The effect of food taxes and subsidies on population health and health costs: a modelling study

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Summary

Background One possible policy response to the burden of diet-related disease is food taxes and subsidies, but the net health gains of these approaches are uncertain because of substitution effects between foods. We estimated the health and cost impacts of various food taxes and subsidies in one high-income country, New Zealand.

Methods In this modelling study, we compared the effects in New Zealand of a 20% fruit and vegetable subsidy, of saturated fat, sugar and salt taxes (each set at a level that increased the total food price by the same magnitude of decrease from the fruit and vegetable subsidy), and of an 8% so-called junk food tax (on non-essential, energy-dense food). We modelled the effect of price changes on food purchases, the consequent changes in fruit and vegetable and sugar-sweetened beverage purchasing, nutrient risk factors, and body-mass index, and how these changes affect health status and health expenditure. The pre-intervention intake for 340 food groups was taken from the New Zealand National Nutrition Survey and the post-intervention intake was estimated using price and expenditure elasticities. The resultant changes in dietary risk factors were then propagated through a proportional multistate lifetable (with 17 diet-related diseases) to estimate the changes in health-adjusted life years (HALYs) and health system expenditure over the 2011 New Zealand population's remaining lifespan.

Findings Health gains (expressed in HALYs per 1000 people) ranged from 127 (95% uncertainty interval 96–167; undiscounted) for the 8% junk food tax and 212 (102–297) for the fruit and vegetable subsidy, up to 361 (275–474) for the saturated fat tax, 375 (272–508) for the salt tax, and 581 (429–792) for the sugar tax. Health expenditure savings across the remaining lifespan per capita (at a 3% discount rate) ranged from US$492 (334–694) for the junk food tax to $2164 (1472–3122) for the sugar tax.

Interpretation The large magnitude of the health gains and cost savings of these modelled taxes and subsidies suggests that their use warrants serious policy consideration.

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Introduction

Many countries have now implemented taxes on sugary beverages,[1] but few have implemented food subsidies or taxes on other products. Mexico implemented an 8% tax on non-essential, energy-dense foods in 2014, which yielded a 6·0% reduction in purchasing of these foods.[1] In 2011, Denmark implemented a €2·14 per kg tax on saturated fat for products with more than 2·3 g per 100 g of saturated fat. Although this tax was subsequently repealed in 2013, for the duration of implementation, saturated fat purchases reduced by 4·0%, and deaths attributable to non-communicable disease were estimated to reduce by 0·4%.[2] Hungary has introduced a tax targeting prepacked foods that are high in salt, sugar, or caffeine (at varying tax rates), which has been associated with a 3·4% reduction in consumption of processed food (and a compensatory 1·1% increase in unprocessed food).[3]

A major challenge of estimating the long-term effects of food taxes and subsidies is allowing for substitution. For example, an increase in the price of foods that are high in sugar might only lead people to purchase more processed foods (that are high in sodium, saturated fat, or both) with no net health gain. Some natural experiment evaluations of real-world interventions examine substitution effects (eg, substituting sugary drinks for water in Mexico[4]), but most do not. Alternatively, one can use estimated price elasticities, including cross-price elasticities that capture the substitution and complementary effects of a change in price of one food on the purchasing of another food.[5,6]

Our study builds on a platform of research into changes in food purchasing in response to price changes. We recently published the results of a virtual supermarket experiment with randomly varying food prices.[7] Using the nutrient profile of purchased foods, in that study, we found an increase in the healthiness of purchased foods for three tax policies (sugar, saturated fat, and salt), but not for a fruit and vegetable subsidy or a sugar-sweetened beverage tax. We also found substitution effects; for example, both the saturated fat and salt tax increased fruit and vegetable purchases as a percentage by weight of all food purchases, but they also increased sugar as a percentage of total energy. Thus, the net effect on health and the relative health gain of different policies remains unknown. The objectives of the current study therefore

Research in context

Evidence before this study

Targeted subsidies and taxes on certain foods might be effective policies to improve population health and lower health-care spending, and a growing number of countries have introduced this type of policy, such as taxes on sugar-sweetened beverages that were introduced in Mexico and the UK. However, estimating the health and health system expenditure effects of food taxes and subsidies is complex, requiring the integration of evidence on how changes in food price change purchasing and consumption (price elasticity), on how changes in food intake change dietary risk factors and thus effect disease incidence rates and healthy life-years gained, and on the cost to the health system for each disease. A few previous simulation studies have estimated health gains (eg, health-adjusted life-years) and health expenditure from food taxes and subsidies. Most studies find health gains, but these are often due to substitution effects, such as a fruit and vegetable subsidy being offset by slight increases in deleterious nutrient intake, or a saturated fat tax leading to deleterious substitution by higher salt intake.

