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From risk to reward: Japan's potential for health and economic improvements

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Abstract
This study examines the relationship between risky consumption behaviors, non-communicable diseases (NCDs), and socioeconomic costs in Japan using the Preventable Risk Integrated ModEl (PRIME). We assess the potential impact of healthier lifestyle choices on NCD incidences and costs in 2019. Japan's rising healthcare expenditures threaten its economic future. Excessive intake of salt, tobacco, and alcohol, along with insufficient fiber and fruit consumption, significantly contribute to high NCD rates. Our analysis shows that healthier behaviors could have prevented 564,000 NCD cases, potentially saving $35 billion in health costs and economic losses in 2019. We consider scenarios where smokers switch to heated tobacco products (HTPs), applying conservative risk reduction estimates. Higher risk reduction levels could triple smoking-attributable savings. Projecting these savings over ten years would increase economic benefits tenfold. The study emphasizes the need for comprehensive public health strategies promoting healthier lifestyles. Targeted interventions, such as stricter regulation of high-risk products and incentives for healthier alternatives, could reduce NCD incidences and healthcare costs. While PRIME provides valuable insights, further research is needed to refine our understanding of risk factor-disease relationships.

1 Introduction

Against the backdrop of a rapidly shifting global landscape, Japan is navigating several challenges: rising inflation has led to the first hike in interest rates since 2007, its economy is stagnating with a GDP growth rate of merely 1% in 2024, and demographic changes have made Japan the country with the oldest population globally [1–3]. The slowdown in economic performance is especially alarming in light of the exploding healthcare costs. While healthcare expenditures in Japan increased on average by 2% per year over the last 20 years, average GDP growth was below 1% [4, 5]. This has led to an increasing proportion of the GDP being dedicated to healthcare expenditures. While healthcare expenditures

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were only 7% of GDP in 2000, they reached almost 11% in 2020. If this trend continues, healthcare expenditures may exceed 20% of GDP in 2050.[1] These factors place immense pressure on the government not only to boost the economy and stabilize its budget, but also to decrease healthcare expenditures.

Concurrently, there is a concerning trend in the Japanese population towards harmful behaviors, specifically poor dietary choices and harmful substance use. Japan's once-renowned adherence to healthy eating is giving way to less healthy, Western-style diets [6].Tackling this transition could play a crucial role in not only enhancing public health and easing associated budgetary pressures, but also in reducing the strain on the workforce and economy.

To achieve this, a long-term policy strategy is essential, aimed at gradually encouraging healthier consumption patterns. Initial steps may include implementing a harm-based policy approach involving stricter regulation of high-risk products compared to their less harmful counterparts and establishing incentive programs for healthier lifestyle choices. Reflecting on the potential benefits of improved consumption patterns, our study evaluates the impact such changes could have had in 2019 on reducing NCD incidences and healthcare costs in Japan. In other words, we simulate a hypothetical reduction in the negative consequences of excessive intake of salt, tobacco, alcohol, and fat, as well as the consequences of insufficient consumption of fiber, fruits, and vegetables. To accurately assess the potential impacts, our study employs the Preventable Risk Integrated ModEl (PRIME), a modeling tool designed to analyze NCD scenarios and drawing on the latest research in this area. Although this is a retrospective analysis, the policy implications remain valid up to the time of writing this study.

The structure of this paper is as follows: after a literature review examining unhealthy consumption patterns and their impact on NCD outcomes and their associated costs in Japan, and providing context of existing improvement policies, we describe our study's methodology and data. This includes focusing on the use of the PRIME to evaluate the hypothetical impacts of lifestyle changes on Japan's healthcare system in 2019. The results section explores the findings from the analysis on disease incidences and their associated direct and indirect costs. The paper concludes with a discussion on the implications and limitations of the PRIME model as well as policy implications.

2 Literature review and background

While GDP growth in Japan is stagnating, healthcare expenditures are not. In the last 20 years, they have increased from 7% of GDP to almost 11% of GDP [4]. Like in most industrialized countries, NCDs are one of the main drivers of healthcare expenditures in Japan, accounting for 30% of total healthcare expenditure in 2019 [7]. Hence, reducing NCDs would be an option to reduce healthcare costs. According to the World Health Organization (WHO), NCDs can be partly attributed to behavioral factors, such as dietary risks and the consumption of alcohol and combustible tobacco [8]. There is a large body of literature that shows that consumption patterns in Japan are unhealthy and lead to a considerable number of NCDs.

As research has shown, actual consumption in Japan deviates from national guidelines and recommendations. Okui examines healthy lifestyle trends from 1995 to 2018, noting an increased salt intake in cohorts born after 1960, varying trends for smoking rates across cohorts, alongside a relative stable alcohol prevalence [6]. Further exploring dietary trends, Yoneoka et al. (2019) reports a stark lack of adherence to Japan's nutrition guidelines, with only 0.3% compliance in a 2016 survey, highlighting low adherence especially in sodium, potassium, dietary fiber, and saturated fats intake [9]. Following this, Tanaka et al. project a continuing decline in vegetable consumption, consistently falling short of government targets and raising doubts about meeting future goals [10]. Lastly, Nomura et al. identify key behavioral and metabolic risk factors in Japan like tobacco smoking, alcohol use, high-sodium diets, and high LDL cholesterol [11]. Collectively, these studies illustrate a persistent disconnect between health guidelines and actual consumption behaviors in Japan.

