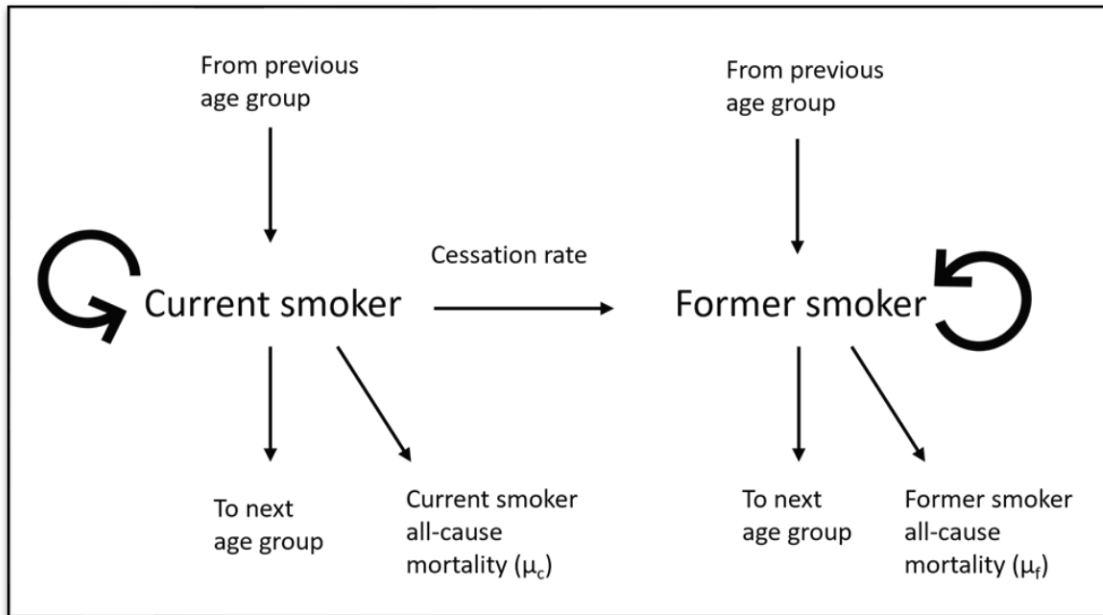


Figure 2: The general model to project the prevalence of current and former smokers.

2.2. Data source

2.2.1. National Health and Nutrition Survey

The National Health and Nutrition Survey (NHNS) is a cross-sectional survey, consisting of health, nutrition and lifestyle questionnaires, conducted nationwide in Japan annually by the collaborative effort of the Ministry of Health, Labour and Welfare (MHLW) and local government public health centers [45]. The smoking habit module of the NHNS captures the prevalence of current, former, and never smokers since 1995. The smoking habit questionnaires changed three times over the years (Table 2): the question "Have you ever smoked more than 100 cigarettes and more than six months?" was removed from 2011 onwards and the question "Have you ever smoked habitually?" was removed from 2013. This alteration in the questionnaire did not affect current smokers' prevalence trend but has resulted in a drastic rise and fall in the prevalence of former smokers in 2011 and 2013 onwards. Hence, we decided to use the prevalence of current smokers up to 2018 and the prevalence of former smokers up to 2010. The smoking prevalence was reported in ten-year age groups (e.g., 20-29, 30-39, ..., 60-69,

70+ years old).

Table 2: Questionnaire change in the smoking habit module of NHNS.

	2003-2010	2011-2012	2013 onwards
Current	Ever smoked >100 cigarettes AND smoked >6 months AND have smoked daily/sometimes in recent 1 month.	Ever smoked habitually AND have smoked daily/sometimes in recent 1 month.	Smoked daily/sometimes in recent 1 month.
Former	Ever smoked >100 cigarettes AND smoked >6 months AND have not smoked in recent 1 month.	Ever smoked habitually AND have not smoked in recent 1 month.	Used to smoked but have not smoked in the recent 1 month.
Never	1. Ever smoked <100 cigarettes AND smoked <6 months AND have not smoked in recent 1 month. 2. Those who never smoked.	Never smoked.	Never smoked.

2.2.2. Population and mortality data

We used sex- and age-specific population data (1958-2018) from Japanese Vital Statistics (Ministry of Health, Labour and Welfare), which is downloadable from the National Cancer Centre Research website [46]. Sex- and age-specific all-cause mortality data (1980-2016) was obtained from Japanese Vital Statistics. Both population and mortality data were available in five-year and ten-year age group stratification.

2.3. Mortality rate projection

2.3.1. Total mortality rate

A Poisson regression model was used to estimate the age-specific time trend in the all-cause

mortality rate for the total population (μ_t), separately for men and women. The regression model was built using data from 1980 to 2016 and the estimates of this all-cause mortality rate were used in population projection up to 2100. The regression coefficients of year variable were also used to project group-specific mortality rates.

2.3.2. Group-specific mortality rate

Mortality relative risks were used to partition the 2018 age-specific total mortality rate (μ_t) into three groups, i.e., current (μ_c), former (μ_f) and never smoker (μ_n) mortality rates. The total number of deaths can be calculated as

$$\mu_t N_t = \mu_c N_c + \mu_f N_f + \mu_n N_n \quad (1)$$

Relative risk of mortality in each of the risk groups is known and defined as

$$RR_c = \frac{\mu_c}{\mu_n} \Rightarrow \mu_c = RR_c \mu_n \quad (2)$$

$$RR_f = \frac{\mu_f}{\mu_n} \Rightarrow \mu_f = RR_f \mu_n \quad (3)$$

Dividing equation (1) by total population (N_t) and inserting equations (2) and (3) we can obtain

$$\mu_n = \frac{\mu_t}{RR_c P_c + RR_f P_f + P_n}$$

Where

t designates total population

c designates current smoker

f designates former smoker

n designates never smoker

μ = mortality rate

N = population count

RR = relative risk of all-cause mortality in relative to never smoker

p = prevalence

Once the mortality rate of never smokers (μ_n) was obtained, the mortality rate of current and former smokers was deduced from equations (2) and (3). The all-cause mortality relative risk for current and former smokers used in this study were 1.6 and 1.24 for men, and 1.48 and 1.24 for women [47].

The age-specific mortality rate in each group was then projected forward using the regression coefficient of year variable from a Poisson regression model of mortality, which is described in section 2.3.1. The age-specific formula for total mortality can be decomposed into contributions from each of the smoking groups as follows:

$$(\mu_t N_t)_i = \gamma(\mu_t N_t) = \gamma r_c \mu_c P_c N_t + \gamma r_f \mu_n P_f N_t + \gamma \mu_n P_n N_t \quad (4)$$

where

$(\mu_t N_t)_i$ = the mortality at time i

γ = the multiplicative time factor at time i , which can be derived from the regression coefficient (β) of year from a Poisson regression model of mortality trend, where $\gamma = \exp(\beta)$.

r = relative risk of mortality risk in relative to never smoker

The age-specific time factor (γ) is applied to the 2018 age-specific mortality rate in each group over time to obtain future group-specific mortality rates in all three groups.

2.4. Population projection

Using the 2010 population as base, the population was projected up to 2100 using parameters such as sex- and age-specific all-cause mortality rate estimates, total fertility rate, and infant sex ratio. The base population and all-cause mortality rate estimates were organized in 5-year age groups (0-4, 5-9, ..., 75-79, 80+) for more accurate estimates. I started by projecting the female population because that would provide the number of newborns each year. In a yearly cycle, first, the mortality cases were removed by multiplying the population by that year's mortality rate, adjusted for the long-term downward trend identified in the regression model of mortality. Second, we multiplied fertility rates by the number of women at reproductive age (15-49 years old) to provide the number of newborns that would enter the 0-4 years old cohort in the following year. The number of newborns was apportioned by sex according to the infant sex ratio. Third, we shifted the age group by 1 year as the population matured into subsequent years and repeated the cycle. The projection of the male population was conducted similarly by adding the number of male newborns into the 0-4 years old male cohort. We assumed a constant total fertility rate (TFR) of 1.44, which is the TFR used in the medium fertility

variant in the population projection conducted by National Institute of Population and Social Security Research, throughout this model [48]. The male to female infant sex ratio used was 1:1.04.

2.5. Input of new smokers into the simulation model

The simulation only considered smoking prevalence for those aged 20 years and above. This model assumes (1) smoking initiation only happens in age group 20 years; (2) age group 20 years only enters as current or never smoker, but not as former smoker; and (3) new entrants to the smoker population enter with a smoking prevalence that matches the current profile of 20-29 years old. These assumptions were necessary because data on smoking behavior in under 20- year-old is difficult to obtain. The number of new entrants into the model at the beginning of each year is as below.

$$N_{C20,j} = P_{C(20-29),j-1} \times 0.2 \times N_{t(15-19),j-1}$$

Where,

$N_{C20,j}$ is the number of current smokers aged 20 years at the j -th year

$P_{C(20-29),j-1}$ is the prevalence of current smokers in the age group 20-29 years old at the $(j-1)$ th year

$N_{t(15-19),j-1}$ is the number of people in the age group 15-19 years old at the $(j-1)$ th year

The factor of 0.2 is applied to the 15-19 age group population to ensure that only the final year of this age group matures into the 20-29 age group. This ensures that each year the model effectively matures one year of the projected 15-19 age group into the 20-29 age group category, then converts a proportion of this 20-years-old population into smokers using the prevalence of smokers in the 20-29 years age group in the previous year.