Added value of this study

This study advances the methods and rigour of simulation modelling in many ways. It uses Bayesian price elasticities estimated from previous New Zealand research and experimental data with large changes in the price of foods. It disaggregates price elasticities to 340 food groups to capture substitution effects, and it sets sugar, salt, and saturated fat taxes to offset a 20% subsidy on fruit and vegetables. The study also allows for time lags from changes in diet to changes in disease incidence, it allows for competing diseases, and it uses many parameters (eg, disease rates and costs) generated from high quality linked national data. The study finds the largest health gain for a sugar tax. All modelled food taxes and subsidies brought health gains larger than a comparably modelled 10% per annum increase in tobacco tax from 2011 to 2025. Health expenditure savings are large, ranging from US$500 to $2000 per citizen over the remainder of their lives, even when discounted at 3% per annum.

Implications of all the available evidence

Policy making at the intersection of health and food systems involves many considerations, one of them being the impact of prices on health. Food taxes and subsidies are one policy lever. The large magnitude of the health gains and cost savings of the modelled taxes and subsidies in this study suggest that their use warrants serious policy consideration.

were to assess the impacts of multiple food taxes and subsidy policies on the change in quantities of nutrients and food groups purchased, and to estimate associated changes in health system expenditure and in health gains, measured in health-adjusted life-years (HALYs).

Methods

Study design

In this modelling study, we used three steps comprising first, the effect of price changes on food purchases; second, the consequent changes in fruit and vegetable and sugar-sweetened beverage purchasing, nutrient risk factors (sodium, polyunsaturated fatty acids [PUFA], energy intake) and body-mass index (BMI); and third, how these changes affect health status, expressed as HALYs, and health expenditure, expressed as 2018 US dollars (appendix p 4). HALYS are similar to quality-adjusted life-years in that they are calculated prospectively in a simulated population (not cross-sectionally as in a disability-adjusted life-year from a burden of disease study), but they use disability weights from the Global Burden of Disease (GBD) rather than other forms of (dis)utility weights. One of our study's innovations was that we simulated the effect of changes in diet onto 17 diseases and then the gains in HALYs with time, allowing for time lags and competing mortality and morbidity risks. Our previous direct analyses[7] of the virtual supermarket experiment did not find a statistically significant impact of a fruit and vegetable subsidy on the overall healthiness of foods (nutrient profiling score), but this does not preclude some effect on HALYs, especially given that the price elasticities matrices used in the current study more comprehensively handle substitution and complementary effects. A second innovation was that we used a 20% fruit and vegetable subsidy that caused a 3·4% decrease in the food price index (ie, the price of all foods using pretax or presubsidy purchasing quantities) as an anchor, and then we set the level of the saturated fat, salt, and sugar taxes each to achieve an offsetting 3·4% increase in the food price index. This increase equated to US$1·27 per 100 g saturated fat tax, $0·52 per 100 g sugar tax, and $0·0166 per 100 mg of sodium. This approach has three advantages: first, it gives built-in comparability of the magnitude of the separate tax and subsidy policies; second, for one of the tax policies combined with the fruit and vegetable subsidy, the probably minimal effect on net food prices (ie, the subsidy and tax offset each other) might be politically and publicly more acceptable; and third, for combined policies, the expected minimal change in the total food price index poses less risk than a 3·4% change to the price index, which might violate the microeconomic assumptions inherent in elasticities. A third innovation of the current study is that we also included an 8% tax on non-essential energy-dense foods to emulate the Mexican junk food tax,[1] generating an international benchmark. A list of foods attracting the 8% Mexican junk food tax can be found elsewhere.[1]

