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Projecting the impact of implementation of WHO MPOWER measures on smoking prevalence and mortality in Japan

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ABSTRACT

Objective This study aimed to quantify the long-term impact of implementing the WHO Framework Convention on Tobacco Control (FCTC) compliant tobacco control measures, MPOWER, on smoking prevalence and mortality in men and women aged ≥20 years in Japan.

Design A Stock-and-Flow simulation model was used to project smoking prevalence and mortality from 2018 to 2050 under eight different scenarios: (1) maintaining the 2018 status quo, (2) implementation of smoke-free policies, (3) tobacco use cessation programmes, (4–5) health warning about the dangers of tobacco (labels, mass media), (6) enforcement of tobacco advertising bans or (7) tobacco taxation at the highest recommended level and (8) all these interventions combined.

Results Under the status quo, the smoking prevalence in Japan will decrease from 29.6% to 15.5% in men and 8.3% to 4.7% in women by 2050. Full implementation of MPOWER will accelerate this trend, dropping the prevalence to 10.6% in men and 3.2% in women, and save nearly a quarter million deaths by 2050. This reduction implies that Japan will only attain the current national target of 12% overall smoking prevalence in 2033, 8 years earlier than it would with the status quo (in 2041), a significant delay from the national government's 2022 deadline.

Conclusions To bring forward the elimination of tobacco smoking and substantially reduce smoking-related deaths, the government of Japan should fulfil its commitment to the FCTC and adopt stringent tobacco control measures delineated by MPOWER and beyond.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Japan's tobacco control has been insufficient despite its ratification of the WHO Framework Convention of Tobacco Control (FCTC), and the prevalence of smoking remains high particularly among men. While quantitative measures of the potential impact of implementing FCTC-compliant tobacco control policies are useful for guiding policy change, such information for Japan is currently scarce.

WHAT THIS STUDY ADDS

⇒ This study suggests that full implementation of tobacco control measures as recommended by MPOWER will accelerate the reduction of smoking prevalence and save nearly a quarter of a million deaths by 2050 in Japan; however, even with full implementation, delay is expected in attaining Japan's current national target of 12% overall smoking prevalence.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The government should adopt stringent measures recommended by MPOWER and beyond to bring forward the elimination of tobacco smoking and substantially reduce smoking-related deaths.

BACKGROUND

Tobacco use is the largest preventable cause of premature death and disability globally. A global public health treaty aimed to address the tobacco smoking epidemic, the WHO Framework Convention on Tobacco Control (FCTC) entered into force in 2005[1] and has been ratified by 182 countries.[2] Since the treaty became effective, an increasing number of countries have implemented evidence-based tobacco control measures conforming to the WHO FCTC (MPOWER): Monitoring tobacco use and prevention policies (M); Protecting people from tobacco smoke (P); Offering help to quit tobacco use (O); Warning about the dangers of tobacco (health warning labels (W-L) and mass media (W-MM)); Enforcing bans on tobacco advertising, promotion and sponsorship (E) and Raising taxes on tobacco (R).[3] Countries that successfully implemented some of these measures at the highest recommended level experienced substantial reduction of tobacco smoking and tobacco-attributable deaths.[4 5]

Japan ratified the WHO FCTC in June 2004. However, implementation has been fragmented and tobacco control remains suboptimal relative to the FCTC standard, with Japan receiving poor (no or minimal policy) ratings in the P, W and E domains in 2018.[3] The 2020 Tokyo Olympic and Paralympic Games created social pressure and political will, and the tobacco control movement has been somewhat enhanced through the adoption of additional policies such as raising tobacco taxes and implementing stricter smoke-free regulations. However, despite these new measures connected to the Games and this renewed social and political focus on denormalisation of tobacco smoking, progress on tobacco control policy in Japan has been slow compared with other countries.[3]

Japan's slow tobacco control progress is reflected in the high smoking prevalence among men at

27% in 2019,[6] which was higher than other high-income countries. Tobacco smoking has been the top risk factor for non-communicable disease (NCD) mortality in Japanese adults,[7] contributing to an estimated 19.1%–24.6% of total deaths in men and 3.6%–6% in women.[8 9] The WHO Global Action Plan for the Prevention and Control of NCDs 2013–2020 established a global target of 30% relative reduction in smoking prevalence by 2025, using 2010 as baseline.[10] Domestically, Japan has a target to achieve 12% smoking prevalence by 2022.[11] However, it is doubtful if Japan can meet either of the targets with its presently suboptimal tobacco control measures.

To catalyse a dialogue about the need for more comprehensive tobacco control measures in Japan, this study aims to estimate:

- smoking prevalence over the next three decades under the status quo scenario and seven enhanced MPOWER implementation scenarios;
- when the international and national targets of smoking prevalence will be met in each scenario and
- the number of lives saved by enhanced MPOWER implementation.

METHODS

Data sources and preparation

Age-specific and sex-specific populations in Japan were projected from 2010 to 2050 using published values for all-cause total mortality rate estimates, birth rates and infant sex ratios from the Japanese Vital statistics[12] and National Institute of Population and Social Security Research.[13] Age-specific and sex-specific smoking prevalence was obtained from the National Health and Nutrition Survey (2010–2018).[6] Mortality rates by smoking status were apportioned and projected forward using estimates of the relative risks of all-cause death derived from a pooled analysis of nine nationally representative Japanese cohort studies; the relative risks for current and former smokers used in this study were 1.60 and 1.24 for men, and 1.48 and 1.24 for women, respectively.[14] Further details of data sources (online supplemental table 1) and preparation methods are described in online supplemental file sections 1 and 2.

Simulation scenarios

Stock-and-Flow System Dynamics models[15] were used to project the number of smokers, smoking prevalence and mortality from current, former and never smokers from 2018 (baseline) to 2050 for men and women aged 20 years or older under the status quo and seven intervention scenarios. The status-quo scenario was based on the status of tobacco control in Japan in 2018 (table 1).[3] A total of six intervention scenarios were hypothesised on implementing each intervention at the highest recommended level. The P, O, W-L, W-MM, E and R measures were selected for the present analysis because they have yet to be implemented at the highest level in Japan.[3] The last intervention scenario is hypothesised on implementing all MPOWER measures at the highest level simultaneously.