Corresponding research indicates that these patterns and trends are a major contributor to a considerable number of non-communicable disease cases and deaths. Nomura et al. (2022) estimate that preventable deaths attributable to smoking, alcohol use, and dietary risk factors exceeded 300,000 in 2019, remaining at a high level since 2013 [11]. Despite Japan's position as the country with the highest life expectancy across OECD nations, adherence to health guidelines could potentially extend it by an additional 0.7–1.4 years [12]. Ikeda et al. (2022) focus on dietary salt intake, projecting that meeting global and national targets could yield health economic benefits by reducing cardiovascular disease incidents [13]. Meanwhile, the projected decline in vegetable intake, as outlined by Tanaka et al. (2021), is anticipated to significantly increase the future burden of cardiovascular diseases, diabetes, cancer and kidney diseases.

[1] Own forecast, based on the constant average growth rate of the GDP and the healthcare expenditures from 2000 to 2020.

Given the projected increase in morbidity and mortality resulting from harmful consumption behaviors, coupled with a rapidly aging society, Japan's healthcare system is expected to face severe challenges and significant costs in the future. Concurrently, the private sector is likely to be curbed by their indirect costs due to absenteeism and reduced productivity in the workforce. These domestic challenges reflect a wider global issue, where unhealthy consumption patterns are similarly driving up healthcare and societal costs worldwide.

Globally, smoking is estimated to cost 1.8% of global GDP [14], while alcohol consumption accounts for 2.6% of GDP in high-income countries [15]. Unhealthy diets, which often lead to obesity and overweight, are estimated to have an economic impact of nearly 2.2% of global GDP [16]. These costs are not confined to direct medical expenses but also include a broader societal impact through indirect costs such as absenteeism and premature mortality, often accounting for a significant portion of the total cost burden, ranging from circa 40–80% depending on the type of consumption, and the scope covered [17–20].

In Japan, the costs associated with tobacco and alcohol consumption were estimated at ¥6.4 trillion and ¥4.1 trillion, amounting to 1.3% and 0.8% of GDP respectively, with indirect economic costs constituting about 75% of the total [17, 18]. While a detailed cost analysis of the impact of unhealthy diets is not available for Japan, a study from Brazil estimates significant costs of excessive sodium consumption at $945 million, with indirect costs accounting for about 80% of this total [19]. Similarly, the costs associated with obesity and overweight in Korea, covering major diseases such as ischemic heart disease, stroke, and colon cancer, are estimated at $1,787 million, of which 40% are attributed to indirect costs [20].

Recognizing these challenges, the Japanese government has implemented *Health Japan 21*, a comprehensive plan targeting primary prevention of non-communicable diseases and addressing key risk factors, which is updated every decade [21]. The current version, the 3rd edition of *Health Japan 21*, outlines specific targets to be achieved by 2032, addressing some of the risk factors previously mentioned such as reducing salt intake to 7g/day and increasing average daily vegetable and fruit intakes to 350g and 200g respectively. Furthermore, it sets goals to reduce the percentage of individuals engaging in heavy alcohol consumption to 10%, and to lower smoking prevalence to 12% [22].

In addition to the targets set by *Health Japan 21*, the need to address risk factors has led to a collaborative approach between the public and private sectors. For instance, Japan's *Metabo Law*, officially known as the Health Examination Law, requires companies to measure employees' waistlines and provide health guidance to those at risk of obesity-related health issues [23].

3 Data

For population data, we sourced information for 2019 from the Ministry of Health, Labour, and Welfare of Japan, detailing the population by age and gender [24].

For incidences, we use data from the Global Burden of Diseases for 2019 to obtain the incidence rates per disease by age group and gender [25]. To accurately capture the incidences of cancer diseases in Japan for the year 2019, considering the long-term nature of cancer longevity, we adopt the approach outlined by Pichon-Riviere et al. to calculate the 10-year cumulative incidence of cancer [26]. This involves summing up the number of new cancer incidences each year with the incidences from the previous year, adjusted by the yearly survival rate for each type of cancer [27]. This formula reflects the methodological rigor necessary for chronic diseases such as cancer, where understanding the long-term progression and survival is essential for accurate estimations of incidence rates and associated direct and indirect costs. Following this model allows us to consider the compounding effect of new cancer cases over a decade, providing a comprehensive view of the disease's long-term impact on the healthcare system.

For risk factor consumption in the baseline scenario, we utilized data from the Japan National Health and Nutrition Survey (JNHNS, https://www.nibiohn.go.jp/eiken/kenkounippon21/en/eiyouchousa/) in 2019 [28]. However, as the raw data is not publicly available, we rely on aggregated data. This includes results from the Nutrient Intake Survey, partially grouped by 10-year age groups starting from 20 years and by gender.[2] Variables such as fat (converted from grams to % of kcal), fiber, salt, fruit, and vegetable consumption, as well as smoking and alcohol consumption figures, were derived from this aggregated data. Specific calculations are needed to determine the average daily consumption of fruits and vegetables among consumers, scaling up from the total daily consumption and dividing by the number of consumers

[2] 20–29 years old, 30–39 years old, 40–49 years old, 50–59 years old, 60–69 years old, 70 years or older.

meeting certain intake thresholds. Standard deviations for these values are calculated using weighted variance based on average intake categories.

For alcohol consumption among drinkers, we again used aggregated data from JNHNS 2019, calculating average consumption among drinkers and its corresponding standard deviation by integrating frequency of drinking, daily alcohol consumption on drinking days, and a conversion factor for the Japanese unit of volume (go) to grams of alcohol.

Finally, to assess the economic consequences of these health outcomes, we utilized 2022 data on medical care expenditure by inpatient and outpatient services, age group, and disease category in Japan [29]. These costs have been adjusted to 2019 values using the Consumer Price Index (CPI), allowing for consistent financial comparisons over time. Importantly, we used only 2019 data as it is the most recent year for which comprehensive data from all sources is available and is unaffected by the disruptions caused by the COVID-19 pandemic.