See Online for appendix

Price and expenditure elasticities

The fourth innovation of the current study was to use an advanced set of price elasticities in a highly disaggregated matrix of 340 food groups to allow for substitution and complementary effects. A 23 by 23 food matrix was generated using a linear almost-ideal demand system, with Bayesian priors for demand equation coefficients generated from a New Zealand food price elasticities matrix.[8,9] The demand equations were first estimated for 11 hierarchical subsets of food groups (appendix p 5), and then aggregated to the 23 by 23 food group price elasticities matrix, as is common practice.[10] This approach was chosen both for computational tractability and theoretical reasons, including that food complements and substitutes for the elasticity estimation of cross-price elasticities are more important between foods considered to be alike (eg, poultry and pork) than for unlike foods (eg, poultry and beverages). The resultant price elasticities matrix is shown in the appendix (pp 9–10), and further details are published elsewhere.[7,11,12]

At the level of 23 food groups, there is still important heterogeneity within food groups in product-level concentrations of sugar and saturated fat. For example, full-fat and low-fat versions of dairy products should be taxed differently, and it was necessary to allow for shifts in purchasing within the dairy food group. Therefore, we disaggregated foods and their price elasticities into a 340 by 340 food matrix, to align with disaggregated consumption data in the 2008–09 New Zealand National Nutrition Survey (appendix p 2).[13]

Applying price elasticities matrices from one context to another, where food consumption patterns and prices differ, might violate assumptions that are inherent in price elasticities matrix estimation, which could result in underestimation or overestimation of postintervention total food purchasing.[14] We therefore constrained total food expenditure using a total food expenditure elasticity (appendix p 2).

Changes in diet and risk factors

We used the 2008–09 New Zealand Nutrition Survey[13] (acquired from the University of Otago's Life in New Zealand Research Group who conducted the survey) to inform our specification of the business-as-usual (BAU) diet, by sex, age, and ethnicity (Māori and non-Māori) for 340 food categories. Percentage changes in purchasing were assumed to be the same as percentage changes in food consumption. BMI change was derived from the change in energy intake.[15]

Epidemiological and expenditure modelling

In the proportional multistate lifetable (PMSLT[16,17]) model, the BAU lifetables for each sex-by-ethnicity-by-age cohort were specified for all-cause mortality and morbidity (with trends to 2026, then rates held constant), and the incidence and case-fatality rates for the remainder of the lifespan for 17 diet-related diseases (coronary heart disease, stroke, osteoarthritis, diabetes, and multiple cancers: endometrial, head and neck, kidney, liver, lung, oesophageal, pancreatic, stomach, thyroid, colorectal, breast, ovarian, and gallbladder). The raw estimates of disease incidence, prevalence, and case-fatality rates were first determined by sex, ethnicity, and age group from linked health records for all New Zealand citizens. They were then processed through an epidemiological calculator (DISMOD[18]) to ensure complete coherence before inputting to BAU in the PMSLT.

At the centre of calculating intervention impacts in the PMSLT is the conversion of intervention-induced changes in risk factors (ie, sodium, PUFA, fruits and vegetables, BMI, and sweetened sugary beverages) to changes in disease incidence rates. This conversion is made using population impact fractions (PIFs) that use rate ratios for each risk factor–disease association, to give percentage changes in disease incidence (appendix pp 2–3). We included risk factor–disease pairings as per the GBD Study 2013,[19] within the constraints of the risk factors that we were able to include in the PMSLT simulation model. Time lags were incorporated by the average of the PIFs 10–30 years before modelling (each limit with probabilistic uncertainty) for cancers and 0–5 years before for other conditions. To capture changes in HALYs, the differences between the BAU and intervention in disease mortality and morbidity rates (by cohort and year into the future) were summed across all diseases. They were then subtracted from the all-cause mortality and morbidity rates in the main lifetable, to give an intervention lifetable. The difference in HALYs between the BAU and intervention main lifetable is the effect size of the tax or subsidy intervention.