Simulation models

The simulation was run in each age- (20–29, 30–39, …, 70+ years) and sex-specific group. 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 2018 population by the 2018 smoking prevalence. Then, cessation rates and former and current smokers' all-cause mortality rates were applied to determine the number of smokers who became former smokers and the number of deaths by smoking status. The present study defines the cessation rate as the net value after considering smoking cessation and initiation. To obtain the cessation rate for the status quo model, current smoker prevalence data was used to fit a linear regression model

Table 1 Intervention scenarios and the respective effect sizes

MPOWER measures	MPOWER status in Japan in 2018*—status quo	Intervention scenario†	Effect size‡
Smoke-free environments (P)	Minimal policy—3–5 public places completely smoke-free	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%
Cessation programmes (O)	Moderate policy—nicotine replacement therapy and/or some cessation services (at least one which is cost-covered)	Have a complete cessation policy that includes a national quit line, and both nicotine replacement therapy and some cessation services cost-covered.	−5%
Health warning (W-L)	Minimal policy—medium size health warning, missing some or many appropriate characteristics¶	Cigarette package to display large health warning that covers >50% and contains all characteristics**	−8.33%
Mass media (W-MM)	Minimal policy—national campaign conducted with 1 to 4 appropriate characteristics¶	Have a national campaign with at least seven appropriate characteristics**	−9%
Advertising bans (E)	No policy—complete absence of ban	Ban all tobacco advertising, promotion and sponsorship	−6%
Taxation (R)	Moderate policy—tobacco tax comprises 50%–75% of the retail price	Increase the tax component of retail price from 63.1% to 75%	Effect by age group: 20–29: −15% 30–39: −10% >40: −5%

*Japan's MPOWER status in 2018, as reported in the WHO Report on the Global Tobacco Epidemic 2019. MPOWER implementation is rated in five levels: no data; no policy; minimal policy; moderate policy; complete policy.[3]
†Intervention scenario is hypothesised on MPOWER measures implemented at complete policy.
‡Effect size is relative to Japan's MPOWER status in 2018. All effect sizes except for R measure were adapted from Levy *et al*.[16] The effect of the R measure was calculated based on effects on price elasticity and was adapted from the Korean SimSmoke model.[17] Further details on the derivation of the effect size are provided in online supplemental file section 2.5 - 2.7.
§WHO FCTC defines "complete" smoke-free environment as smoking is not permitted. Exemptions such as ventilation system and designated smoking areas (DSA) should not be accommodated.
¶According to the WHO Report on Global Tobacco Epidemic 2021, the policy rating for W-L has changed to moderate policy because the area of warning labels has increased from 30% to 50%, while the policy rating for W-MM has changed to complete policy. Our simulation used 2018 policy rating as the status quo scenario.
**Characteristics of cigarette package label and national campaigns are as recommended by MPOWER guideline.

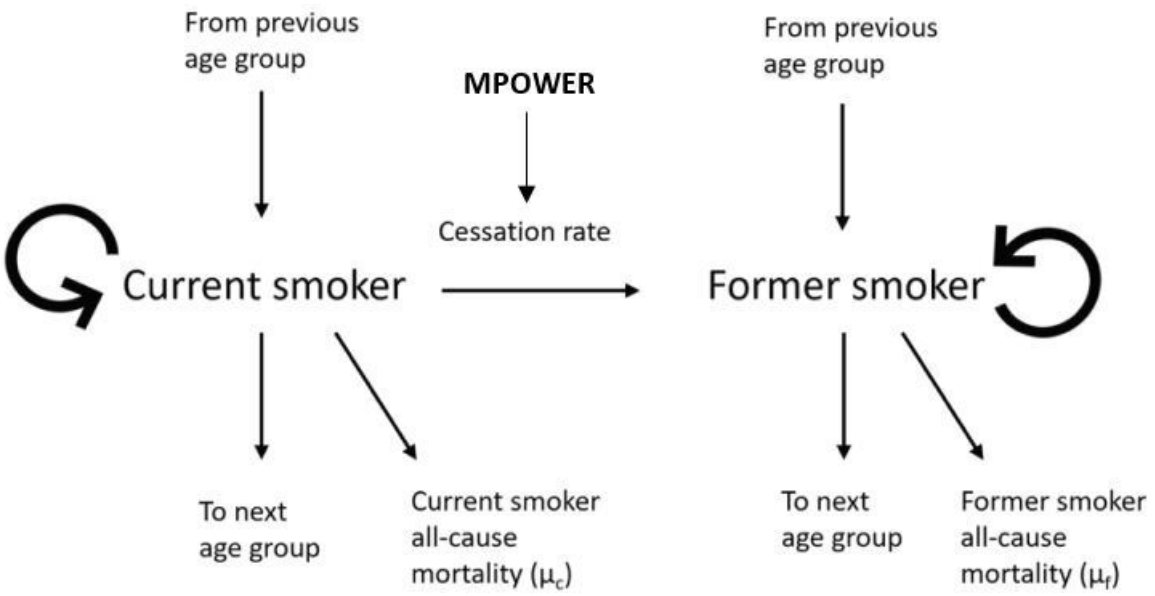

Figure 1 Diagram of the Stock-and-Flow simulation model. A diagram illustrating the simulation model used to assess the impact of MPOWER tobacco control measures on smoking prevalence and mortality.

on the log of prevalence (online supplemental figure S1). The estimated annual trend in each age group was used as the age-specific cessation rate (online supplemental table S2) and applied throughout all years in the status quo model (2018–2050) and for 2 years in the intervention model (2018–2019).

The cessation rates for all intervention scenarios were converted from intervention-specific effect sizes adapted from Levy *et al*,[16] defined as the long-run (40-year horizon) relative reduction in smoking prevalence of full implementation relative to zero/minimal implementation. The effect sizes used in our study reflect the magnitude of the effect expected from implementation of the highest recommended policy level relative to Japan's MPOWER policy level in 2018, converted to annual cessation rates (table 1) (see online supplemental file 2.5 - 2.7). The effect size was assumed to be equal across all age groups and sexes, except for the R measure, which was larger among younger age groups who are more cigarette price-sensitive than their older counterparts.[17 18] The derived cessation rates (online supplemental table S2) were applied as constant from 2020 onwards in each intervention scenario.

Having calculated changes in the distribution of current, former and never smokers due to cessation and mortality, the population matured by 1 year, and 10% of the remaining population in each 10-year age group was shifted to the next age group. We considered smoking prevalence for those aged 20 years and above and assumed that the new cohort of 20 year-olds entered the population with a smoking prevalence that matches the current profile of 20–29 year-olds. At the end of each full year-cycle, the numbers of current, former and never smokers were converted to prevalence, and the respective number of deaths was totalled (figure 1). Equations for all simulation steps are provided in online supplemental file section 2.

National and international smoking prevalence targets

The Ministry of Health, Labour and Welfare established a national target of 12% overall prevalence of smoking by 2022.[11 19] The WHO Global Action Plan for the Prevention and Control of NCDs 2013–2020 established a global target of 30% relative reduction in smoking prevalence by 2025 using 2010 as baseline,[10] which means reduction of smoking prevalence from 32.2% to 22.6% in men and 8.4% to 5.9% in women in Japan.

Averted deaths

The number of averted deaths was calculated as the difference between the number of deaths in the status quo and intervention scenarios, including deaths from current, former and never smokers. A positive value for averted deaths indicates fewer deaths in the intervention scenario than the status quo scenario.