4 Methods

Our study focuses on evaluating the health incidences and associated direct health and indirect economic costs arising from excessive intake of salt, smoking, alcohol, and fat, as well as from insufficient consumption of fiber, fruits, and vegetables in Japan for the year 2019. Utilizing the PRIME, developed by the University of Oxford, we assess the impact of changes in dietary and lifestyle risk factors on NCD incidences [30]. PRIME, a scenario modeling tool, compares actual 2019 data in the baseline scenario against hypothetical scenarios informed by meta-analyses to simulate the potential reduction in NCD incidences resulting from healthier consumption patterns.

The model calculates the number of incidences that could have been averted by adjusting these risk factors, employing relative risks and population attributable fractions (PAFs) from existing literature. This allows for estimating the percentage of preventable disease cases under alternative scenarios. By inputting data on Japan's population demographics, NCD rates, and risk factor behaviors, we apply PRIME to project averted incidences.

We utilize PRIME to estimate both total status quo costs and avertable costs if Japanese adults consumed healthier. Total costs are derived using a population attributable fraction approach, while avertable costs are calculated based on the number of disease cases that could be prevented as identified through our scenario modeling. Costs are categorized into direct and indirect types. Direct costs are estimated by multiplying the number of NCD cases with the annual treatment costs per disease. For indirect costs, which vary by consumption good, we use literature-based estimates. Indirect costs usually consist of economic losses from morbidity and premature mortality such as productivity losses from absenteeism. These estimates inform our calculation of direct costs by applying literature-derived ratios of direct to indirect costs for each consumption good. This study does not take into account long-term effects such as future economic losses. Especially in the context on smoking, it can take years for negative health consequences to become apparent. Those future costs, and correspondingly the savings arising from it in case smokers switch or quit, are not considered in this study.

This method provides a comprehensive understanding of how lifestyle modifications could lead to significant health and economic benefits, offering evidence-based insights for public health policy and intervention strategies.

Our counterfactual scenarios are pre-filled with WHO recommended levels of consumption [31] for the considered risk factors when the observed risk factor consumption behavior is worse than the WHO recommendations. However, an exception is made for the counterfactual scenario concerning tobacco consumption. Here, we follow the approach introduced by Espinosa Herrera (2024) [32]. This study simulates a counterfactual scenario for tobacco products utilizing the PRIME model, where users switch to potentially less harmful tobacco alternatives instead of quitting.

In our model, we assume that 70% of smokers switch to HTPs, reflecting the ongoing trend in Japan, where combustible smokers switch to heated tobacco products (HTP). HTPs held a market share of 36% in 2022, making Japan the world's largest HTP market [33–35]. HTPs were introduced into the market in 2016, and a large body of literature has investigated the differences in toxicants inhaled by the user compared to combustible cigarettes [36]. Current research states that HTPs have lower levels of toxicants up to 97% [37, 38]. While there is insufficient research on how this translates into the risk of developing smoking-related diseases, we assume that a reduction in toxicants is followed by a reduction in disease risks. Due to the uncertainty of this assumption, we allow a conservative reduction in disease risk of 30%. This lower risk reduction bound of 30% largely impacts potential savings from reduced smoking. If we implemented a higher risk reduction level, as it was done by Moscone (2023), Espinosa Herrera (2024) and Koch (2024) among others, savings would be significantly higher [32, 39, 40]. We would then expect potential health and economic savings from smokers switching to HTPs to be three times higher. Finally, our models assume that NCDs are caused by unhealthy consumption ways. We do not discuss diseases caused by genetic factors, as risky behaviors can exacerbate the negative impact of a genetic predisposition to certain diseases.

Table 1 Baseline and Counterfactual Model Values

Risk Factors	Males		Females	
	Baseline	Counterfactual	Baseline	Counterfactual
Fruit (grams/day)*	224	200	230	200
% with < 1 fruit per day	71	0	60	0
Vegetable (grams/day)**	276	200	268	200
% with < 1 vegetable per day	7	0	8	0
Fiber (grams/day)	19	25	17	25
Salt (grams/day)	11	5	9	5
Total fat (% total energy)	28	22.5	29	22.5
Cholesterol (milligrams/day)	371	300	317	300
% low alcohol consumers***	39	99	69	99
Alcohol (grams/day)	24	10	12	10
% Former smoker	12	18	3	5
% Current smoker	28	22	8	6

Of those consuming more than 1 fruit portion (100g) per day

**Of those consuming more than 1 vegetable portion (70g) per day*

***Consuming < 1 g of alcohol per day*

Source: Own calculations, based on the Japan National Health and Nutrition Survey (2019)

5 Results

As illustrated in the previous chapters, the literature suggests that the Japanese population has unhealthy consumption patterns. In particular, the consumption of salt, alcohol and combustible tobacco is too high, while the intake of dietary fiber is notably low. Our data analysis confirms these findings and reveals distinctive consumption patterns in Japan that diverge significantly from nutritional guidelines.

Table 1 illustrates these disparities, comparing the baseline model values of fruits, vegetables, fiber, salt, cholesterol, fat, alcohol, and combustible tobacco with counterfactual model values of those substances. As described in the methodological and data chapter, the baseline model values are the actual consumption derived from survey data. The counterfactual model values consist of recommended consumption amounts for dietary risk factors and considered limits for the consumption of alcohol and combustible tobacco.

We observe a national dietary behavior that closely aligns with the recommended intake levels of fruit and vegetables but deviates markedly in other crucial areas. Specifically, the Japanese diet is characterized by a significantly higher intake of salt, fat, and cholesterol and a markedly lower consumption of dietary fiber than recommended. This trend shows negligible differences between genders, indicating that both men and women share dietary habits in these respects. Salt illustrates this well: while the recommended limit of salt consumption is 5 g per day, women consume around 9 g and men around 11 g.