2.6. MPOWER intervention scenarios and effect sizes

MPOWER describes a set of six high impact and cost-effective tobacco control measures suggested by WHO FCTC to help countries reverse the tobacco epidemic. The *WHO report on the global tobacco epidemic* rates country's MPOWER implementation by 5 levels: 0 for no data, 1 for no policy, 2 for

minimal policy, 3 for moderate policy, and 4 for complete policy. The intervention scenarios used in this analysis are hypothesized on the MPOWER measures implemented at its highest level (4, complete policy), that is, full MPOWER implementation. These measures were selected because they have yet to be implemented in Japan at the time of analysis, except for the "M" measure where Japan have already attained the highest policy level. Seven intervention scenarios were included in this analysis—six individual MPOWER measures and one combined MPOWER measure.

The effect sizes of each intervention were obtained from Levy *et al.* 2018. The effect size is defined as the long-run (40 years horizon) relative reduction in smoking prevalence of full MPOWER implementation relative to zero MPOWER implementation. However, Japan's current MPOWER implementation levels do not start at the lowest level, so the effect sizes need to be adjusted accordingly. The effect sizes for intervention scenarios are apportioned equally by level, so that the four levels of any intervention lead to equally sized increments in effect size up to the maximum. The effect size is assumed to be universal across all age groups and both sexes, except for the "R" (tax) measure, where the effect size is larger among younger age groups due to differences in cigarette affordability. The proposed intervention and effect sizes are summarized in Table 3.

2.6.1. Scenario P – Smoke free policy

Although Japan received a rating of "minimal policy **【2】**" for the P measure in the *WHO report on the global tobacco epidemic 2019*, the smoke free policy was not implemented until April 2020. Therefore, in scenario P, the model started with "no policy **【1】**" in 2018, and the full MPOWER implementation commences from 2020 onwards. The proposed intervention is to have a complete smoke-free policy for all public places (including healthcare facilities, educational facilities, universities, government facilities, indoor workplaces, restaurants, public places, and others). The effect size is -12.5%.

2.6.2. Scenario O – Offer help to quit smoking

Japan has achieved "moderate policy **【3】**" for the "O" measure and is only one level away from complete policy. The proposed intervention is to have a national quit line, financial coverage for more

smokers to access smoking cessation services, and more intervention from healthcare professionals. The effect size from Levy *et al.* 2018 is -11%, but because Japan has already achieved moderate policy, we apportioned it to -5%.

2.6.3. Scenario W (L) – Warning label on cigarette package

Japan achieved a "minimal policy **【2】**" for the "W(L)" measure by mandating warning labels to cover at least 30% of cigarette packaged, but many appropriate characteristics were missing. The proposed intervention for scenario W(L) is to mandate a large warning label covering at least 50% of the cigarette package and contains all characteristics. The effect size from Levy *et al.* is -10%, but the effect size used in this study was apportioned to -8.33%.

2.6.4. Scenario W (MM) – Warning though mass media campaign

Japan was rated "minimal policy **【2】**" for the "W(MM)" measure by running national anti-tobacco campaign between 2016 and 2018 with two appropriate characteristics. The proposed intervention is to have a national campaign with all seven appropriate characteristics, including airing warning messages on television and radio. The effect size from Levy *et al.* is -12%, but the effect size used in this study was apportioned to 9%.

2.6.5. Scenario E – Ban on advertising, promotion and sponsorship

Japan has "no policy **【1】**" to ban tobacco advertising, promotion and sponsorship as per *WHO report on the global tobacco epidemic 2019*. Scaling up the intervention scenario to the highest policy level means implementing bans on tobacco advertising to adults and youth, as well as all tobacco promotion and tobacco company sponsorship to any events. The effect size from Levy *et al.* is -6% for total ban on tobacco advertising but no mentioning of promotion and sponsorship bans. The effect size used in this study is -6%.

2.6.6. Scenario R – Raise tobacco tax

According to the WHO report on the global tobacco epidemic 2019, the selling price of most cigarette brands in Japan is ¥440 and the tax component is 63.1% (i.e., cigarette price is ¥163 while tax is ¥277). If tax were to be raised to 75% of cigarette price, the cigarette selling price would be ¥652 (i.e., cigarette price is ¥163 while tax is ¥489). The cigarette price would increase 48% if the tax component were to be increased to 75%. The long-run tobacco price elasticity for high-income countries is estimated to be -0.36[4], which means a 1% increase in price will reduce tobacco consumption by 0.36% and therefore reduce smoking prevalence. Price elasticity can be multiplied by the projected relative change in cigarette price (in this case 48%) to get the prevalence change, i.e. the effect size of the policy implementation (in this case $48 \times -0.36 = -17.2\%$). Price elasticity is higher for youth and young adults than older adults due to price affordability. This analysis adopted the age-specific price elasticity reported in the Korean and Chinese SimSmoke models because of the comparable cigarette price and tobacco control policies between Japan, Korean and China. A slight modification was made on the age group of Korean SimSmoke price elasticity so it can be applied to this model. The finalized age-specific price elasticities and effect sizes used in this model are -0.30 for age group 20-29, -0.20 for age group 30-39 and -0.10 for age group ≥ 40 . This translates to the effect size of -15%, -10% and -5% for the respective age groups.

Table 3: Summary of intervention scenarios and its effect sizes.

MPOWER	MPOWER status*		Intervention scenario	Effect size in Levy <i>et al.</i> 2018	Effect size in this study†
	2018	Scaled-up			
P	2	4	All public places (including healthcare facilities, educational facilities, universities, government facilities, indoor workplaces, restaurants, public places, and others) to be completely smoke-free‡.	-12.5%	-12.5%
O	3	4	Have a complete cessation policy that includes a national quitline, financial coverage and intervention from healthcare professional.	-11%	-5%
W (L)	2	4	Cigarette package to display large warning that covers >50% and contains all characteristics.	-10%	-8.33%
W (MM)	2	4	Have a national campaign with 7 appropriate characteristics	-12%	-9%
E	1	4	Ban all tobacco advertising, promotion and sponsorship.	-6%	-6%
R	3	4	Increase the tax component from 63.1% to 75%.	Price elasticity by age groups: 18-24 : -0.30 25-34 : -0.20 ≥35 : -0.10	Price elasticity by age groups: 20-29: -0.30 30-39: -0.20 >40 : -0.10 Effect size by age groups: 20-29: -15% 30-39: -10% >40 : -5%

* Country MPOWER status in June 2018, as reported in *WHO report on the global tobacco epidemic 2019*. MPOWER implementation level is rated in 5 levels: 0, no data; 1, no policy; 2, minimal policy; 3, moderate policy; 4, complete policy.

† Effect size used when scaling up an MPOWER intervention from 2018 status to level 4-complete policy.

‡ WHO FCTC defines "complete" smoke-free environment as no ventilation and designated smoking areas (DSA) are allowed.

2.7. Cessation rate

The study describes cessation rate as net cessation rate, which is the net value after considering smoking cessation rate and initiation rate. Sex- and age-specific cessation rates were used in this study.

2.7.1. Net cessation rate of status quo model

To obtain the age-specific cessation rate for the status quo model, current smoker prevalence data from the NHNS (1995-2018) was used to run a linear regression model on the log of prevalence. The basic linear regression model equation is:

$$\ln(p_i) = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i1} x_{i2} + \epsilon_i \quad (5)$$

Define the prevalence for observation i (in year i) as p_i . Define year variable for the i -th year as x_{i1} , where x_{i1} is 0 in 1995, and age group variable as x_{i2} . This ensures the intercept of all models is the value of prevalence in 1995. In practice, the age group variable x_{i2} is decomposed as a set of dummy variables (one for each age group with the reference category omitted). However, for simplicity, it is represented as a single variable in equation (5). The estimated coefficient of the year variable ($\beta_1 + \beta_3$) is the estimated age-specific cessation rate and is summarized in Table 4. In female 50-59 and 60-69 age groups, the estimated coefficients were positive, indicating growth in the number of current smokers. However, the values were small (0.0042 and 0.0028) and assumed to be zero in our model, indicating no cessation or growth for the 50-59 and 60-69 age groups. The predicted prevalence fits well with the original data (Figure 3). The status quo cessation rate was applied throughout all years in the status quo model (2018-2100) and for two years in the intervention model (2018-2019).