Sensitivity analyses

We performed two sensitivity analyses. Sensitivity analysis 1 assumed that intervention policies' effects start to wane after 10 years. The cessation rates from 2018 to 2030 were applied as constant, and from 2030 onwards, the cessation rates were set to reduce by 3% annually. In sensitivity analysis 2, long-term effects were realised in 10 or 20 years instead of 40 years.

RESULTS

Smoking prevalence under the status quo scenario and MPOWER policy scenarios

Under the status quo scenario, the smoking prevalence is projected to steadily fall from 29.6% to 15.5% for men and from 8.3% to 4.7% for women between 2018 and 2050 (figure 2, online supplemental figure S2). In both sexes, a greater downward trend in prevalence of current smokers was observed in younger age groups than in older age groups. A slight increase in smoking prevalence before a steady downward trend was observed in older age groups, most prominently in the 70+ age group and in women. In the individual policy scenarios, smoking prevalence reduced to 14.0%–14.9% in men and 4.2%–4.5% in women by 2050 (figure 3); smoke-free policies enforced at the highest level (P) achieved the biggest prevalence drop, followed by W-MM, W-L, E, R and O. The reduction in smoking prevalence is greater and faster when all MPOWER measures were implemented simultaneously at the highest level, reducing the smoking prevalence to 10.6% in men and 3.2% in women by 2050 (figure 3).

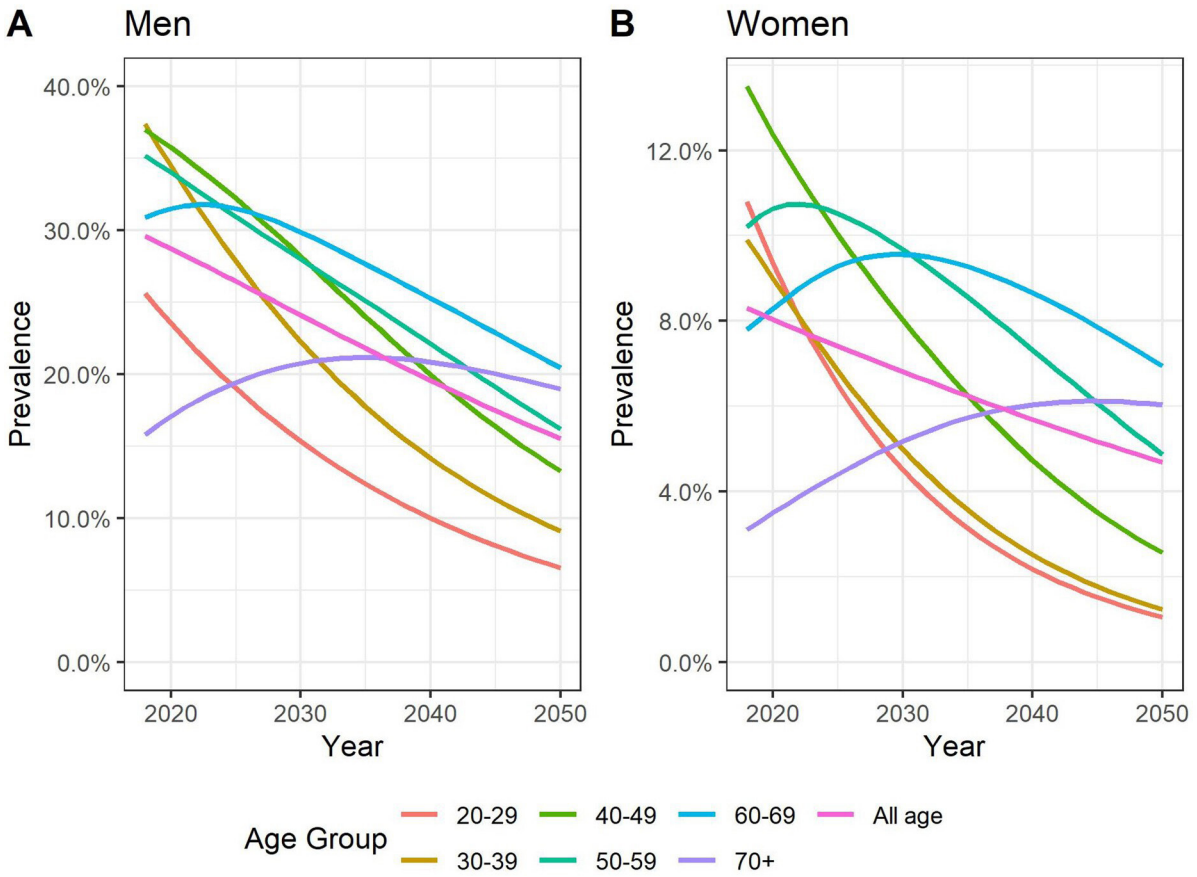

Figure 2 Projected sex-specific and age-specific prevalence of current smokers from 2018 to 2050 under the status quo scenario. Each plotted line indicates the projected age-specific prevalence (%) of current smokers in (A) men and (B) women from 2018 to 2050.

Expected time to attain the targets of smoking prevalence

Under the status quo, Japan will achieve the international target of 30% relative reduction in smoking prevalence in men by 2034 and in women by 2038, and the 12% national target of overall smoking prevalence by 2041 (figure 3, online supplemental table S3). With full MPOWER implementation, Japan will achieve the male and female international smoking prevalence targets by 2028 and 2031 respectively, and the national overall smoking prevalence target by 2033. Although MPOWER interventions will shorten the time to meet targets, Japan still falls short of the stipulated timeframe (international: 2025, national: 2022). In the analysis where cessation rates were set to reduce by 3% annually from 2030 (Sensitivity analysis 1), expected time to attain the targets remained the same. In Sensitivity analysis 2, where the long-term effects are assumed to be realised in 10 or 20 years, the international target would be achieved in time only in the 10-year horizon model, and the national target would be achieved 7 or 3 years earlier than the main model, respectively (online supplemental figure S3, online supplemental table S3).

Number of deaths averted from each MPOWER policy scenario

Table 2 shows the cumulative number of deaths averted from each intervention scenario at years 2030 and 2050. By 2050, scaling up P can prevent 71 332 deaths (59 001 men and 12 331 women), and scaling up O can prevent 27 982 deaths (23 143 men and 4840 women). If all MPOWER measures were to be implemented at the highest level simultaneously, a total of 237 299 deaths (196 455 men and 40 844 women) would be averted by 2050, which is three to eight times more deaths averted than any individual MPOWER policy. In the sensitivity analyses, the corresponding numbers were 223 265 deaths (Sensitivity analysis 1), 694 585 deaths (Sensitivity analysis 2: 10 year horizon) and 425 087 deaths (Sensitivity analysis 2: 20 year horizon) (online supplemental table S4).