Beyond dietary behavior, Table 1 also illustrates the consumption of the harmful substances alcohol and combustible tobacco. For both products, the consumption is considerable and exceeds the counterfactual model values by far. Interestingly, whereas dietary behavior was similar between men and women, the consumption of alcohol and tobacco exhibits a stark gender disparity. Men in Japan consume alcohol and tobacco at rates far exceeding the recommended limits, whereas women's consumption patterns are closer to the guidelines. For instance, 31% of Japanese women consume alcohol, with an average of 12 g of alcohol per day, whereas 61% of men consume alcohol, with almost 25 g per day. That is, more than twice as much.

The gender divergence in alcohol and tobacco consumption is not only a matter of lifestyle choice but also impacts health outcomes, as shown in Fig. 1. The excessive and risky consumption patterns observed among men have profound implications for public health, with the potential to reduce disease incidence significantly. With PRIME we estimate the number of avertable NCD incidences for 2019 if individuals had adhered to recommended dietary and lifestyle guidelines. We find that approximately 346,000 disease cases among men and 218,000 cases among women could have been prevented.

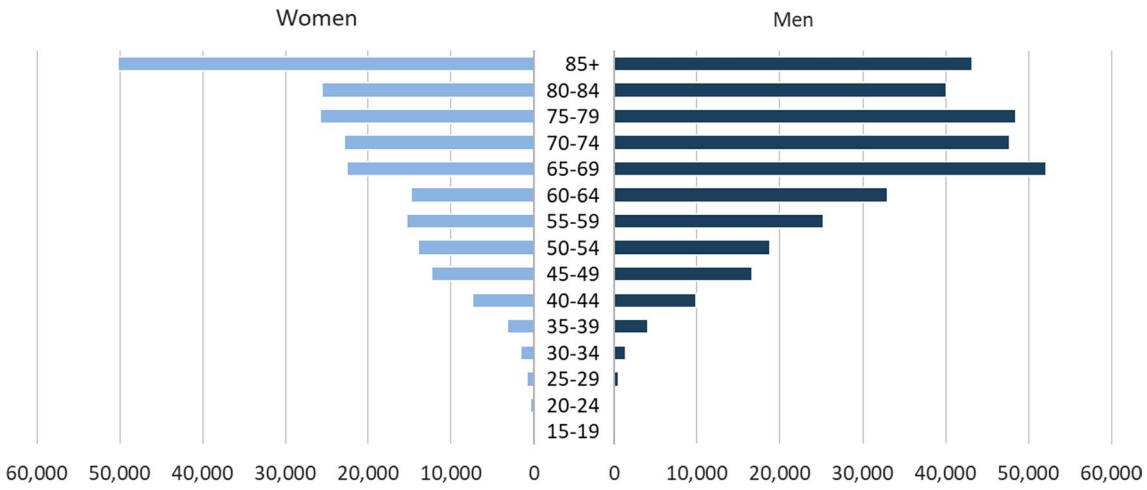

Fig. 1 Avertable disease incidence in the Counterfactual Scenario by gender and age group. Source: Own calculations, based on the PRIME

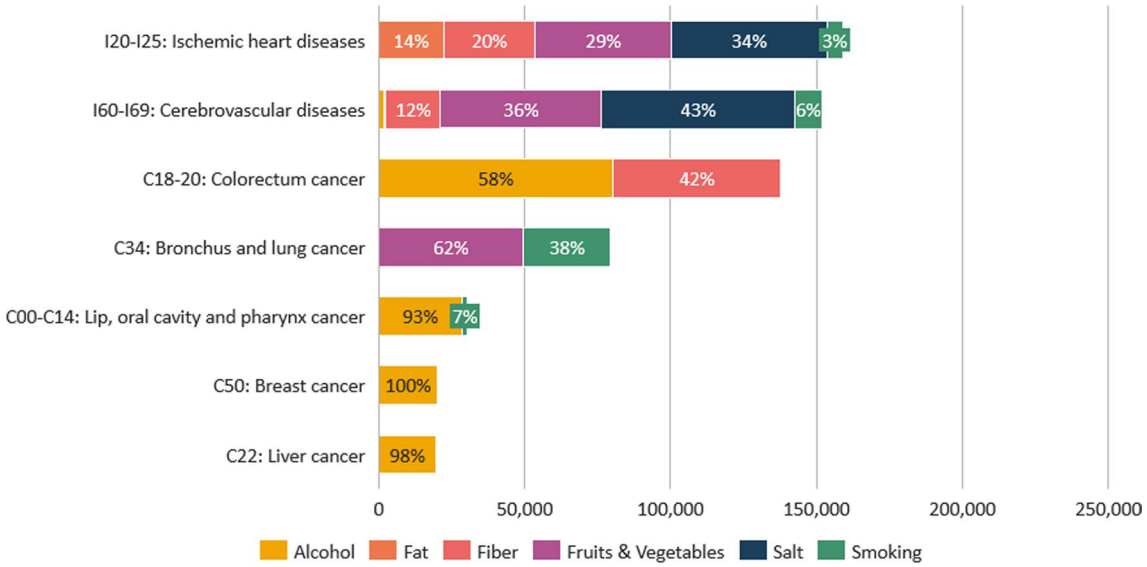

Fig. 2 Estimated avertable disease incidence in the Counterfactual Scenario by disease group and risk factor in 2019. Source: Own calculations, based on the PRIME

Furthermore, the age-related analysis of avertable disease cases reveals another layer of gender differentiation. For men, the incidences of preventable diseases sharply increase between the ages of 40–44 and 65–69 years, thereafter remaining at varying high levels. In contrast, women experience a moderate increase, with incidences plateauing between the ages of 65–69 and 80–84, followed by an abrupt spike beyond the age of 85. The differences in age-related patterns between men and women suggest that lifestyle choices, such as higher alcohol consumption and smoking behavior among men, contribute to earlier incidences of NCDs in men.