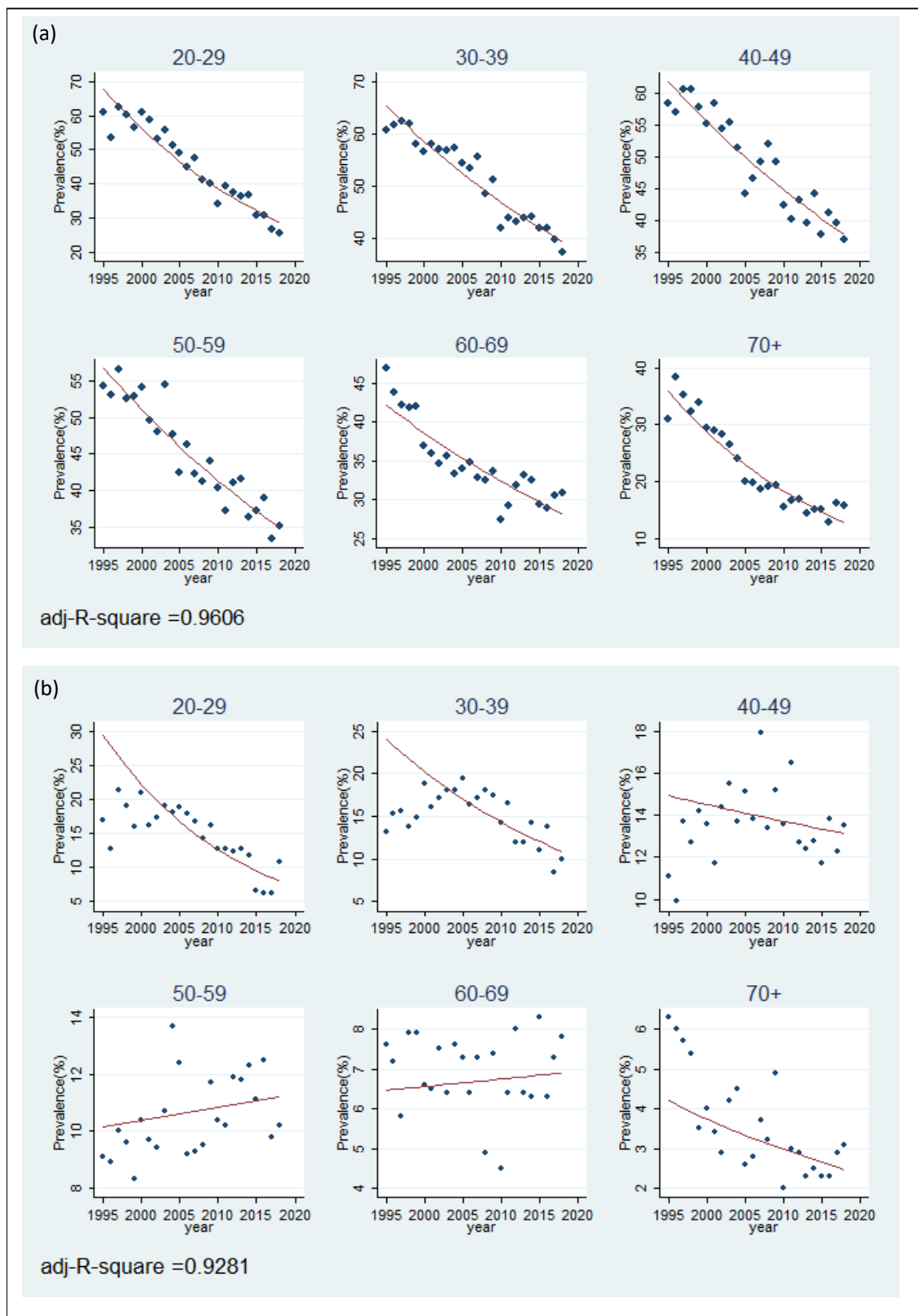


Figure 3: Fitted graph of observed male current smoker prevalence from NHNS data and predicted prevalence from regression model. (a) Male model, (b) Female model.

2.7.2. Net cessation rate of intervention (full MPOWER) model

The cessation effect of the intervention model was calculated based on the effect size in Table 3, added on to the cessation rate for status quo, and then applied to the intervention model from 2020 onwards. The formula to derive cessation rate of each intervention is described below.

Consider the original text in Levy *et al.* 2018 about effect size, "*we convert their estimates to relative terms, that is, the absolute change relative to the initial smoking prevalence.*" From this, the effect size is defined as,

$$ES = \frac{p_0 - p_1}{p_0}$$

$$ES = \frac{p_0 - p_1}{p_0} = 1 - \frac{p_1}{p_0} = 1 - r \quad (6)$$

Assume $p_1 < p_0$ because the prevalence is on a declining trend. Define the relative prevalence as $r = \frac{p_1}{p_0}$. Rewrite r as a multiplier,

$$p_1 = rp_0$$

Decompose this into a series of t time steps, so that

$$p_1 = (1 - \alpha)^t p_0$$

So,

$$\alpha = 1 - r^{1/t} \quad (7)$$

Where α is the annual percentage change, also known as the cessation rate. In the case of the status quo model, the cessation rate has been estimated from a regression model (section 2.7.1). So now, with a declining status quo trend and an intervention, let us define the annual intervention effect as α_I and the annual status quo trend term as α . Then, a single year's change in smoking prevalence, from year j to year j+1, can be calculated as

$$p_{j+1} = (1 - \alpha_I)(1 - \alpha)p_j$$

An intervention applied to a starting prevalence over t years would be,

$$p_t = (1 - \alpha_I)^t (1 - \alpha)^t p_0$$

Rewrite the equation,

$$p_t = [(1 - \alpha_I)(1 - \alpha)]^t p_0$$

Expand the terms in the square brackets,

$$(1 - \alpha_I)(1 - \alpha) = 1 - \alpha_I - \alpha + \alpha_I \alpha \approx 1 - (\alpha_I + \alpha)$$

Provided that the annual percentage changes (α and α_I) are small, so $\alpha_I \alpha$ would be very small and negligible. Therefore, the cessation rate of the intervention model is the summation of cessation rate for the status quo (α) and the annual intervention effect (α_I). α_I can be deduced by inserting equation (6) into equation (7),

$$\alpha_I = 1 - r^{1/t}$$

$$\alpha_I = 1 - (1 - ES)^{1/t}$$

For example, given that the effect size of P is 12.5% (from Levy *et al.* 2018), the annual P intervention effect over a 40-year horizon is

$$\alpha_I = 1 - (1 - 0.125)^{1/40}$$

$$\alpha_I = 0.0033$$

Then, given that the cessation rate of male 20-29 age group from status quo model is 0.0372 (from section 2.7.1 regression model), the cessation rate of male 20-29 age group under full P intervention is $(\alpha_I + \alpha) = 0.0033 + 0.0372 = 0.0405$.

2.7.3. Net cessation rate of combined MPOWER model

For the combined MPOWER model, the cessation rate is obtained by multiplying the separate terms together. So, the cessation rate for the combined MPOWER model is

$$(1 - \alpha) \prod_{I=1}^6 (1 - \alpha_I)$$

Again, under the condition that all annual percentage terms are very small and $\alpha_I \alpha$ would be very small and negligible. The equation (8) can also be expressed approximately by

$$1 - \sum_{k=0}^6 \alpha_k$$

where $k=0$ corresponds to the status quo cessation rate (α) and $k=1,2, \dots, 6$ corresponds to each full intervention.

Table 4: Summary table of age- and sex-specific cessation rates used in models.

			P	O	W(L)	W(MM)	E	R	Combined MPOWER
			Effect size						
			12.50%	5.00%	8.33%	9.00%	6.00%	20-29: 15%, 30-39: 10%, >40: 5%	-
			Annual intervention effect (α_i)						
			0.0033	0.0013	0.0022	0.0024	0.0015	20-29: 0.0041, 30-39: 0.0026, >40: 0.0013	-
			Cessation rate of full intervention model ($\alpha+\alpha_i$)					($\alpha+\alpha_{i1}+\alpha_{i2}+\alpha_{i3}+\alpha_{i4}+\alpha_{i5}+\alpha_{i6}$)	
Male	20-29	0.0372	0.0405	0.0385	0.0394	0.0396	0.0387	0.0413	0.0519
	30-39	0.0219	0.0252	0.0232	0.0241	0.0243	0.0234	0.0245	0.0352
	40-49	0.0215	0.0248	0.0228	0.0237	0.0239	0.0230	0.0228	0.0335
	50-59	0.0212	0.0245	0.0225	0.0234	0.0236	0.0227	0.0225	0.0332
	60-69	0.0176	0.0209	0.0189	0.0198	0.0200	0.0191	0.0189	0.0296
	70+	0.0447	0.0480	0.0460	0.0469	0.0471	0.0462	0.0460	0.0567
Female	20-29	0.0567	0.0600	0.0580	0.0589	0.0591	0.0582	0.0608	0.0714
	30-39	0.0346	0.0379	0.0359	0.0368	0.0370	0.0361	0.0372	0.0479
	40-49	0.0058	0.0091	0.0071	0.0080	0.0082	0.0073	0.0071	0.0178
	50-59	0	0.0033	0.0013	0.0022	0.0024	0.0015	0.0013	0.0120
	60-69	0	0.0033	0.0013	0.0022	0.0024	0.0015	0.0013	0.0120
	70+	0.0228	0.0261	0.0241	0.0250	0.0252	0.0243	0.0241	0.0348

2.8. Lung cancer mortality rate

Because lung cancer is a major mortality consequence of smoking, I modeled lung cancer mortality as a sub-analysis of all-cause mortality. The proportion of lung cancer mortality relative to all-cause mortality was consistent in recent years, so I used this proportion to predict the lung cancer mortality rate from total mortality. In this model, it was assumed that this proportion is constant until 2100.