DISCUSSIONS

This study projected tobacco smoking prevalence and mortality in the Japanese population up to 2050 under status quo and hypothetical tobacco control scenarios. It showed that strengthening tobacco control in all MPOWER domains to the highest level can accelerate the decline in smoking prevalence in Japan, reducing prevalence to 10.6% in men and 3.2% in women by 2050, and avert a total of nearly a quarter million deaths over the next three decades. Japan will not be able to achieve international and national targets in time, but with MPOWER interventions at the highest recommended level, Japan will meet these targets 6–8 years sooner than with current tobacco control measures.

Of the six individual interventions, comprehensive smoke-free legislation (P) would have the greatest impact on smoking prevalence. As of 2018, P was rated as minimal.[3] In anticipation of the Tokyo 2020 Olympic and Paralympic Games, the 2020 revision of the Health Promotion Act introduced smoking bans for all eateries with penalties for facilities that violate the rule. However, this policy exempts nearly half of all eateries with seating areas not more than 100 m^2,[20 21] far from the FCTC Article 8 requirement of a complete smoking ban in all public

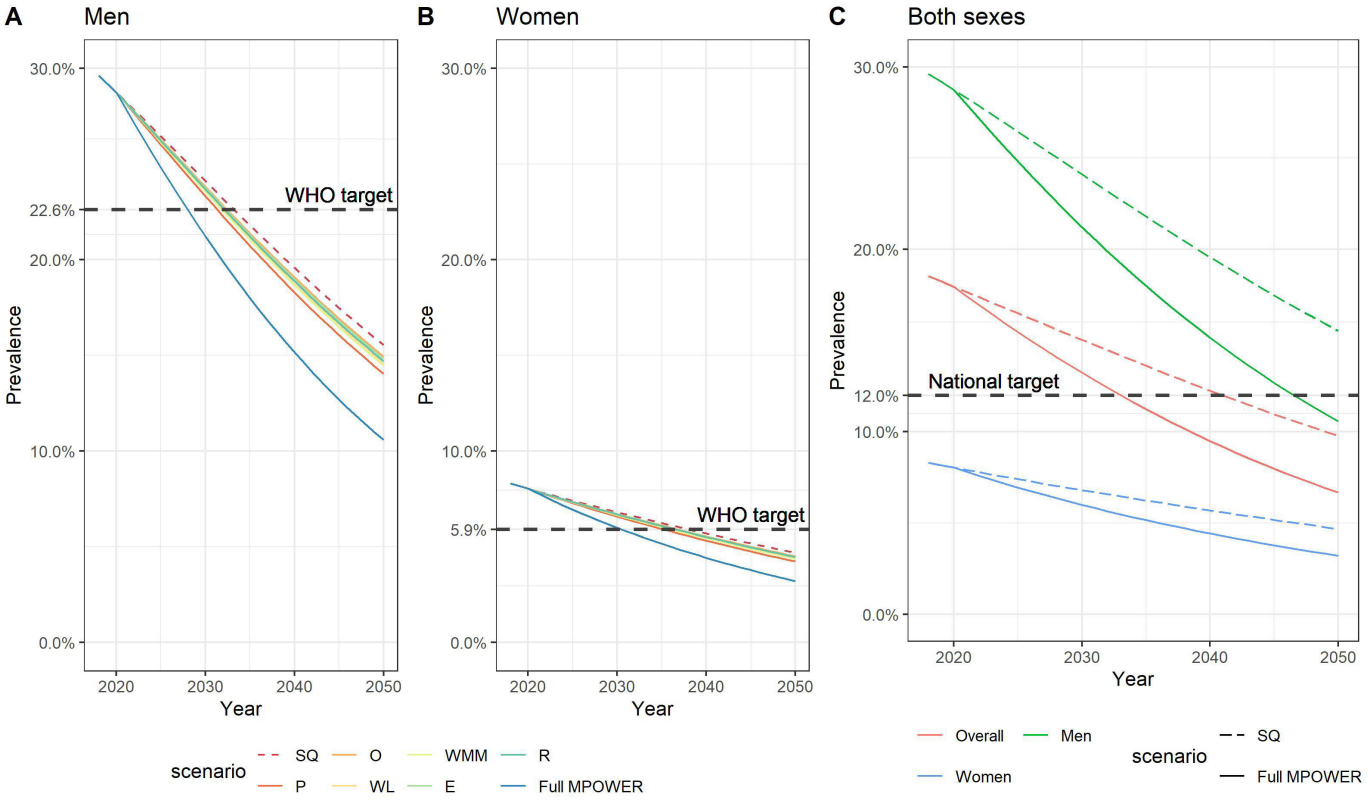

Figure 3 Projected smoking prevalence by MPOWER tobacco control policy scenario and (A, B) international and (C) national targets of smoking prevalence. WHO target is as stipulated in the WHO Global Action Plan for the Prevention and Control of Non-Communicable Disease 2013–2020, that is, to work towards 30% reduction in smoking prevalence by 2025, relative to the prevalence in 2010. In Japan, the smoking prevalence in 2010 was 32.2% in men and 8.4% in women. Therefore, the WHO target is defined here as 22.6% in men and 5.9% in women by 2025. National target is to achieve an overall smoking prevalence (combined both sexes) by 12% by 2022, as stipulated in National Health Promotional Movement in the 21st Century (Healthy Japan 21, the second term). E, Enforce bans on tobacco advertising, promotion and sponsorship; Full MPOWER, Simultaneous implementation of all MPOWER tobacco control measures at the highest recommended level; O, Offer help to quit tobacco use; P, Protect people from tobacco smoke; R, Raise taxes on tobacco; SQ, Status quo; WL, Warn about the dangers of tobacco (Labelling); WMM, Warn about the dangers of tobacco (Mass Media).

places,[22] leaving some risk of secondhand smoke exposure for customers and workers. Therefore, any exemption should be removed.[23]

Improving W-L and W-MM from the minimal level to the complete level can reduce smoking prevalence. Japanese cigarette packaging warnings are inconspicuous,[24] in contrast with countries like Australia. Although labelling surface area has improved from 30% to 50% in 2020, the impact is likely small compared with graphic warnings.[19] The WHO Report on the Global Tobacco Epidemic 2021[25] upgraded Japan's W-MM rating from minimal to highest level despite limited changes in practice. A nationwide antitobacco campaign is needed to denormalise smoking habits, curb smoking initiation and promote cessation.[19]

Our study found only a small effect of tobacco taxation on reducing smoking prevalence, compared with other MPOWER measures. Japan has already achieved a moderate level of implementation with 63.1% tobacco taxation in 2018,[3] but the price of the most commonly sold brand of cigarettes in international dollars as of 2018 was low at $4.45/pack in Japan, in contrast to countries like Sri Lanka ($22.17), Singapore ($16.87), New Zealand ($16.08) and Ireland ($14.95).[26] Although the sales price for a pack of 20 cigarettes increased by approximately 50 JPY in 2020, this price remains highly affordable,[27] especially for older age groups, and a 75% tax component is unlikely to deter smokers from tobacco use. Tobacco taxation beyond 75% and other tax and price-based measures should be considered.