In Fig. 1, we introduced the concept of avertable incidence, which we further dissect in Fig. 2 by presenting avertable incidences by disease and risk factor. This breakdown offers insights into the changes needed to improve health outcomes in Japan over the long term. The largest potential reductions in disease incidence are associated with cerebrovascular disease, diseases of the colorectum and ischemic heart disease, accounting for preventable cases of 152,000, 138,000, and 115,000, respectively. The distribution of risk factors contributing to these diseases is notably heterogeneous, indicating that interventions across various areas are necessary to enhance public health. Simultaneously, many areas present opportunities for significant health improvements through targeted measures. The sectors of dietary fiber, fruit and vegetable intake, smoking, alcohol, and salt consumption each contribute 15 to 20 percent to the potential reduction

in disease incidence. This diverse contribution of risk factors underscores the complexity of public health challenges in Japan and highlights the multifaceted approach required to address them effectively.

While avertable incidence provides a measure of the potential reduction in disease and subsequent mortality rates, the pragmatic aspect of cost savings associated with treating these diseases is equally pertinent for governments. Given that costs for various diseases can differ substantially, a detailed examination of the cost savings achievable through modifications in risk factors is crucial.

This analysis is presented in Table 2. Results for avertable costs through decreased alcohol consumption exclude diabetes and ischemic heart disease. This is further discussed in the limitations sub-section. According to our counterfactual scenario, which posits a shift towards healthier living, overall savings of $35.1 billion USD could be realized, as indicated in column (1) and (2). Of these savings, $17.9 billion could be saved through reduced salt intake, $6.5 billion through reduced alcohol consumption, $6.0 billion through increased consumption of fruits and vegetables, and $3.4 billion from changes in smoking habits.

We assume that HTPs are associated with a 30% lower health risk than cigarettes, which is a conservative assumption in the context of the current body of literature. Assuming that the lack of combustion in HTPs leads to even less emitted toxicants and a likely risk reduction level of up to 90%, this would increase savings. In such a case, we would expect the current savings of $3.4 billion to increase three times. If we projected the savings of former and current smokers into the future, this would increase economic savings by a factor of ten. Such high long-term savings of ten times the 2019 savings can be explained by a large number of middle-aged current smokers that are expected to cause smoking-attributable costs in the future. Those future costs for potentially 10 to 20 years can be reduced if they switched to HTPs today.

To put our estimated cost savings for 2019 into perspective, we estimate the total attributable costs following a population-attributable fraction approach. Such an approach includes all costs attributable to harmful consumption, even if consumers have already adopted healthier behaviors but their health is not yet equivalent to that of non-risky consumers. In the case of tobacco, total attributable costs include costs from current and former smokers. 75% of total costs can be attributed to current and 25% to former smokers. Thus, only the 75%-portion of costs can actually be reached by policy interventions and be reduced.

We find that the unhealthy consumption habits in Japan in 2019 can be associated with $343.2 billion in total costs, as can be seen in Table 2 in column (3) and (4). Of which $113 billion can be attributed to salt, $80.3 billion to alcohol and $66 billion to current and former smokers. Consequently, we infer that at least 10% of the costs attributable to unhealthy consumption could have been averted in 2019 if individuals had adhered to healthier lifestyles.

The significant financial impact of unhealthy consumption underscores the complex relationship between health behavior, disease incidence, and social and economic costs. It highlights the importance of considering both the health and economic benefits of risk factor modification. This dual focus not only supports the goal of improving public health but also aligns with governmental objectives of reducing healthcare expenditures. By targeting these key areas—alcohol and salt consumption as well as smoking—policymakers can devise strategies that not only enhance the population's health but also generate substantial economic savings, thereby creating a win–win scenario for both public health and the economy.

5.1 Sensitivity analysis—MONTE CARLO simulation

The Monte Carlo simulation, used in this study as a sensitivity analysis for the PRIME model, is a statistical technique that explores variance in model outcomes by drawing random samples from probability distributions of uncertainty sources. This approach assesses the robustness of the model's results considering the uncertainties in underlying data. By incorporating confidence intervals for the lower and upper bounds of relative risks, the simulation provides a detailed evaluation of the dispersion of outcomes across 5,000 iterations. This offers a more comprehensive perspective on the potential impacts of behavioral risk factors on the prevention or delay of disease incidences than a single analysis might.

The Monte Carlo results for this study, assessing the avertable incidences associated with excessive consumption of salt, smoking, alcohol, fats, and insufficient intake of fiber, fruits, and vegetables in Japan in 2019, are shown in Table 3. Notably, the results illustrate that dietary factors, specifically fruits and vegetables, have the most significant effect with an average of 151,000 averted incidences, followed by salt, fiber, alcohol, smoking, and fats.

However, it should be noted that the averted incidences for fruits and vegetables in Japan might be overstated due to the PRIME model's inability to aggregate daily consumption of fruits and vegetables. This limitation overlooks the compensatory health benefits of high vegetable intake when fruit consumption is low, potentially skewing incidence rates and associated healthcare costs, especially in populations like Japan's, where fruit and vegetable intake significantly