Disease-specific excess expenditure was assigned to the prevalent disease cases in each annual cycle of the model, and a background health expenditure was assigned to all alive simulants. Health expenditure was tallied up under both BAU and intervention scenarios, with the difference between BAU and intervention being that ascribed to the tax or subsidy policy. Calibration and validation of the epidemiological aspects of the PMSLT is described in a technical report.[20]

Statistical analysis

The modelling was done in Microsoft Excel. We used Monte Carlo simulation to estimate uncertainty in the HALY outputs, by drawing randomly from probability distributions about all input parameters. A more complete list of input parameters is given in the appendix (pp 7–8) and elsewhere,[20] including probability distributions for own-price and cross-price elasticities in the 23 by 23 food matrix. 2000 iterations were used, because this leads to reasonable stability in means, medians and the 2·5th and 97·5th percentile over repeated reruns of 2000 simulations. HALYs and costs are presented both undiscounted and, as recommended,[21] discounted at 3%.

Role of the funding source

The funder had no role in the study design, data collection, data analysis, data interpretation, the writing

	Total price index	Fruit	Vegetables	Saturated fat	Poly-unsaturated fatty acids	Sugar	Salt	BMI
Fruit and vegetable subsidy of 20%	−3·4%	16·2% (14·7 to 17·6)	32·0% (29·8 to 34·8)	−2·1% (−2·9 to −0·9)	−0·2% (−0·9 to 0·9)	1·7% (0·9 to 2·9)	−1·9% (−2·8 to −0·6)	−0·4% (−0·8 to 0·3)
Saturated fat tax	3·4%	3·3% (2·2 to 4·3)	3·5% (2·3 to 4·6)	−10·3% (−13·6 to −7·4)	−5·4% (−8·8 to −2·0)	0·1% (−1·3 to 1·4)	−2·6% (−3·9 to −1·6)	−2·0% (−2·8 to −1·3)
Sugar tax	3·4%	4·7% (3·6 to 5·6)	5·1% (3·9 to 6·2)	1·6% (0·3 to 2·8)	1·4% (−0·1 to 2·7)	−33·3% (−45·2 to −26·4)	2·2% (0·7 to 3·9)	−3·3% (−5·0 to −2·2)
Salt tax	3·4%	3·0% (2·0 to 3·8)	4·0% (2·7 to 5·1)	−2·1% (−3·4 to −0·9)	−3·5% (−5·3 to −1·7)	2·1% (0·7 to 3·5)	−12·0% (−15·9 to −9·4)	−1·9% (−2·8 to −1·2)
Junk food tax at 8% (as in Mexico)	0·9%	0·0% (−0·3 to 0·4)	0·6% (0·2 to 1·1)	−0·7% (−1·2 to −0·4)	−1·7% (−2·3 to −1·2)	−0·8% (−1·3 to −0·5)	−0·3% (−0·6 to 0·1)	−0·7% (−1·0 to −0·5)

Data are n (95% uncertainty interval). Percentage weighting is by proportionate sex by ethnic group distribution. Results by sex and age and for combination policies are shown in the appendix (pp 7–8). BMI=body-mass index.

Table 1: **Weighted average percentage changes in total food price index, nutrient purchasing, and BMI per intervention after 2011 start point**

	Coronary heart disease incidence	Stroke incidence	Colorectal cancer incidence	Diabetes incidence	Osteoarthritis incidence	All-cause mortality rate
Fruit and vegetable subsidy of 20%						
Men	−9·2%	−16·3%	−0·6%	−3·3%	−1·6%	−2·5%
Women	−9·2%	−11·3%	−0·2%	−3·9%	−1·9%	−2·0%
Saturated fat tax						
Men	−10·3%	−12·5%	−3·7%	−20·1%	−10·2%	−3·4%
Women	−8·8%	−10·1%	−1·0%	−16·4%	−8·2%	−2·2%
Sugar tax						
Men	−15·8%	−18·2%	−5·9%	−32·7%	−16·3%	−3·7%
Women	−13·6%	−14·7%	−1·5%	−26·8%	−12·8%	−2·3%
Salt tax						
Men	−11·6%	−13·9%	−3·6%	−20·4%	−10·2%	−3·7%
Women	−9·4%	−10·7%	−1·0%	−15·6%	−7·7%	−2·3%
Junk food tax at 8% (as in Mexico)						
Men	−3·5%	−4·2%	−1·3%	−7·0%	−3·6%	−1·1%
Women	−3·2%	−3·5%	−0·4%	−6·5%	−3·3%	−0·8%

Age-standardisations are to WHO World Standard.