Enforcement of bans on tobacco advertising, promotion and sponsorship (E) is also effective in reducing smoking prevalence, but Japan currently lacks such bans, and more than 40%

Table 2 Estimated number of sex-specific cumulative averted deaths from each intervention scenarios

	2018–2030			2018–2050		
Scenarios	Men	Women	Total	Men	Women	Total
P	8443	1378	9821	59 001	12 331	71 332
O	3268	533	3801	23 143	4840	27 982
W-L	5523	902	6424	38 886	8130	47 016
W-MM	5984	977	6961	42 088	8799	50 886
E	3938	643	4581	27 842	5822	33 664
R	3363	544	3907	24 607	5017	29 624
MPOWER	29 597	4826	34 423	196 455	40 844	237 299

Number of averted deaths was calculated as the difference between the number of deaths in the status quo and intervention scenarios.
E, Enforce bans on tobacco advertising, promotion and sponsorship; MPOWER, Simultaneous implementation of all MPOWER tobacco control measures at the highest 513 recommended level; O, Offer help to quit tobacco use; P, Protect people from tobacco smoke; R, Raise taxes on tobacco; W-L, Warn 510 about the dangers of tobacco (Labelling); W-MM, Warn about the dangers of tobacco (Mass Media).

of smokers and 66% of non-smokers continue to be exposed to cigarette advertising.[28] Furthermore, coverage of smoking cessation services (O) is suboptimal, with comprehensive cost-coverage only available for heavy smokers[29] and no national quitline. Many smokers resort to unassisted smoking cessation methods[30] which are unreliable.[31] Given that 26% of smokers (25% of men and 31% of women) in Japan expressed quit intentions,[6] cost-covered cessation services should be expanded to all smokers.

We found that implementation of comprehensive MPOWER measures is far more effective than a fragmented approach in reducing smoking prevalence, but still insufficient to attain national or international smoking prevalence reduction targets in time. Our model showed a relatively small number of averted deaths (1% of male deaths and 0.2% of female deaths), largely due to greater prevalence of former smokers (online supplemental figure S2) for whom the risk of mortality stays elevated for years, though to a lesser degree than for current smokers. Another reason could be the assumption of constant cessation under the status quo, which could have overestimated the reduction of smoking prevalence in this scenario. The conservative assumptions in our analysis likely yielded conservative estimates of the policy effects, yet even in the most optimistic scenario where intervention effects were realised in 10 years, the national target will not be achieved. These results point to the urgent need to shift all smokers to former smokers and deter non-smokers from initiating smoking by implementing full MPOWER measures and enhanced measures beyond MPOWER.

Although public health gains from an enhancement of tobacco control measures are evident, Japan faces many challenges to tobacco control implementation due to industry interference in policymaking; the pre-eminent political challenge is the Japanese government's 33% financial stake in Japan Tobacco.[32] Japan was rated the poorest in the Global Tobacco Industry Interference Index which measures efforts by governments to address tobacco industry interference.[33] Countries that shield against industry interference have succeeded in implementing strong tobacco control.[34 35] Enhanced action to bring forward the elimination of tobacco smoking in Japan will be easier to achieve if the government enacts strict regulations on tobacco industry's interference on health policies and conforms to WHO FCTC Article 5.3.[1]

To our knowledge, this is the first study to assess the potential impact of MPOWER tobacco control measures on smoking prevalence and mortality in Japan. Our results can facilitate public and political dialogue on strengthening the nation's tobacco control policies by illustrating the public health gains achievable from more comprehensive interventions. The strengths of our study 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 enables a comparison of benefits between policies and managed expectation on time needed to attain tobacco control targets. Another strength is that 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.[14]

Nevertheless, our results have some limitations. First, it did not take into account the potential impact of the growing popularity of heated tobacco products (HTPs).[36–38] HTP use in Japan increased especially among male smokers of younger ages, and smokers use HTPs with or without intention to quit smoking.[37] While use of HTPs can influence individual patterns of smoking,[39 40] the effect of HTP use on smoking cessation or prevalence remains inconclusive.[41] Continued efforts to better understand the impact of HTP use on smoking patterns and subsequent mortality risk should be encouraged and resulting evidence should be incorporated into future simulation studies. Second, our projection model did not incorporate variations in mortality risk according to time since smoking cessation, which may have underestimated the number of averted deaths in former smokers. Third, we did not simulate the impacts of MPOWER on never smokers. With about 15 000 deaths per year in Japan attributable to secondhand smoke exposure,[42] some averted deaths from never smokers can be expected with stricter smoke-free policies. Last, our projection did not include people aged under 20 years because the rapidly declining smoking rate among minors[43] could underestimate the smoking initiation rate of early adulthood.

CONCLUSION

Full implementation of MPOWER tobacco control measures can accelerate the reduction of tobacco smoking prevalence and is expected to save nearly a quarter of a million deaths by 2050. However, even with full implementation, Japan is unable to attain the national and international targets in time. To end the tobacco epidemic and its associated preventable mortality, an acceleration of progress with tobacco control is needed, for which the government should realise their commitment to greater public health and begin the final steps to eliminate tobacco use, the largest preventable risk factor for global premature death and disability, from Japanese society.

Contributors SLY and KT are co-first authors and contributed equally to the article. SG and SLY had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Conception and design: SG, KK, KT, SLY. Development of methodology: SG, KK, SLY. Acquisition of data and analysis: SLY. Interpretation: SG, KK, MEL, IS, KT, SLY. Initial writing of the manuscript: KT, SLY. Review and revision of the manuscript: SG, KK, MEL, IS, KT, SLY. Supervision: SG, KK. Guarantor: KK.

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Supplements

Contents

1. Summary of data used in this study 2
1.1. Preparation of mortality and population data 2
Table S1. Database and parameters used to prepare mortality and population data. 2
2. Supplementary on method 3
2.1. Mortality rate projection 3
2.2. Group-specific mortality rate projection 3
2.3. Population projection 4
2.4. Cessation rates for status quo model 4
Figure S1. Fitted graph of observed current smoker prevalence from the National Health and Nutrition Survey data and predicted prevalence from regression model. 5
2.5. Adaptation of effect size 6
2.6. Cessation rates for intervention scenarios 6
2.7. Cessation rate for combined MPOWER intervention model 7
Table S2. The cessation rates used in the status quo model, and individual and combined intervention model. 8
3. Supplementary results 9
3.1. Smoking prevalence under the status quo scenario 9
Figure S2. Sex- and age-specific prevalence of current and former smokers under the status quo scenario. 9
4. Sensitivity analysis 10
4.1. Results of sensitivity analysis: smoking prevalence and time to achieve target 10
Figure S3. Projected prevalence of current smokers from 2018 to 2050 under the status quo, main model and the sensitivity scenarios. 10
Table S3. Time to achieve the national and international targets. 10
4.2. Results of sensitivity analysis: number of averted deaths 11
Table S4. The number of sex-specific averted deaths from main model and sensitivity analysis scenarios. 11
5. Reference 12

This document describes the data used in the simulation method, supplement method and supplement result. In the supplement method section, we show in detail the method to obtain cessation rates for status quo model and the equations involved in converting the effect size of MPOWER measures into cessation rates used in individual and combined intervention scenario models.