Table 2 Estimated costs (direct and indirect) by risk factor in 2019

Risk factor	(1) Avertable direct costs in bn USD (JPY)		(2) Avertable indirect costs in bn USD (JPY) and		(3) Total direct costs in bn USD (JPY)		(4) Total indirect costs in bn USD (JPY)		(5) Indirect cost Reference
Salt	$ 3.6	(¥ 387.8)	$ 14.3	(¥ 1,561.8)	$ 22.9	(¥ 2,503.3)	$ 90.1	(¥ 9,828.1)	[19]
Fruits & Vegetables	$ 3.6	(¥ 396.2)	$ 2.4	(¥ 258.7)	$ 14.1	(¥ 1,542.5)	$ 9.2	(¥ 1,007.1)	[20]
Alcohol	$ 1.6*	(¥ 175.0)*	$ 4.9*	(¥ 530.6)*	$ 19.9	(¥ 2,174.9)	$ 60.4	(¥ 6,594.7)	[18]
Smoking	$ 0.9	(¥ 93.3)	$ 2.5	(¥ 272.6)	$ 16.8	(¥ 1,837.0)	$ 49.2	(¥ 5,366.9)	[17]
Fiber	$ 0.5	(¥ 50.9)	$ 0.3	(¥ 33.2)	$ 22.3	(¥ 2,429.2)	$ 14.5	(¥ 1,586.0)	[20]
Fat	$ 0.3	(¥ 38.0)	$ 0.2	(¥ 24.8)	$ 14.3	(¥ 1,560.8)	$ 9.3	(¥ 1,016.0)	[20]
Total costs	$ 10.5	(¥ 1,151.1)	$ 24.6	(¥ 2,681.6)	$ 110.4	(¥ 12,047.6)	$ 232.8	(¥ 25,401.8)	

*Excluding E11, E14 Diabetes and I20-I25 Ischemic heart diseases

Source: Own calculations, based on the PRIME and the literature on indirect cost

Table 3 Incidences averted or delayed by behavioral risk factor, in thousands

Risk factor	2.5th percentile	Mean	97.5th percentile
Salt	52	120	180
Fruits & Vegetables	112	151	193
Alcohol	28	85	137
Smoking	60	79	96
Fiber	69	110	151
Fat	16	23	30
Total*	461	564	663

Source: Own calculations, based on the PRIME

*Risk Factors and Total are simulated separately within Monte Carlo simulation, thus values do not necessarily add up

surpasses recommended levels. This must be considered when interpreting dietary behaviors' impact on public health outcomes.

The average averted incidences for salt intake stand at 120,000, highlighting the importance of salt reduction in the diet. Smoking and alcohol, well-recognized health risk behaviors, show averages of 79,000 and 85,000 averted incidences respectively, underscoring the impact of substance use on public health. Fiber shows a significant preventative potential with 110,000 incidences averted on average, while reduced consumption of fats is associated with the least impact, showing a mean of 23,000 averted incidences. Overall, sensitivity analysis results show a total mean of 564,000 averted incidences across all risk factors, underscoring the potential for public health interventions to lessen the impact of NCDs. By transitioning towards a healthier population, between 461,000 (at the 2.5th percentile) and 663,000 (at the 97.5th percentile) incidences could have been averted. This range highlights the profound effect that comprehensive health promotion and disease prevention strategies can have, illustrating a scenario where a shift in population health behaviors towards recommended guidelines dramatically reduces the burden of disease.

6 Limitations

Despite its strengths, the PRIME model, designed to evaluate changes in risk factors for non-communicable diseases, faces several limitations that affect its utility in public health strategy formulation. Unlike tools geared towards forecasting, PRIME is tailored to retrospective analysis, relying on fixed relative risks, which may not fully encapsulate the evolving nature of risk factor-disease relationships over time. This inherent design choice restricts its application mainly to historical data assessment rather than predicting future trends in NCD incidence.

The PRIME model is supposed to incorporate mortality data as input, but in this paper, we consider incidence data. This shift towards preventable disease incidences emphasizes the importance of healthier consumption patterns, underlining how such changes can lead to decreased healthcare costs associated with treating NCDs. This perspective not only broadens the understanding of disease impact but also paves the way for more effective prevention strategies in public health policy. However, the model's dependence on literature-based relative risks introduces potential biases, especially since some of these risks are more aligned with mortality than with the likelihood of contracting a disease. Nevertheless, the relative risks in the PRIME model are not consistently solely based on mortality, but also on contracting a disease.

Furthermore, the PRIME model's limitation in aggregating daily fruit and vegetable consumption fails to account for the nuanced dietary patterns observed in some populations. By not considering the combined daily intake of these foods, the model overlooks how a high-vegetable diet might offset the lower consumption of fruits, a factor that could significantly alter disease incidence rates and the associated healthcare costs projected by the model. Consequently, this oversight likely leads to an overestimation of avertable incidences and the related healthcare costs in the model's results. This overestimation is particularly critical in contexts like Japan's, where the consumption levels of vegetables mainly surpass standard dietary recommendations, while fruit consumption falls short of expectations. This potentially leads to discrepancies in the model's predictions regarding health outcomes and costs.

The reliance on incomplete Global Burden of Disease (GBD) incidence data further complicates the model's accuracy. For example, the absence of data on hypertensive disease in Japan may lead to an underestimation of disease burden

attributable to risk factors. Additionally, while the model's use of incidence data over mortality offers a broader view of disease impact, the application of mortality-based relative risks could bias the results.

The direct financial savings estimated in this paper must also be interpreted with caution, as they are potentially underestimated in the model due to the lack of disaggregated cost data for some individual NCDs in PRIME.[3] Moreover, the estimates of indirect costs represent only rough approximations of their potential scale, as they are derived from the indirect cost fractions of total costs found in the related literature. For tobacco and alcohol consumption, studies specifically for Japan are available, reflecting country-specific characteristics [17, 18], whereas for the dietary factors studies from other countries had to be used. To estimate the impact of salt intake, a study from Brazil provided a useful framework [19], while for fruit and vegetable intake, fat and fiber, we referred to a study on the cost of obesity and overweight for Korea [20]. Both studies cannot capture country-specific aspects, however they both use a cost-of-illness approach, connecting to our methodology of linking risk factors to disease incidences. Furthermore, the similarity in risk factors considered in these studies results in a significant overlap in the types of diseases analyzed to capture the total cost. In addition, our total cost estimates for the baseline scenario may be overestimated due to the challenge of disentangling and precisely matching disease incidences to a specific consumption good, particularly given the complex nature of interaction effects and estimation methods in PRIME.