Table 2: **Percentage changes in age-standardised incidence rates for selected diseases and all-cause mortality rate for people older than 30 years, 30 years after the tax or subsidy intervention**

of the report, or the decision to submit the paper for publication. TB, CC, AM, NN, and NW had access to the raw data used in the model. The corresponding author had full access to all of the data and the final responsibility to submit for publication.

Results

A fresh fruit and vegetable subsidy of 20% reduced the total food price index by 3·4% (table 1). The junk food tax increased the total price index by 0·9%. The percentage changes in risk factor levels show that each policy produces a notable change in the target nutrient purchasing (table 1). For example, the fruit and vegetable subsidy produced a 16·2% (95% uncertainty interval [UI] 14·7 to 17·6) increase in fruit and a 32·0% (29·8 to 34·8) increase in vegetable purchasing, the saturated fat tax gave a 10·3% (7·4 to 13·6) reduction in saturated fats, the sugar tax gave a 33·3% (26·4 to 45·2) reduction in sugar, and the salt tax gave a 12·0% (9·4 to 15·9) reduction in salt (table 1). Beneficial substitution effects included that the fruit and vegetable subsidy decreased saturated fat and salt purchasing, the saturated fat tax increased fruit and vegetables and reduced salt, the sugar tax increased fruit and vegetables, and the salt tax increased fruit and vegetables and decreased saturated fat (table 1). There were also deleterious substitution effects; the fruit and vegetable subsidy increased sugar; the saturated fat tax reduced PUFA; the sugar tax increased saturated fat and salt; and the salt tax increased sugar. The 8% junk food tax had more modest effects, increasing vegetables, and decreasing saturated fat, PUFA, and sugar. All policies lowered the midpoint BMI in each category, although for the fruit and vegetable subsidy the uncertainty interval includes an increase in BMI (–0·8 to 0·3; table 1).

We calculated the percentage differences between the intervention and BAU scenarios for selected age-standardised disease incidence and all-cause mortality rates, at 30 years after the 2011 start point, in 2041, to allow for time lags (table 2). Diabetes incidence fell more than any other disease for all tax options, ranging from a 6·5% fall among women for the junk food tax up to a 32·7% fall among men for the sugar tax (table 2). For the fruit and vegetable subsidy, the largest disease incidence reduction was for stroke (16·3% for men; 11·3% for women; table 2).

Undiscounted health gains were measured in HALYs gained during the first 20 years and during the remaining lifespan of the population (figure 1). HALYs for the lifespan ranged from 127 per 1000 people (95% UI 96–167) for the 8% junk food tax and 212 per 1000 people (102–297) for the fruit and vegetable subsidy, up to 361 per 1000 people (275–474) for the saturated fat tax, 375 per 1000 people (272–508) for the salt tax, and 581 per 1000 people (429–792) for the sugar tax (figure 1). The fruit and vegetable policy combined with the three nutrient taxes generated just less than the additive effects of the separate interventions. For example, the HALYs gained for the fruit and vegetable