1. Summary of data used in this study

1.1. Preparation of mortality and population data

Table S1. Database and parameters used to prepare mortality and population data.

Data	**Details**	**Reference**
Mortality data	Sex- and age-specific all-cause mortality data (1980-2016) from Japanese Vital Statistics.	[1]
Population data	Sex- and age-specific population data (1958-2018) from Japanese Vital Statistics.	[2]
Smoking prevalence data	National Health and Nutrition Survey (NHNS) (1995-2018) recorded the prevalence of current, former and never smokers in ten-year age groups (e.g., 20-29, 30-39, …, 60-69, 70+ years old)	[3]
Total fertility rate	1.44	[4]
Infant sex ratio	Male:Female=1:1.04	[4]
All-cause mortality relative risk (RR)	RR for current male smokers: 1.6 RR for former male smokers: 1.24 RR for current female smokers: 1.48 RR for former female smokers: 1.24	[5]

2. Supplementary on method

2.1. Mortality rate projection

A Poisson regression model was used to estimate the time trend in the all-cause mortality rate for the total population (μ_t). 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 2050. The group-specific mortality rate projection was obtained by apportioning the 2018 total mortality rates using the mortality relative risk of current and former smokers, and then projected forward using the regression coefficients of year variable of total mortality model.

2.2. Group-specific mortality rate projection

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 smokers (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

$$r_c = \frac{\mu_c}{\mu_n} \quad \Rightarrow \quad \mu_c = r_c \mu_n \quad (2)$$
$$r_f = \frac{\mu_f}{\mu_n} \quad \Rightarrow \quad \mu_f = r_f \mu_n \quad (3)$$

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

$$\mu_n = \frac{\mu_t}{r_c P_c + r_f P_f + P_n}$$

Where
t designates total population
c designates current smoker
f designates former smoker
n designates never smoker
μ = mortality rate
N = population count
r = 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.[5]
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 total mortality. The age-specific formula for total mortality can be decomposed into contributions from each of the smoking groups as follows:

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

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 $\gamma = \exp(\beta)$.

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.

2.3. Population projection

Using the 2010 population as base, the population was projected up to 2050 using parameters such as all-cause total mortality rate estimates, total fertility rate, and infant sex ratio. The base population and all-cause total mortality rate estimates were organized in 5-year age groups (0-4, 5-9, …, 75-79, 80+) for more accurate estimates. We 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. 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 and male-to-female infant ratio of 1:1.04 throughout the model. TFR of 1.44 is the medium fertility variant in the population projection conducted by National Institute of Population and Social Security Research, throughout this model [4].

2.4. Cessation rates for status quo model

To obtain the cessation rate for the status quo model, the 2010 to 2018 current smoker prevalence data from the National Health and Nutrition Survey (NHNS) was used to run a linear regression model on the log of prevalence. The basic linear regression model equation is:

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

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_{11} 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 the above equation. The estimated coefficient of the year variable ($\beta_1 + \beta_3$) is the estimated age-specific cessation rate.
The predicted prevalence using the estimated coefficients fits well with the original data (Figure S1). In male 60-69, female 60-69 and female 70+ age groups, the estimated coefficients were positive, indicating growth in the number of current smokers, but the values were small (0.005, 0.039 and 0.020) and so we set them to zero in our model, indicating no cessation or growth in number of smokers. The status quo cessation rate was applied throughout all years in the status quo model (2018-2050) and for two years in the intervention model (2018-2019).