Another important point is the nuanced impact of low amounts of alcohol on health, particularly in the context of NCDs such as diabetes and stroke. In the model, relative risks for diabetes and partially for stroke are less than one, indicating that alcohol consumption is associated with a lower risk of these diseases than no consumption. Consequently, this results in negative avertable incidences for alcohol consumption in Japan in 2019, since low amounts of alcohol are deemed healthy, and the considered counterfactual scenario represents less alcohol consumption than the baseline scenario. These resulting negative avertable incidences also lead to negative financial health savings. The scientific literature further complicates the narrative by presenting a dual-faced impact of alcohol consumption on the risk of developing NCDs. While certain studies advocate for the protective effect of moderate alcohol consumption against diseases like type 2 diabetes and stroke, others caution against the harmful effects of excessive intake [39]. A particularly notable finding is the variability in alcohol's impact among the Asian population, attributed to genetic factors that affect alcohol metabolism. The presence of specific genetic variants, particularly involving the ALDH2 and ADH1B genes, may alter the risk dynamics for NCDs within this demographic. This genetic predisposition suggests a differential effect of alcohol that could elevate the risk for certain diseases, underscoring the necessity for a tailored approach in public health recommendations and the critical need for further research to delineate alcohol's health implications more clearly [41, 42]. Given these insights, the alcohol-related results of the PRIME Model warrant cautious interpretation. The genetic underpinnings, particularly those affecting populations differently, as seen in the Asian context, highlight the complexity of formulating universal guidelines on alcohol consumption.

In summary, while PRIME serves as a critical tool for quantifying the impact of lifestyle changes on NCD mortality, offering invaluable insights for evidence-based public health strategies worldwide, its limitations underscore the need for cautious interpretation of its outputs. These include its design focus on retrospective analysis, reliance on fixed relative risks, the methodological oversight of reduced tobacco consumption or switching to less harmful alternatives, and the challenges posed by incomplete data and the model's specific assumptions about diet. Acknowledging these constraints is crucial for leveraging PRIME effectively within the broader context of public health policy and prevention strategies.

7 Conclusions and policy implications

We find that retrospectively, for 2019, $35.1 billion (¥3,832 billion) in direct health costs and indirect economic losses could have been averted if individuals had adhered to WHO-recommended intake levels for dietary habits, reduced alcohol consumption and switched from combustible smoking to risk-reduced products such as e-cigarettes or heated tobacco products (HTPs). Excessive consumption of salt, at $17.9 billion (¥1,949.6 billion), alcohol at $6.5 billion (¥705.6 billion), and smoking at $3.4 billion (¥365.9 billion), exhibit the largest potential in cost savings. Taking into account rather conservative assumptions, these estimates could be regarded as minimum lower bound. Assuming that the lack of combustion in HTPs leads to substantially less emitted toxicants and a likely risk reduction level of up to 90%, this would increase savings. In such a case, we expect current savings of $3.4 billion to increase three times. If we projected

[3] Not available for C00-C14: Lip, oral cavity and pharynx, C25: Pancreas cancer, C64: Kidney cancer, C53: Cervix cancer, C15: Oesophagus, I05-09: Rheumatic heart disease.

the savings of former and current smokers into the future, this would increase economic savings by a factor of ten. Such high long-term savings of ten times the 2019 savings can be explained by a large number of middle-aged current smokers that are expected to cause smoking-attributable costs in the future. Those future costs for potentially 10 to 20 years can be reduced if they switched to HTPs today.

We argue that our estimated avertable cost savings could be allocated to support other national priorities. To contextualize these figures, total savings of $35.1 billion (¥3,832 billion) represent 7.4% of Japan's expenditures on COVID-19 measures [43]. These savings could also be utilized to reduce the debt incurred in managing the pandemic, thereby improving the nation's fiscal health. Furthermore, the estimated savings in direct medical costs of $10.5 billion (¥1,151 billion) match the additional budget required for defense, which was announced in April 2024 to increase from ¥6.8 trillion to ¥7.95 trillion [44].

Our findings underscore significant policy implications for Japan's aging population and economic challenges. The demographic shift towards an older population increases the strain on healthcare systems, elevating healthcare costs and reducing productivity due to the rising prevalence of NCDs. To address these challenges, a multifaceted approach is necessary. This includes expanding preventive healthcare programs targeting diet, physical activity, and alcohol consumption; promoting regular health check-ups and early detection of NCD risk factors; and updating nutritional guidelines. Integrating health promotion with aging strategies through community-based health programs tailored to the elderly is crucial. Additionally, implementing taxes on unhealthy foods and alcohol while subsidizing healthier options can effectively shift consumption patterns. Addressing cultural barriers, such as traditional dietary habits and social norms around alcohol, requires culturally sensitive interventions. These may include modifying traditional recipes, promoting healthier dining options, and launching awareness campaigns on the risks of excessive alcohol consumption. By adopting these strategies, Japan can significantly reduce the burden of NCDs, improve public health outcomes, and potentially realize substantial cost savings in healthcare expenditures.

The best-case scenario is to lead a completely health-conscious life on all levels. This would require a perfect balance of dietary intake and renouncing harmful—and unfortunately often enjoyable—goods, such as alcoholic beverages and tobacco products. However, given our irrational and gratification-seeking human nature, a different solution is required. This second-best solution involves the highest possible reduction of unhealthy dietary intake and the switch to less harmful products—if quitting is not an option.