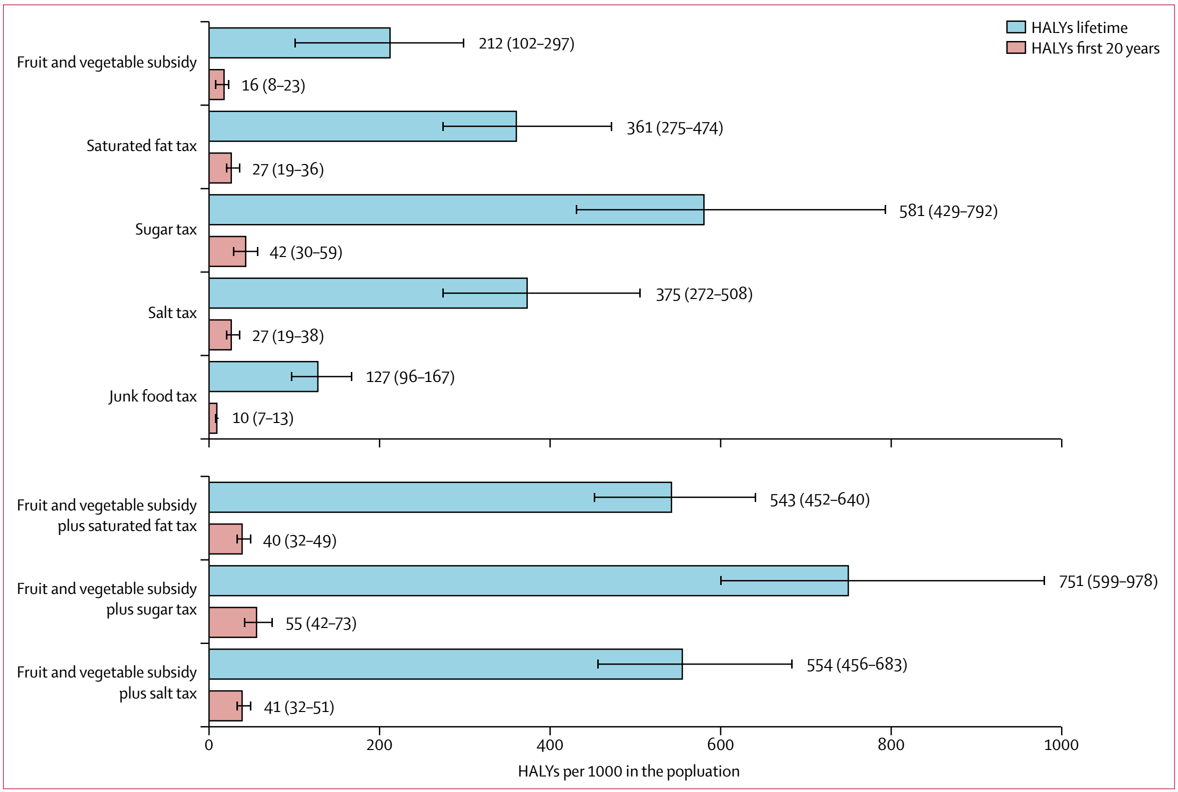

Figure 1: **Health gain in HALYs per 1000 people for tax and subsidy policies at a 0% discount rate**
Data are n (95% uncertainty interval). HALYs=health-adjusted life-years.

	0% discount rate			3% discount rate	
	HALYs gained	Proportion of BAU	Costs saved (millions)	HALYs gained	Costs saved (millions)
Fruit and vegetable subsidy of 20%	935 000 (448 000 to 1 310 000)	0·54%	$5130 (–116 to 9 460)	258 000 (231 000 to 283 000)	$2210 (1830 to 2570)
Saturated fat tax	1 590 000 (1 210 000 to 2 090 000)	0·92%	$16 300 (11 100 to 23 400)	436 000 (326 000 to 576 000)	$5870 (3980 to 8440)
Sugar tax	2 560 000 (1 890 000 to 3 490 000)	1·48%	$26 600 (17 900 to 39 400)	697 000 (519 000 to 944 000)	$9530 (6480 to 13 800)
Salt tax	1 650 000 (1 200 000 to 2 240 000)	0·95%	$16 200 (10 600 to 23 900)	453 000 (327 000 to 621 000)	$5900 (3920 to 8730)
Fruit and vegetable subsidy and saturated fat tax	2 390 000 (1 990 000 to 2 820 000)	1·38%	$20 100 (14 300 to 27 000)	647 000 (537 000 to 772 000)	$7500 (5390 to 9970)
Fruit and vegetable subsidy and sugar tax	3 310 000 (2 640 000 to 4 310 000)	1·91%	$30 100 (20 400 to 42 200)	894 000 (704 000 to 1 160 000)	$11 000 (7640 to 15 500)
Fruit and vegetable subsidy and salt tax	2 440 000 (2 010 000 to 3 010 000)	1·41%	$20 100 (14 300 to 27 900)	659 000 (535 000 to 816 000)	$7500 (5380 to 10 100)
Junk food tax at 8% (as in Mexico)	561 000 (421 000 to 735 000)	0·32%	$6060 (4080 to 8660)	156 000 (116 000 to 204 000)	$2170 (1470 to 3060)

Data are n (95% uncertainty interval) unless otherwise indicated. All costs are in 2018 US dollars, and HALYs and costs are rounded to 3 significant figures. HALYs=health-adjusted life-years. BAU=business-as-usual.

Table 3: **Health gain and health system costs saved over the population's remaining lifetime for 0% and 3% discount rates, and percentage gain from BAU**

subsidy (212) and sugar tax (581) equate to 793 per 1000 people, which is not much greater than the estimated effect of both policies applied jointly: 751 HALYs gained per 1000 people. 8% of the undiscounted health gains occurred in the first 20 years following implementation across all policies (figure 1).