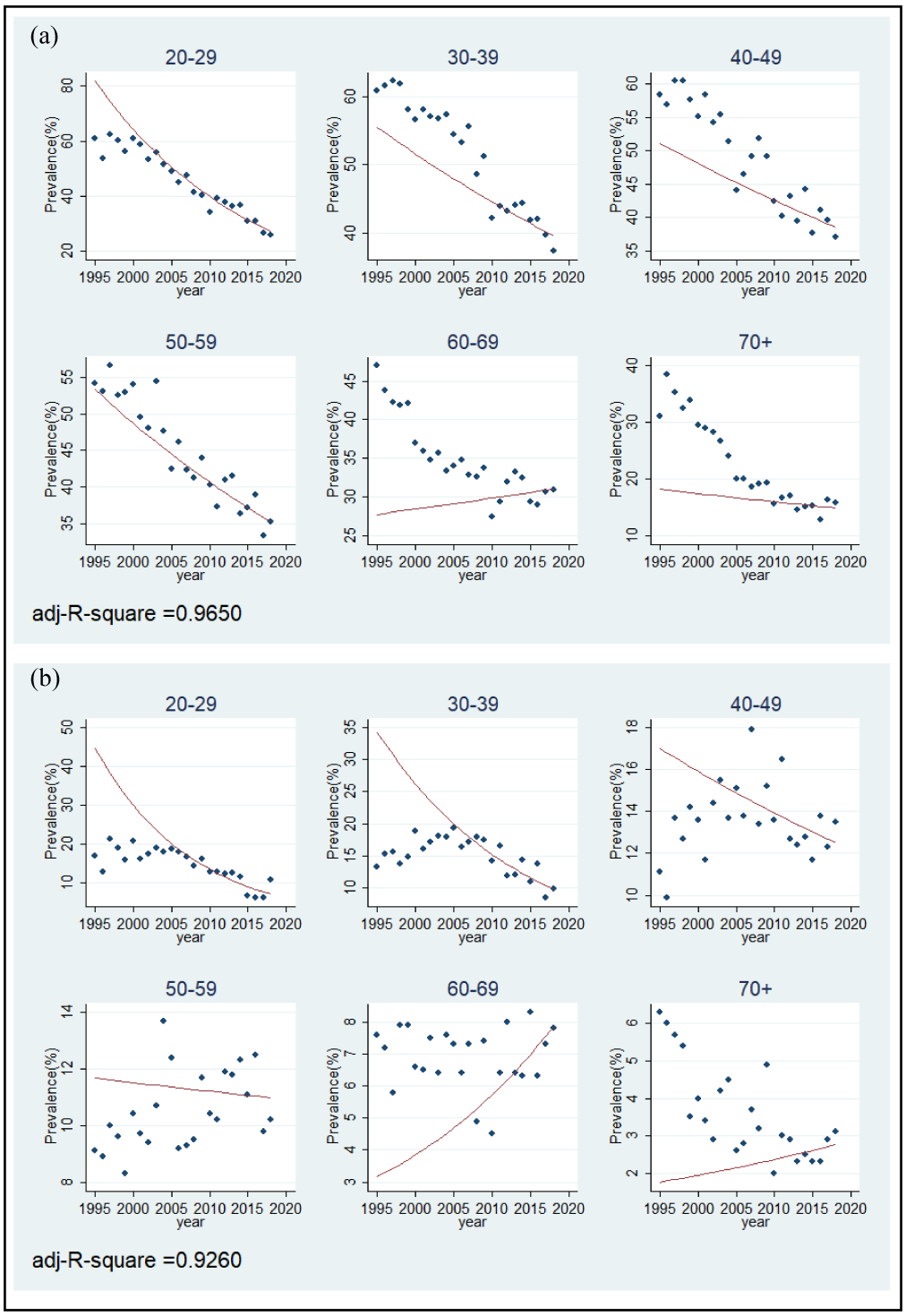

Figure S1. Fitted graph of observed current smoker prevalence from the National Health and Nutrition Survey data and predicted prevalence from regression model.

Red lines were fitted to the observed prevalence of current smokers from 2010 to 2018 for (a) men and (b) women.

2.5. Adaptation of effect size

We used the 40-years horizon effect size reported in Levy et al's table 1 [6] as the basis of our adaptation. The table provides the effect sizes with upper and lower bound values that are to be adjusted according to national policy implementation. We use the central or "best" value as the basis of our adjustment to reflect the current policy status of Japan. For example, Japan's 2018 grading for the P component of MPOWER is 1, minimal policy with weak enforcement. To improve from 1 (minimal policy) to 4 (comprehensive smoke-free regulations), we calculated the effect size to be 12.5%, using the "best" case scenario. For improvement between intermediate stages and comprehensive policy, we divided the full effect into steps to allow for movements between measures. For example, Japan's 2018 grading for W(MM) component of MPOWER is 2, weak policy. To improve from 2 (weak policy) to 4 (comprehensive policy) is a 75% improvement. The central value effect size reported by Levy et al for W(MM) component is 12% and therefore our adjusted effect size is 9%, that is 0.75*12%.

2.6. Cessation rates for intervention scenarios

The cessation effect of the intervention model was calculated based on the effect size in Table 1 of the main text, 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 [6] 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,

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

$$ES = \frac{p_0 - p_1}{p_0} = 1 - \frac{p_1}{p_0} = 1 - r \qquad (5)$$

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,

$$\alpha = 1 - r^{1/t} \qquad (6)$$

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 2.4). 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 (5) into equation (6),

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

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 0.0483 (from the regression model outlined in section 2.4), the cessation rate of male 20-29 age group under full P intervention is $(\alpha_I + \alpha)$= 0.0033 + 0.0483 = 0.0516. (Table S2.)

2.7. Cessation rate for combined MPOWER intervention 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 above equation 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, …, 6 corresponds to each full intervention.

Table S2. The cessation rates used in the status quo model, and individual and combined intervention model.

			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)						
	Age group	**Status quo cessation rate (α)**	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	0.0483	0.0516	0.0496	0.0505	0.0507	0.0498	0.0524	0.0630
	30-39	0.0147	0.0180	0.0160	0.0169	0.0171	0.0162	0.0173	0.0280
	40-49	0.0123	0.0156	0.0136	0.0145	0.0147	0.0138	0.0136	0.0243
	50-59	0.018	0.0213	0.0193	0.0202	0.0204	0.0195	0.0193	0.0300
	60-69	0	0.0033	0.0013	0.0022	0.0024	0.0015	0.0013	0.0120
	70+	0.0088	0.0121	0.0101	0.0110	0.0112	0.0103	0.0101	0.0208
Female	20-29	0.0797	0.0830	0.0810	0.0819	0.0821	0.0812	0.0838	0.0944
	30-39	0.0542	0.0575	0.0555	0.0564	0.0566	0.0557	0.0568	0.0675
	40-49	0.0133	0.0166	0.0146	0.0155	0.0157	0.0148	0.0146	0.0253
	50-59	0.0027	0.0060	0.0040	0.0049	0.0051	0.0042	0.0040	0.0147
	60-69	0	0.0033	0.0013	0.0022	0.0024	0.0015	0.0013	0.0120
	70+	0	0.0033	0.0013	0.0022	0.0024	0.0015	0.0013	0.0120

3. Supplementary results

3.1. Smoking prevalence under the status quo scenario

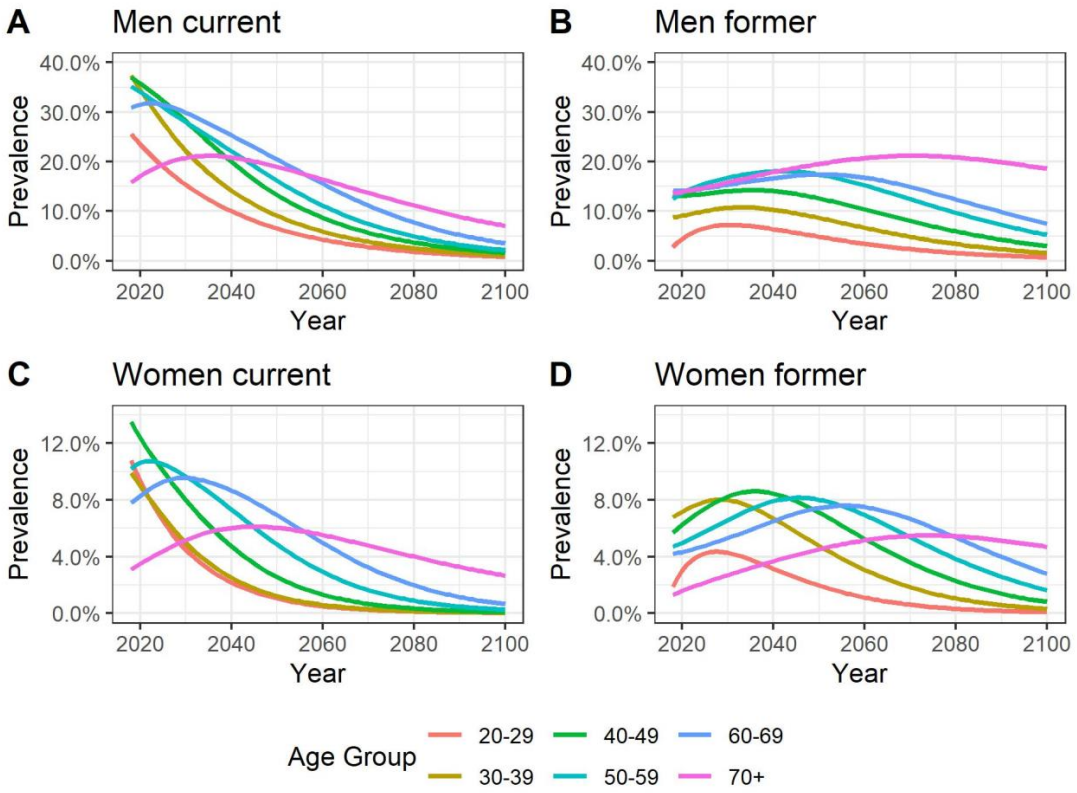

Figure S2. Sex- and age-specific prevalence of current and former smokers under the status quo scenario.