Let x_c be the proportion of lung cancer mortality relative to all-cause mortality from current smokers,

$$x_c = \frac{Death_{lung,c}}{Death_{allcause,c}} = \frac{\frac{Death_{lung,c}}{Pop_c}}{\frac{Death_{allcause,c}}{Pop_c}} = \frac{MR_{lung,c}}{MR_{allcause,c}} \quad (8)$$

Equation 8 showed that the proportion of mortality cases equates to the proportion of mortality rate. The proportion for formers smokers (x_f) and never smokers (x_n) was deduced in a similar way. The group-specific lung cancer mortality rates were adopted from a pooled analysis of three cohort studies[16,49]. Because the cohort studies did not include subjects less than 40 years old and tobacco-related lung cancer rarely occurred in individuals less than 40 years old, lung cancer mortality rates for 20-29 and 30-39 age groups were assumed to be 0. The group-specific all-cause mortality rates were deduced in section 2.3.2. These proportions were then applied to the all-cause mortality generated from the simulation models to obtain the number of lung cancer deaths. The proportions are summarized in Table 5.

Table 5: Summary table of group- and age-specific lung cancer mortality proportion.

Age group	Male			Female		
	X_c	X_f	X_n	X_c	X_f	X_n
20-29	0	0	0	0	0	0
30-39	0	0	0	0	0	0
40-49	0.072	0.054	0.037	0.052	0.197	0.000
50-59	0.036	0.080	0.057	0.053	0.143	0.044
60-69	0.045	0.131	0.078	0.064	0.107	0.087
70+	0.025	0.080	0.055	0.016	0.051	0.050

2.9. Averted death calculation

Averted death is the difference between the number of deaths from the status quo scenario and policy intervention scenario. The deaths from current, former, and never smokers were all included in calculating the total number of deaths. A positive value for averted death indicates fewer deaths in the policy scenario than the status quo scenario.

3. RESULTS

3.1. Smoking prevalence under the status quo scenario

Under the status quo scenario, even without additional intervention policies, the male smoking prevalence continues on a downward trend in all age groups. The male smoking prevalence falls below 5% in all age groups at the end of 2100 (Figure 4a). The prevalence of male former smokers in all age groups increases for several years or decades before it starts decreasing (Figure 4b). The prevalence of former smokers in all age groups, except for the 70+ years old age group, falls below 10% at the end of 2100. When combining all age groups, the smoking prevalence fall steadily falls from 29.6% in 2018 to 0.7% in 2100. In contrast, the prevalence of former smokers rises from 11.3% and peaks at 23.5% in 2050 before falling to 15.5% in 2100 (Figure 4c).

In general, women have lower prevalence of current and former smokers than men. The female smoking prevalence falls below 2% in all age groups at the end of 2100 (Figure 5a). The smoking prevalence of younger age groups (<50 years old) shows a continuous downward trend, whereas the prevalence increases slightly before falling again in the older age groups (>50 years old). The prevalence of female former smokers increases slightly before falling to less than 7% at the end of 2100 in all age groups (Figure 5b). When combining all age groups, the prevalence of current smokers falls continuously from 8.3% in 2018 to 0.4% in 2100, whereas the prevalence of former smokers rises from 3.7%, peaks at 7.0% in 2053 before falling to 4.8% in 2100 (Figure 5c).

There were more current smokers in both sexes than former smokers at the beginning of 2018 but ended with more former smokers than current smokers at the end of 2100. (Figure 4c and 5c).

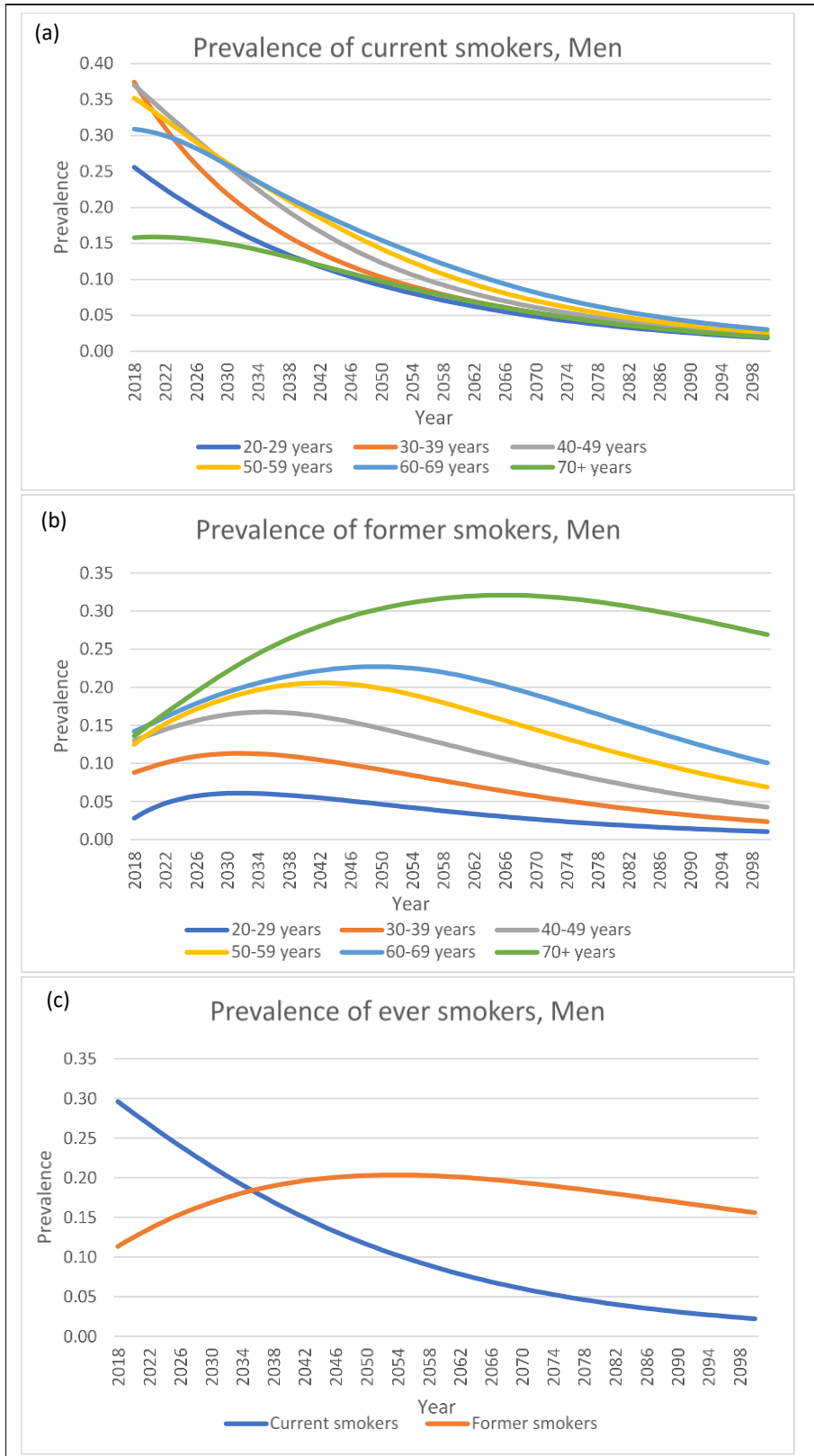


Figure 4: Projection of smoking prevalence among men under the status quo. (a)Prevalence of current smokers; (b) Prevalence of former smokers; (c) Prevalence of ever smokers.