This raises the question of how harm reduction and switching can be induced. Possible policies range from awareness-raising measures to consumer nudging and close mentoring by the government and employers. Japan is already at the forefront of dietary awareness, often in collaboration with the private sector. It has implemented measures like the Health Examination Law, which involves companies actively participating in monitoring employees' weight, aimed at reducing obesity-related health risks [23]. Alongside these measures, the government's health promotion program *Health Japan 21* plays a crucial role in raising public awareness of dietary habits. It emphasizes the importance of regular health checkups and educational awareness measures [45].

But the Japanese government has scarcely recognized the potential of alcohol drinkers and smokers that have not yet switched to low-alcohol beverages and HTPs. Tax incentives for less damaging products are crucial in steering consumers towards substitutes and incentivizing suppliers to invest in innovation. Thus, practices of health-based regulatory measures are already in place; however, their application could be more effectively focused on the relative harmfulness of products in alignment with the recommendations of the United Nations and the International Monetary Fund. A simple yet cost-effective fiscal policy that consistently imposes strict regulations on harmful products and concurrently offers benefits for less harmful alternatives could serve as an incentive for consumers to adopt healthier behaviors. Moreover, it is also known that the timing of tax increases can have a significant impact on how disruptive they are to the market. The Japan tax research suggests that gradual tax increases are less disruptive to the economy than large one-off tax increases, and they are less jeopardizing for consumption and for tax revenues [46].

Consequently, economic theory suggests that maintaining (or even better, increasing) a differential between harmful and risk-reduced products, while implementing a progressive tax increase can lead to better results for the Japanese Treasury. This multi-faceted approach, combining regulatory measures with incentives and targeted interventions, could form a robust strategy for enhancing public health in Japan.

In sum, in this study we investigated the potential cost savings in Japan for 2019 had there been adherence to healthier consumption patterns utilizing the Preventable Risk Integrated ModEl (PRIME). Our findings indicate that by adopting healthier eating habits, reducing alcohol intake, and substituting cigarettes with less harmful alternatives, up to 564,000 incidences of NCDs could have been prevented in Japan in 2019, potentially saving $35.1 billion (¥3,832 billion). While

our analysis provides retrospective insights for 2019, the results remain valid for future years as consumption behavior has not changed drastically.

Despite Japan's relatively healthy lifestyle and its reputation for the world's highest life expectancy, our study identifies areas of concern, particularly in the consumption of salt, alcohol, and tobacco. The average salt intake is notably high, with consumption levels double the recommended intake of the WHO. Alcohol consumption among men is twice that of women, standing at 24 g. Tobacco use remains high, with a prevalence of 28% among men and 8% among women, indicating a predominantly male-dominated risk behavior in alcohol and tobacco consumption. The consumption of fruits and vegetables in Japan remains controversial within our analysis. While over 90% of the population eat sufficient vegetables per day and even exceed the amount recommended by the WHO, the consumption of fruit is below the recommended level for 65% of the population. Based on the calculations in PRIME, the low consumption of fruit is a driving factor in disease cases in Japan. However, if the recommended amount of fruit and vegetables is considered as a total amount, a large part of the population is close to the recommendation of 400 g of fruit and vegetables per day. Thus, the PRIME model might overestimate the number of preventable disease cases when the diet contains a lot of vegetables but less fruit.

An example of the emerging shift in Japan towards health-conscious lifestyles is the reduced consumption of harmful substances, particularly the decline in alcohol consumption [47] as recommended by the Japanese government [48], and the switch from conventional cigarettes to HTPs [49], suggesting their acceptance as a healthier substitute for conventional cigarettes by the population. Building on this trend, our study simulated the healthcare cost savings that could have been achieved if 99% of the adult population consumed less than one gram of alcohol per day, and 70% of smokers switched to heated tobacco products, assuming an associated reduced health risk of heated tobacco of 30% [50–52]. Our estimates suggest that this switch could have resulted in minimum savings of $6.5 billion (¥705.6 billion) for alcohol and $3.4 billion (¥365.9 billion) for smoking in 2019 alone.

Our findings indicate, therefore, that harmful consumption is not only responsible for many NCD disease cases, but also causes strikingly high costs. Japan's regulatory measures should try to stay ahead of the game to lessen the burden of unhealthy habits such as smoking and alcohol consumption. If consumers do not quit their unhealthy habits, harm-based regulation offers a vital approach for the Japanese government to disincentivize consumers away from risky towards harm-reduced consumption.

Author contributions E.S and F.P. wrote the main manuscript text and E.S collected the data and F.P. conducted analysis and prepared Tables 1, 2 and 3 and Figs. 1, 2. All authors reviewed the manuscript.

Data availability Data are publicly available and information for retriving it is provided in the the manuscript. https://www.mhlw.go.jp/english/. Incidences: Global Burden of Diseases: https://www.healthdata.org/research-analysis/gbd. Costs: Ministry of Health, Labour and Welfare of Japan. Social insurance: Medical care expenditure of medical care by inpatient—outpatient, age group and category of disease. In: Handbook of Health and Welfare Statistics 2022. Ministry of Health, Labour and Welfare of Japan. 2022. https://www.mhlw.go.jp/english/database/db-hh/5-1.html. Accessed 3 Apr 2024. Japan National Health and Nutrition Survey (JNHNS): https://www.nibiohn.go.jp/eiken/kenkounippon21/en/eiyouchousa/. Prime model can be obtained from Modelling the impact of national policies on noncommunicable disease mortality using PRIME (who.int):https://www.who.int/europe/tools-and-toolkits/modelling-the-impact-of-national-policies-on-noncommunicable-disease-mortality-using-prime.

Declarations

Competing interests The authors declare no competing interests.

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