A. Current smoking in men, B. Former smoking in men, C. Current smoking in women, D. Former smoking in women.

4. Sensitivity analysis

In the main method, the cessation rates for the status quo and intervention scenarios are applied as constant from 2018 through 2050. In sensitivity analysis 1 we assume that the intervention policies effects start to wane after 10 years, the cessation rates from 2018 to 2030 were applied as constant, and from 2030 onwards, the cessation rates were set to reduce by 3% annually.

$$\alpha_{n+1} = \alpha_n \times 0.97$$

Where n = 2030, 2031, 2032, …, 2049

In sensitivity analysis 2, we assume that the long-term effects are realized in 10 or 20 years instead of 40 years.

4.1. Results of sensitivity analysis: smoking prevalence and time to achieve target

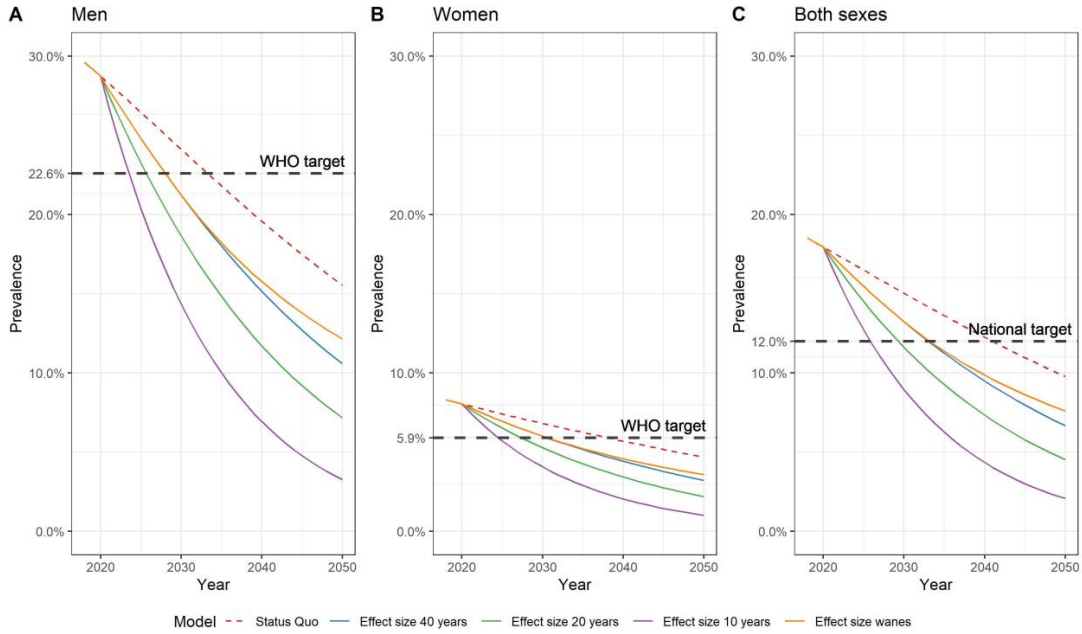

Figure S3. Projected prevalence of current smokers from 2018 to 2050 under the status quo, main model and the sensitivity scenarios.

A. Current smokers in men, B. Current smokers in women, C. Current smokers in men and women combined.

Table S3. Time to achieve the national and international targets.

Effect size over x years	Time to achieve WHO target		Time to achieve Japan's target
	Men	Women	Overall
Status quo	2034	2038	2041
40 years	2028	2031	2033
20 years	2026	2028	2030
10 years	2024	2025	2026

4.2. Results of sensitivity analysis: number of averted deaths

Table S4. The number of sex-specific averted deaths from main model and sensitivity analysis scenarios.

	Scenarios	2018-2030			2018-2050		
		Men	Women	Total	Men	Women	Total
Main model (for comparison)	P	8,443	1,378	9,821	59,001	12,331	71,332
	O	3,268	533	3,801	23,143	4,840	27,982
	WL	5,523	902	6,424	38,886	8,130	47,016
	WMM	5,984	977	6,961	42,088	8,799	50,886
	E	3,938	643	4,581	27,842	5,822	33,664
	R	3,363	544	3,907	24,607	5,017	29,624
	MPOWER	29,597	4,826	34,423	196,455	40,844	237,299
Sensitivity analysis 1: (effect size wanes after 10 years)	P	8,443	1,378	9,821	55,148	11,289	66,437
	O	3,268	533	3,801	21,580	4,420	26,000
	W-L	5,523	902	6,424	36,298	7,433	43,731
	W-MM	5,984	977	6,961	39,295	8,046	47,341
	E	3,938	643	4,581	25,970	5,318	31,288
	R	3,363	544	3,907	23,064	4,599	27,664
	MPOWER	29,597	4,826	34,423	185,471	37,794	223,265
Sensitivity analysis 2: (effect size 10 years)	P	32,570	5,316	37,886	213,836	44,552	258,389
	O	12,888	2,104	14,992	89,037	18,598	107,635
	W-L	21,573	3,521	25,094	145,723	30,405	176,127
	W-MM	23,330	3,808	27,138	156,880	32,725	189,605
	E	15,487	2,528	18,015	106,277	22,191	128,468
	R	13,254	2,144	15,398	94,259	19,231	113,490
	MPOWER	105,692	17,220	122,912	575,988	118,597	694,585
Sensitivity analysis 2: (effect size 20 years)	P	16,682	2,723	19,405	114,120	23,826	137,945
	O	6,504	1,062	7,566	45,685	9,550	55,235
	W-L	10,958	1,789	12,746	76,081	15,895	91,977
	W-MM	11,866	1,937	13,803	82,195	17,171	99,365
	E	7,831	1,278	9,110	54,815	11,457	66,272
	R	6,693	1,083	7,775	48,503	9,891	58,394
	MPOWER	56,965	9,286	66,251	352,120	72,967	425,087

Abbreviations. P: Protect people from tobacco smoke, O: Offer help to quit tobacco use, W-L: Warn about the dangers of tobacco (Labelling), W-MM: Warn about the dangers of tobacco (Mass Media), E: Enforce bans on tobacco advertising, promotion and sponsorship, R: Raise taxes on tobacco, MPOWER: Simultaneous implementation of all MPOWER tobacco control measures at the highest recommended level.

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