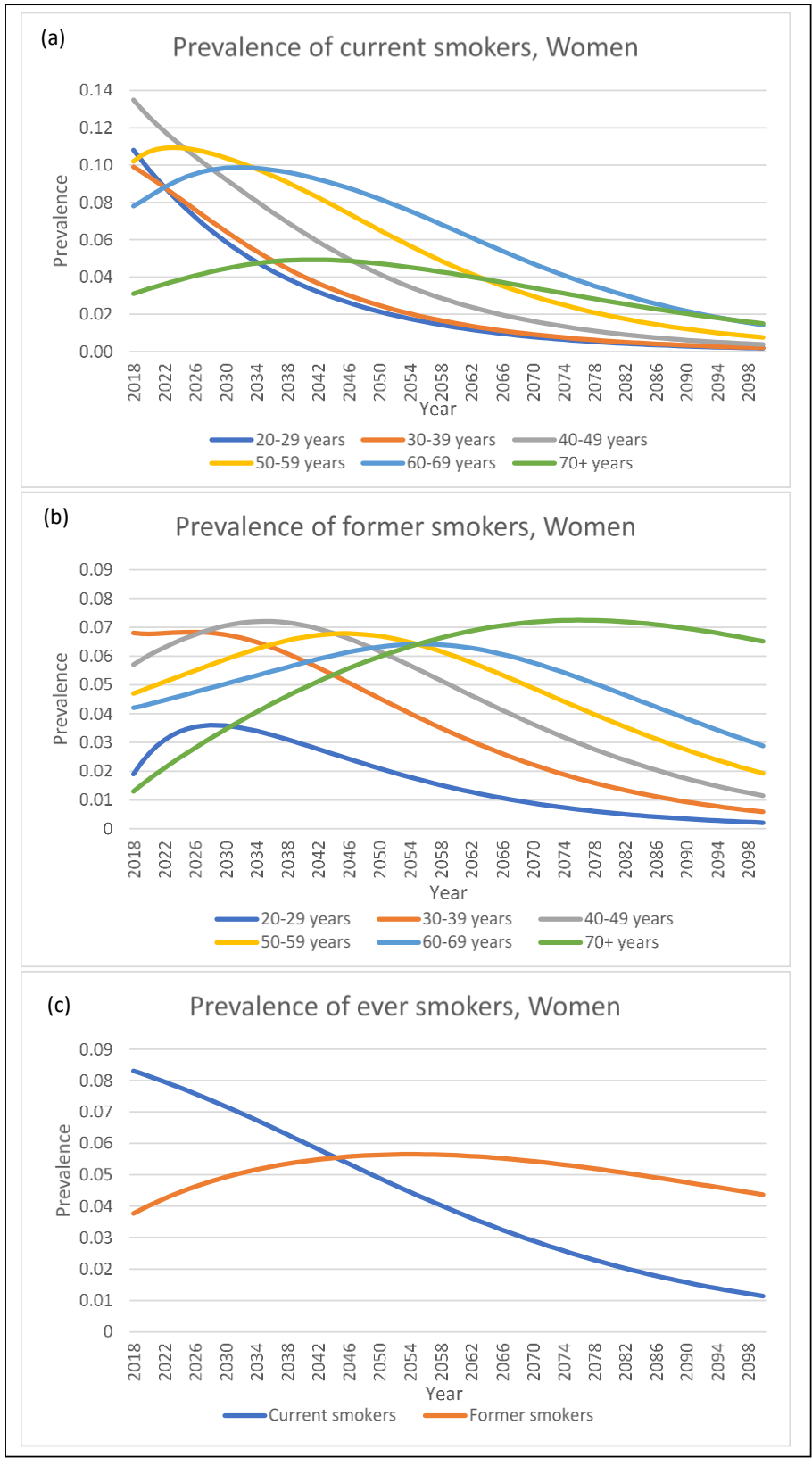


Figure 5: Projection of smoking prevalence among women under the status quo. (a)Prevalence of current smokers; (b) Prevalence of former smokers; (c) Prevalence of ever smokers.

3.2. Smoking prevalence under different policy scenarios

The effect of different policy scenarios on smoking prevalence is shown in Figure 6. Smoking prevalence is projected to have a downward trend in both sexes, even without scaling up any MPOWER interventions. Among the individual policy scenarios, enhanced public smoke-free policy (P) achieved the biggest prevalence drop, followed by raising taxes (R), mass media campaigns (W(MM)), warning labels (W(L)), advertising and promotion bans, and offering cessation services (O). The projected male smoking prevalence by 2100 is 2.2%, 1.7–2.0% and 0.7% under the status quo, individual MPOWER and combined MPOWER scenarios, respectively. In the female model, the projected prevalence in 2100 is 1.1%, 0.8–1.0% and 0.4% under the status quo, individual MPOWER and combined MPOWER scenario, respectively.

The differences are more noticeable in the combined MPOWER scenario, where the prevalence declines lower and faster. It requires 17 years to achieve 50% relative reduction from baseline prevalence in men with the implementation of combined MPOWER measure, compared to 24 years in the status quo (7 years shorter). In the female model, combined MPOWER policy takes 25 years to reduce baseline prevalence by 50%, compared to 40 years in the status quo scenario (15 years shorter). With the combined MPOWER policy intervention, Japan is expected to see male smoking prevalence drop to 5% in 2060, 16 years faster than the status quo scenario; female smoking will drop to 1% in 2081, 20 years faster than the status quo scenario.

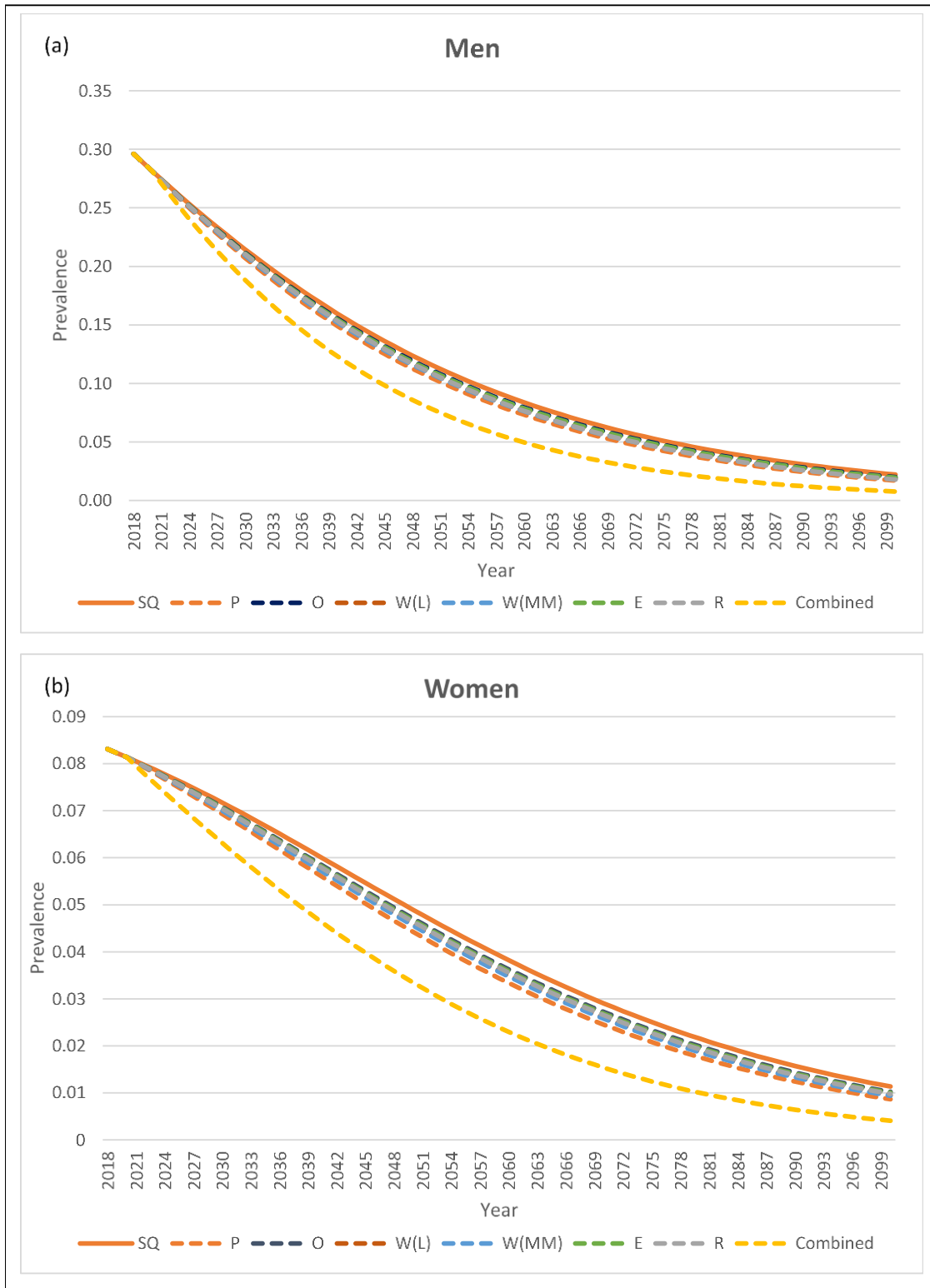


Figure 6: Projection of smoking prevalence up to 2100 under different policy scenarios.

SQ, status quo; P, smoke-free law; O, offer cessation service; W(L), warning on label; W(MM), warning through mass media; E, advertising bans; R, raise tax; combined, combined all policies.

3.3. Averted deaths from different policy scenarios

Averted deaths is the number of preventable deaths should there be a policy intervention instead of the status quo. As shown in Table 6, all intervention policy scenarios result in fewer all-cause deaths than the status quo scenario. In other words, all intervention policies are effective in preventing deaths from tobacco smoking. Scaling up any one of the individual MPOWER measures helps prevent as many as 127,907 deaths with smoking free (P) policy or as few as 51,124 deaths with the offering cessation (O) policy. If all MPOWER measures were to be implemented at the highest level, Japan would be able to prevent a total of 405,910 all-cause deaths (295,048 from men and 110,863 from women) in the coming 80 years. The combined MPOWER policy is the most effective; it can prevent 3 – 8 times more deaths than any individual MPOWER policy.

The number of averted all-cause deaths includes the deaths from lung cancer. Under the combined MPOWER scenario, 59,349 (14.6%) of the total averted all-cause deaths are attributable to lung cancer, that is, 51,441 averted deaths from men and 7,908 averted deaths from women (Table 7).

Figure 7 plots the number of averted all-cause and lung cancer deaths in a single graph to illustrate the difference between the two sexes and the proportion of lung cancer deaths in all-cause deaths. On average, the averted lung cancer deaths comprised 17.4% of all-cause averted deaths in men and 6.8-8.1% in women. There are more averted deaths in men than women, regardless of all-cause or lung cancer deaths (Table 6 and 7).

Table 6: Averted all-cause deaths from different policy scenarios (2018–2100).

Policy scenario	Men		Women		Total	
	All-cause death	Averted death	All-cause deaths	Averted deaths	All-cause deaths	Averted deaths
SQ	41,749,936	-	44,329,421	-	86,079,357	-
P	41,657,885	92,050	44,293,564	35,857	85,951,450	127,907
O	41,713,209	36,726	44,315,023	14,398	86,028,233	51,124
W (L)	41,688,685	61,250	44,305,476	23,945	85,994,162	85,195
W (MM)	41,683,744	66,192	44,303,559	25,862	85,987,303	92,054
E	41,705,851	44,085	44,312,153	17,268	86,018,004	61,353
R	41,700,011	49,925	44,311,775	17,646	86,011,786	67,571
MPOWER	41,454,888	295,048	44,218,559	110,862	85,673,447	405,910

Table 7: Averted lung cancer deaths from different policy scenarios (2018–2100).

Policy scenario	Men		Women		Total	
	Lung cancer death	Averted death	Lung cancer death	Averted deaths	Lung cancer death	Averted deaths
SQ	1,842,142	-	988,872	-	2,831,014	-
P	1,826,104	16,038	986,418	2,454	2,812,522	18,492
O	1,835,746	6,396	987,891	981	2,823,637	7,377
W (L)	1,831,473	10,669	987,238	1,635	2,818,711	12,304
W (MM)	1,830,612	11,530	987,106	1,766	2,817,718	13,296
E	1,834,464	7,678	987,695	1,177	2,822,159	8,855
R	1,833,513	8,629	987,449	1,423	2,820,962	10,052
MPOWER	1,790,701	51,441	980,965	7,908	2,771,666	59,349

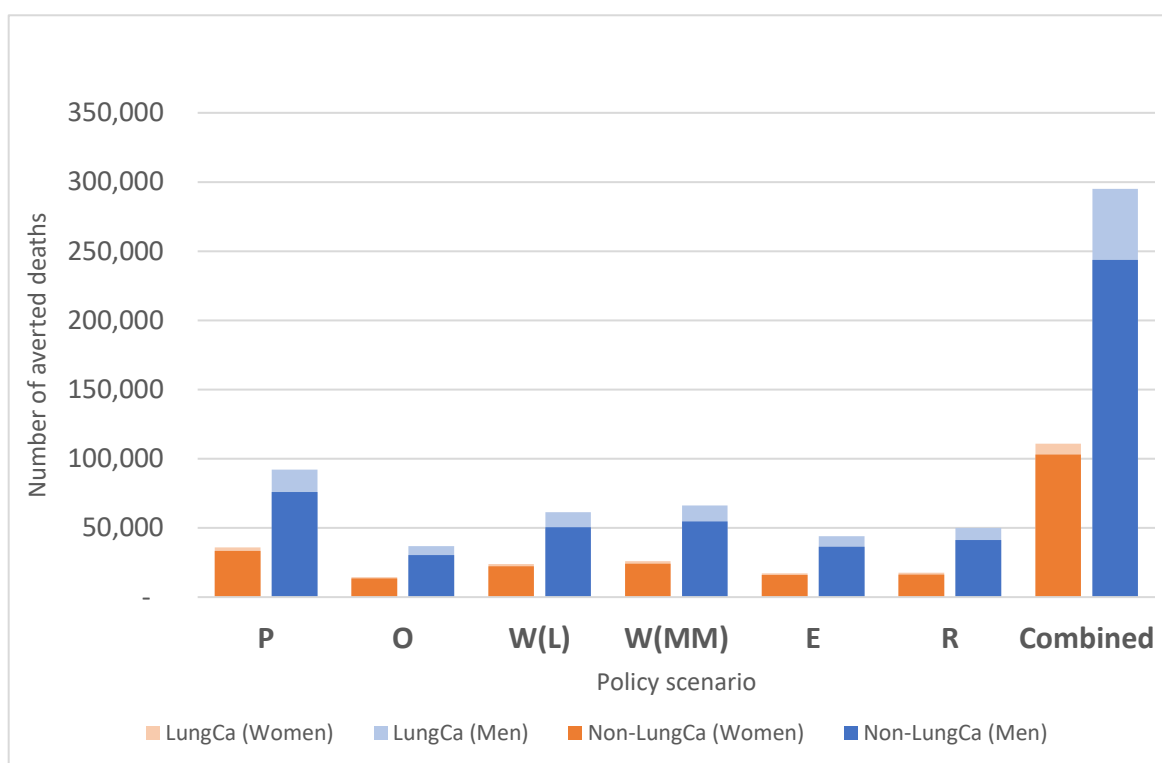


Figure 7: Averted all-cause and lung cancer deaths from different policy scenarios (2018–2100).

P, smoke-free law; O, offer cessation service; W(L), warning on label; W(MM), warning through mass media; E, advertising bans; R, raise tax; Combined, combined all policies; LungCa, lung cancer; Non-LungCa, non-lung cancer.

3.4. Effect of combined MPOWER policy

The effect of combined MPOWER policy is described in more detail because it is the largest among all policy interventions (Figure 7). Figure 8 shows that the same policy has different effects on men and women; the cumulative number of averted deaths is almost three times higher in men. In the male model, the policy will avert the first 100,000 deaths by 2045 (i.e., 25 years after implementing policy), 200,000 deaths by 2065, and almost 300,000 deaths by 2100; the female model only achieves the first 100,000 averted deaths in 2090 (i.e., 70 years after implementing policy). The policy averts more deaths in men and the time taken to achieve a certain number of averted deaths is also shorter in the male model.

When analyzing the number of averted deaths per year, the male and female models follow a

similar pattern, the difference is only the magnitude and the time taken for averted deaths to peak (Figure 9). The key driver of averted deaths in both sexes is the averted deaths that occurred in the 70+ years old age group. The averted deaths in the 70+ age group comprised 81.7% of total averted deaths in men; the proportion is higher in women, at 93.8%. The number of total averted deaths per year increases for a few decades before gradually decreasing. In men, it peaks at 5628 cases per year in 2043 (i.e., 23 years after implementing policy); in women, it peaks at 1962 cases per year in 2055 (i.e., 35 years after implementing policy). Compared to the 70+ age group, the younger age groups contribute relatively little to the number of averted deaths. The 20-29, 30-39, and 40-49 age groups among men contribute less than 100 averted deaths per year while all the below 70 years old age groups in women have less than 100 averted deaths per year (Figure 10).

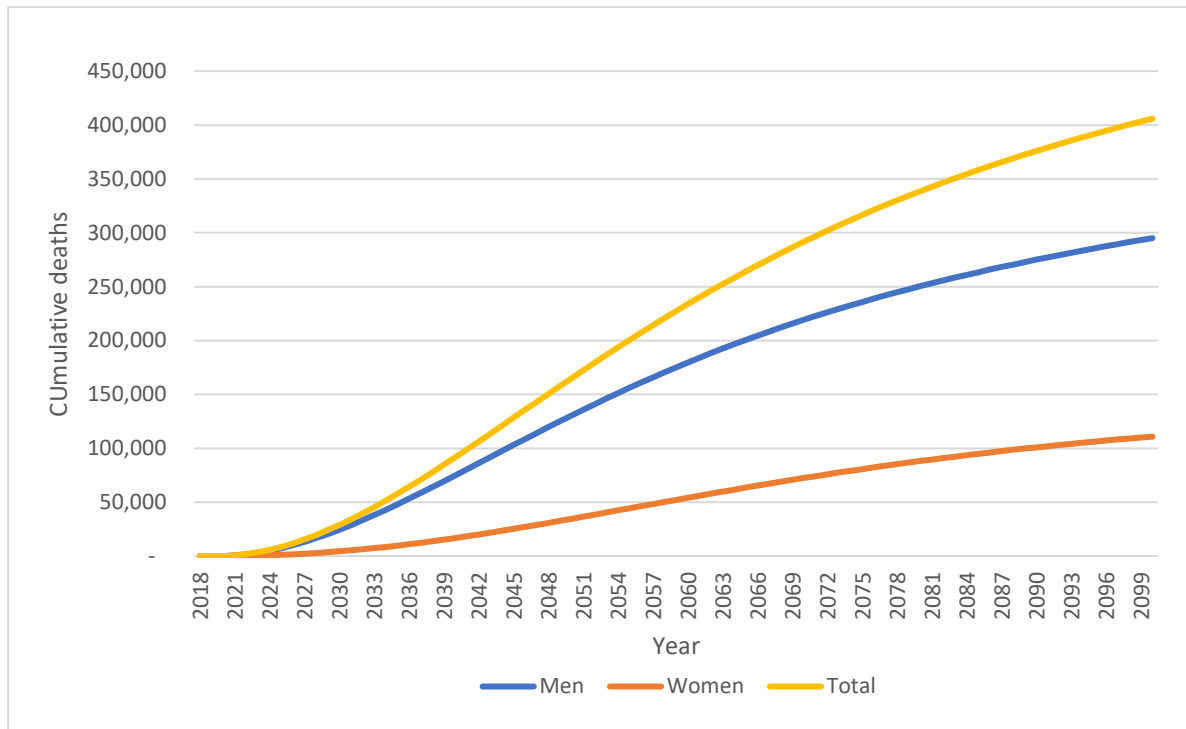


Figure 8: Cumulative deaths over 80 years under the combined MPOWER policy scenario (2018-2100).

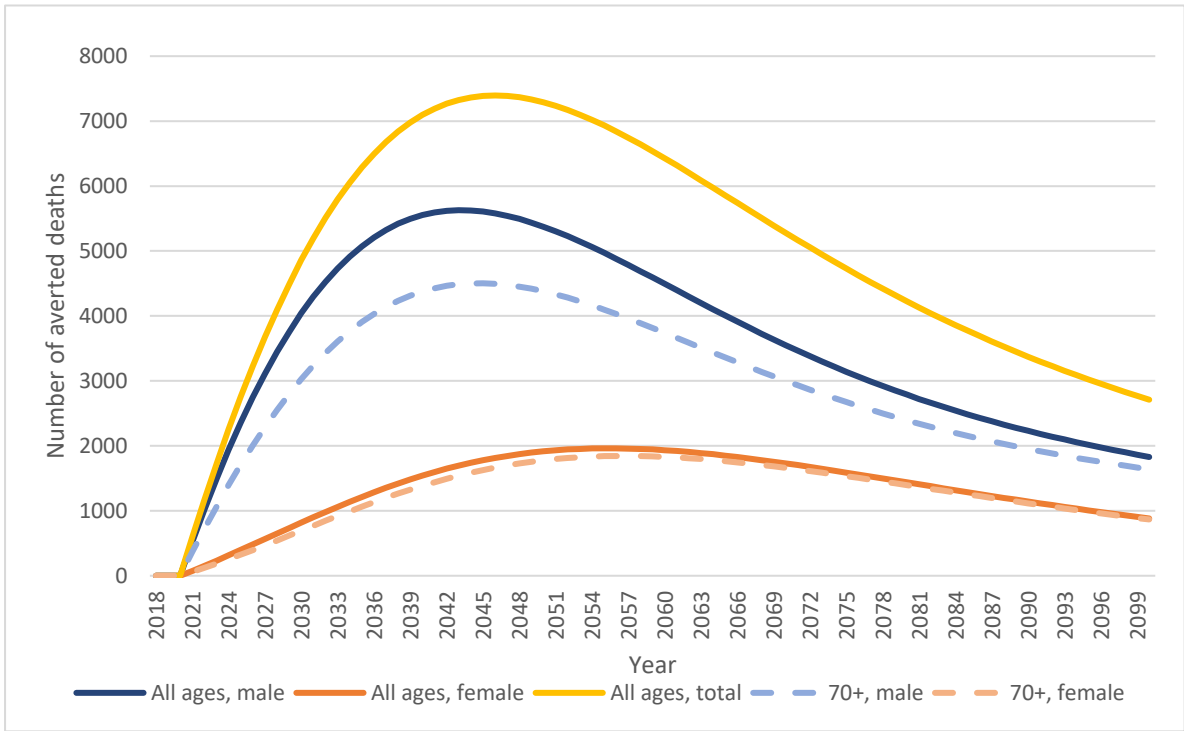


Figure 9: Total averted deaths and averted deaths from 70+ age group only.

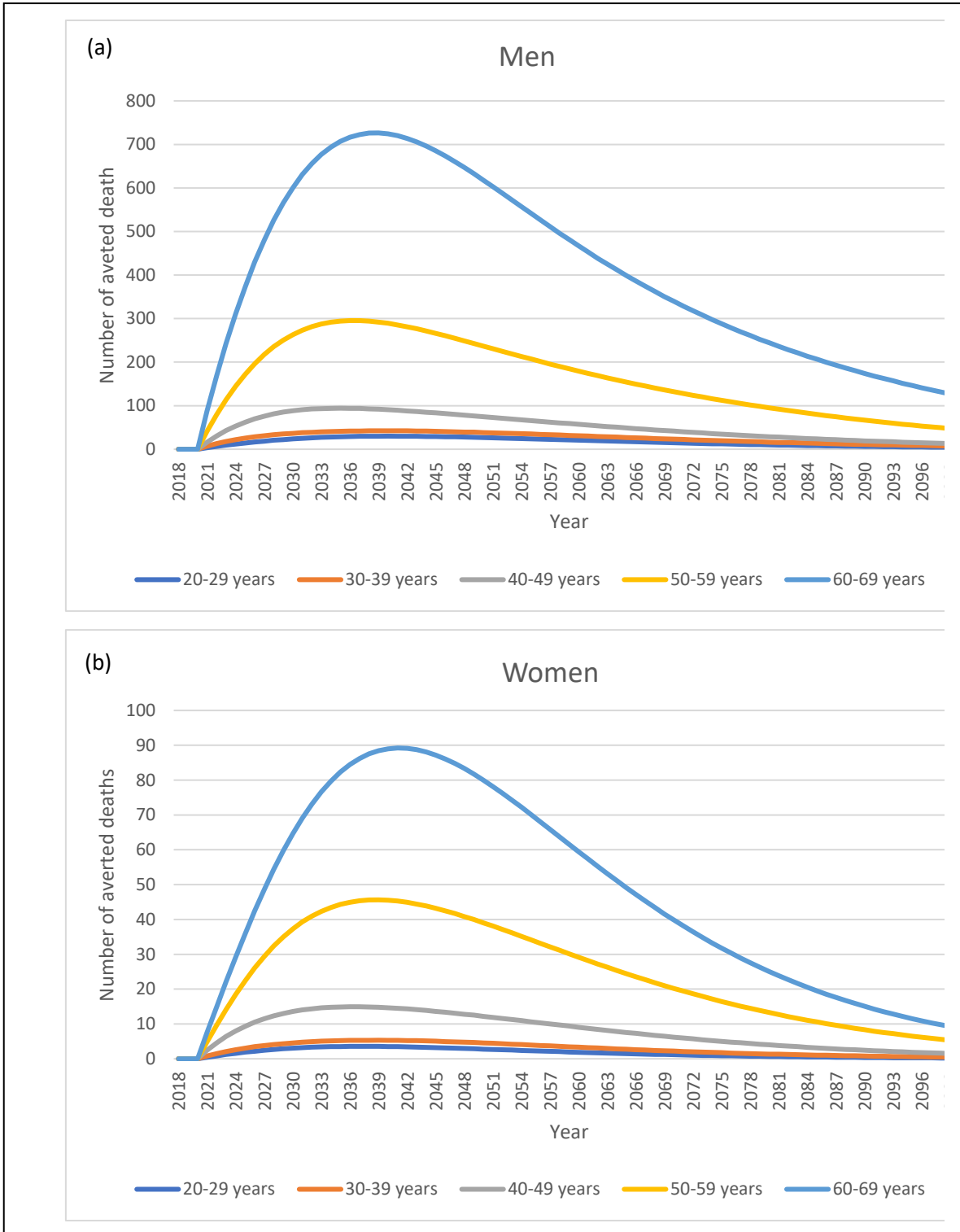


Figure 10: Averted deaths from age groups below 70 years old. (a) Men; (b) Women.

4. DISCUSSION

This study projected the smoking prevalence and mortality under the status quo tobacco control and complete MPOWER measure scenarios. The implementation of MPOWER measures will escalate the declining trend in smoking prevalence in Japan, pushing prevalence down to 0.7–2.0 % and 0.4–1.0% in men and women, respectively, in 2100. It is estimated that the combined MPOWER measures will avert 405,910 all-cause deaths by 2100, nearly 60,000 (14.6%) of which are attributable to lung cancer. Implementing combined MPOWER measures at the highest level is able to prevent 3-8 times more deaths than individual MPOWER policies. The majority of the averted deaths come from male current smokers aged more than 70 years old.

4.1. Smoking trends and behaviour

This study found a general downward trend in male and female smoking prevalence, although the trajectories differ by sex (Figure 4a and 5a). This is because the male and female populations have different age-specific cessation rates under the status quo, consistent with their different stages in the tobacco pandemic [50]. This difference in smoking uptake behaviour has resulted in female smoking prevalence rising slightly in older age groups over the medium term before dwindling to less than 2% as younger generations with lower smoking prevalence mature into older age groups. This lower smoking prevalence amongst women also means fewer deaths averted in women, with the majority of gains from all MPOWER measures being seen in men.

The prevalence of former smokers projected in this study is different from the historical NHNS data. In the NHNS data, the prevalence is stagnant despite the changes in current smokers' prevalence and ageing population. Also, former smokers are defined in the NHNS as those who smoked in the past but have not smoked in the most recent one month. In this study, the prevalence of former smokers rises in parallel with the decline in current smokers in the first few decades because those who ceased smoking enter the former smoker group until the end of life (Figure 2). The older age groups have the former smokers' prevalence peak at a later time (Figure 4b and 5b) as the model considers a population dynamic where people matured into older age groups and carried the former smoker status with them

to the next age group. After the peak, the prevalence of former smokers declines in parallel with the decline in current smokers because there are fewer smokers who can quit smoking to become former smokers in the younger generation, and the population is growing smaller.

4.2. Policy interventions

This study found that it will take 22–24 years to achieve 50% prevalence relative reduction from the baseline male prevalence with full implementation of individual MPOWER measures, and 17 years with the implementation of combined measures. However, even with the most optimistic scenario, Japan would still fall short of the 12% smoking prevalence (male and female combined) target by the end of fiscal year 2022, as stipulated in National Health Promotion Movement in the 21st Century (Healthy Japan 21 second term) [51]. According to my model, Japan will only achieve the 12% target in 2036 under the status quo or in 2031 if MPOWER measures are implemented concurrently at the highest level, which is a delay of one or one-and-a-half decades relative to the government’s goal.

The WHO Global Action Plan for the Prevention and Control of Non-communicable Disease 2013-2020 established a global target of 30% relative reduction in smoking prevalence by 2025 (using 2010 as baseline) [52]. In 2010, 32.2% of men and 8.4% of women smoked in Japan; a 30% relative reduction would mean a smoking prevalence of 22.6% and 5.9% in men and women, respectively, by 2025. However, this target is not attainable for Japan, under either the status quo or the combined MPOWER scenario (Figure 6). More efforts and commitments are needed to hasten the downward trajectory in smoking prevalence. That would mean implementing MPOWER measures with a high level of compliance, enforcement and urgency, and developing more extensive anti-tobacco policy beyond the scopes of MPOWER.

The progress of implementing MPOWER measures in Japan has been slow. From 2008 to 2018, only one MPOWER component (i.e., W-warning through mass media campaign) has improved status from “no policy” to “minimal policy” [2,53,54]. In 2020, the smoke-free policy (P) improved from “no policy” to “minimal policy” when a provision banned smoking at healthcare, education, university and government facilities. However, the Health Promotion Act also makes exemptions for smoking in

designated smoking areas and eateries smaller than 100sqm. The viability of half-hearted MPOWER policies in reducing the smoking prevalence is questionable. Furthermore, half-hearted partial smoke-free bans continue to expose never smokers to secondhand smoke [55] and continue to allow peer-influence on smoking initiation [56].

Policy to reduce smoking initiation, especially among younger generations, plays a crucial role in reducing population smoking prevalence in the long run. As observed from my model, the declining smoking prevalence in the younger age group in the beginning years will eventually reduce the prevalence of current and former smokers in older age groups when they mature into a later phase. Fewer former smokers also mean fewer people with high risk of smoking-attributable mortality, therefore preventing more deaths from tobacco-related diseases. Therefore, escalating measures that help reducing smoking initiation, such as (1) introducing a complete smoke-free air law in all public places with *no exemption clauses*, (2) large-scale mass media campaign with *all* appropriate characteristics to raise awareness about the dangers of tobacco smoking and de-normalize smoking habits, and (3) making tobacco products unaffordable and unappealing for the younger generation, are essential.

Smoking cessation policies are essential too, as shown in this study, where prevalence decline is sensitive to the cessation rate. Although Japan has achieved a moderate policy rating for the “offering cessation services (O)” measure of MPOWER on paper, there are limitations in practice. Despite the wide availability of treatments like nicotine replacement therapy, varenicline, and behavioral modification therapy, still, unassisted attempts are the most common method used to quit smoking, and unassisted attempts often end in failure [33]. Although it is easier for a light smoker to quit smoking, ironically, the cost-covered cessation service is only eligible for heavy smokers [33]. Therefore, not only should we make cessation service and support available, more importantly it should be made more accessible and directly target smokers who have the intention to quit to improve the cessation rate. A study showed that if brief intervention was offered to 75% of smokers by health care providers during health checkups, it would increase the cessation rate by 34% [57]. This will change the prevalence projection quite drastically by improving the effect size of the O measure, and enhance the government’s commitment to helping current smokers reduce their mortality risk regardless of the severity of their

exposure.

4.3. Averted deaths

Implementing combined MPOWER measures can potentially avert 405,910 deaths (295,048 in men and 110,862 in women) over 80 years. Of these, 59,349 (14.6%) are attributable to lung cancer deaths (51,441 in men and 7,908 in women). The mortality gain from enhanced MPOWER measures translates to tremendous health gains for the nation and less healthcare expenditure for tobacco-related diseases.

To date, no study projects the long-term mortality gain of tobacco control policies in Japan, but medium-term results can be compared with other published studies. In the most optimistic combined MPOWER model, from 2020-2040, the male prevalence drops from 28% to 12%, and the cumulative number of male averted deaths is about 75,000 deaths. The number of averted deaths is smaller than Katanoda *et al.*, who estimated a 15-percentage point reduction in prevalence in 20 years would avert 176,000 deaths [43]. This discrepancy is likely due to methodological differences and differences in estimated starting prevalence. It also shows that when smoking cessation is applied to an already declining prevalence trend the medium-term achievements are much smaller.

In the best case scenario, the number of averted deaths peaks at about 5600 cases per year in men and 2000 cases per year in women, which is low compare to 127,000 and 23,000 smoking-attributable deaths from men and women in 2016 (calculated using the population-attributable fraction of mortality associated with smoking [16]). This calls for stricter measures that are beyond the MPOWER package, as per article 2 in WHO FCTC, which states “Parties are encouraged to implement measures beyond those required by this convention and its protocols”. For instance, Australia was applauded by the global health community for its introduction of a tobacco plain packaging law. Japan’s tepid response in implementing full MPOWER policies must be improved by first removing tobacco industry influence from all policy-making as per article 5.3 in the WHO FCTC. Policymakers should place public health above political and economic interests to better legislate anti-tobacco policy, or meeting the WHO tobacco elimination target will remain an unattainable dream.

Although the driver of the number of averted deaths in this study was mainly from current smokers above 70 years old, the preventable deaths among men aged less than 70 years old are not negligible. With many delaying retirement age, most are still in their productive working years, financially independent and vital for the labour market and the national economy [58]. So, MPOWER measures are effective, if not more important, in preventing this group from dying at their most productive years and reducing years lived with disability because patients usually suffer years of morbidity before death.

The present study shows that full implementation of MPOWER measures can avoid nearly 60,000 lung cancer deaths by 2100, which is about 15% of total averted deaths. Although recent advances in lung cancer treatment have improved the survival rate, the disease remains highly fatal if diagnosed at stage III and IV, causing tremendous health and financial burden for individuals, families and the country. The implementation of MPOWER measures can reduce this disease burden.

There are more averted deaths in the male than the female population. This is because the smoking prevalence and current smoker relative risk for all-cause mortality are higher in men than in women. Therefore, to increase the number of averted deaths, effective cessation interventions should be targeted at men. Because there is a huge gap between men and women's prevalence, combining analysis for both sexes will underestimate the problem for men and overestimate the problem for women.

4.4. Strengths and limitations

Many public health experts have criticized the inadequate anti-tobacco policies in Japan and advocated the importance and urgency of implementing the stricter tobacco control measures of the MPOWER package [12,39]. This is the first study to assess the potential impact of the full MPOWER package in Japan by forecasting smoking prevalence and tobacco-related avoidable deaths. The strengths include assessing, separately and in combination, the effects of various tobacco control policies as benchmarked against MPOWER strategies and calibrated to Japan's status quo policies. This analysis allows comparison of benefits between policies and managed expectation on time needed to attain tobacco control target.

Unlike many studies which forecast for 10–20 years, this study ran the simulation model up to 80

years. The strengths of long-term projection include, (1) it takes into account the long term population dynamics and ensures the effect of MPOWER measures to be fully represented in this population; (2) it accounts for the hazards of tobacco smoking, which usually appear only after years of exposure and ensures the full benefits of prevention activity are recorded; and (3) It models the drop in smoking initiation rate as a consequence of past declines in smoking prevalence in older age groups.

The third strength is the estimation of lung cancer mortality gain from all-cause averted deaths. About 29% of tobacco-related deaths in men (18% in women) are attributable to lung cancer[16], and this estimation offers insight into the impact of MPOWER on lung cancer mortality burden. In fact, the mortality of other smoking-related diseases can also be estimated in similar ways.

Lastly, the datasets used in this study were sourced from government-funded, nationally representative cross-sectional surveys and large-scale cohort studies conducted among the Japanese population. The data, stratified by sex and age, allowed us to study the impact of tobacco control policies on these specific subgroups with more accuracy.

There are a few limitations in this study. First, this study focused only on conventional cigarettes, despite the growing popularity of newer tobacco products such as electronic nicotine delivery system and heated tobacco products. However, there are limited data on long-term mortality risk of newer tobacco products, therefore not suitable to use as parameter in this model. Second, this study did not simulate the impact of MPOWER measures on never smokers through the effects of secondhand smoke. Assuming the prevalence of exposure to SHS declines with the reduced smoking prevalence, the number of averted deaths is expected to be even greater than my estimates. Third, this model did not incorporate the lag time between smoking cessation and mortality risk reduction, and so may have underestimate the averted deaths from former smokers. Although not adjusted for quitting years, the mortality relative risk used in this study was derived from a meta-analysis that pooled the mortality risks from nine nationally representative cohort studies that have adjusted for other risk factors. Fourth, this model did not stratify the smokers according to smoking intensity and duration due to the limited data and risk of introducing unreliable parameters that will increase model instability. Fifth, the effect size of MPOWER measures was assumed to be homogenous across age groups (except for tax) and sexes when it might not be in practice. However, the intervention effect is often evaluated in population

study as a whole and therefore adopted as such in this study. Lastly, the effect of MPOWER intervention was not considered in the projection of mortality rate and future population (section 2.3 and 2.4) at the beginning of the study. This was because the dataset of population projection was a prerequisite for the simulation of MPOWER scenarios.

4.5. Conclusion

This study provides a better understanding of the effect of MPOWER measures on tobacco control in Japan, and shows that these measures are effective in saving thousands of lives. There is no lack of criticism of the government's shortcomings in addressing the tobacco epidemic in Japan, and scientists have long advocated strengthening the implementation of MPOWER as a pressing matter. This study has shown in detail the likely huge impact of the policies that Japan's public health community has long advocated. If the government of Japan can properly implement MPOWER measures it will save hundreds of thousands of lives over the next century, and set the stage for legislation of tobacco control laws that are beyond the MPOWER measures to achieve a tobacco-free society in Japan. If the recommendations of my study are followed, we can realize our commitment to greater public health and begin the final steps to eliminate tobacco use, the second biggest risk factor for global ill-health, from Japanese society.

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