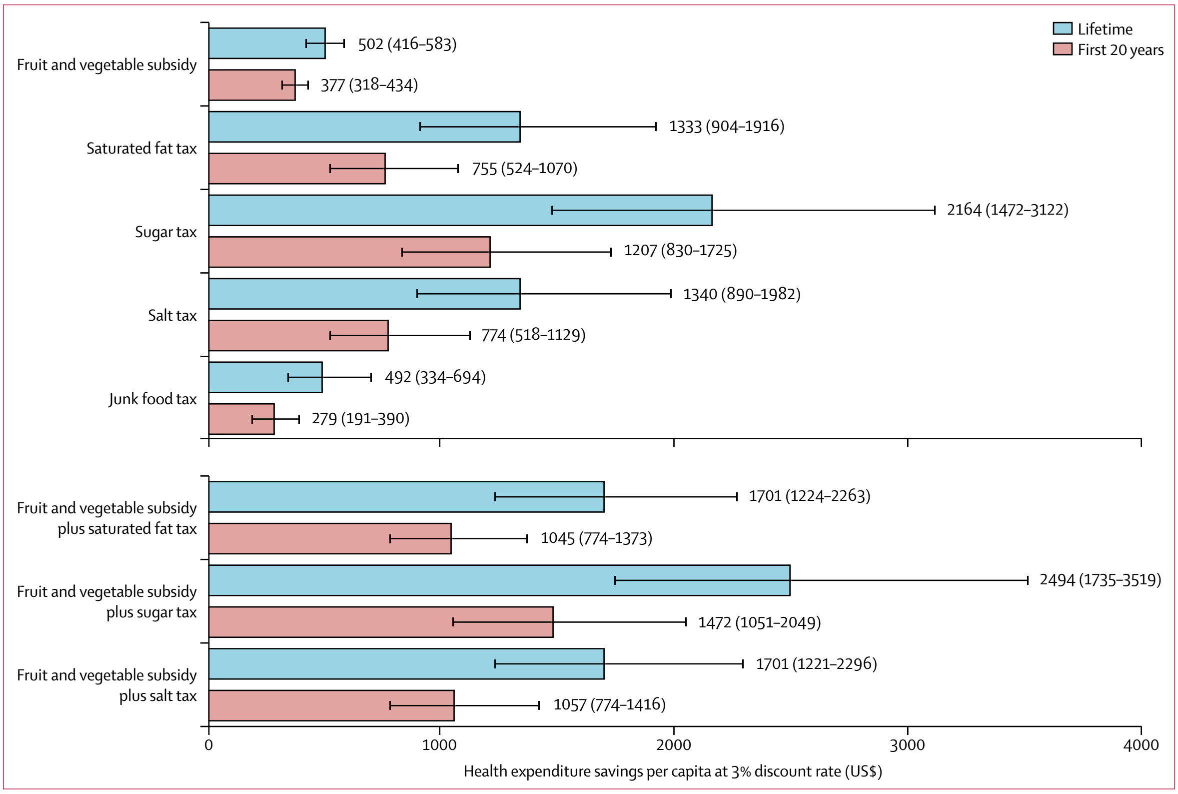

Figure 2: **Health system expenditure savings per capita for tax and subsidy policies at a 3% discount rate**
Data are n (95% uncertainty interval). Costs are in 2018 US dollars.

To better understand the magnitude of these health gains, it is useful to quantify them as the percentage gain in HALYs beyond that expected for the population under BAU (173 million HALYs for the remainder of the lifespan). The fruit and vegetable subsidy brought a gain of 935 000 HALYs (95% UI 448 000–1 310 000), which is a 0·54% increase on 173 million HALYs beyond BAU, and the combination of the fruit and vegetable subsidy with a sugar tax brought a gain of 3·31 million HALYs, which is an increase of 1·91% beyond BAU (table 3).

Most of the health gains arose because of reductions to BMI (appendix p 6), even for the salt tax (high-salt foods are also often energy dense). Per capita, all tax and subsidy policies generated as much or more age-standardised HALYs per capita for Māori compared with non-Māori people (ranging from a ratio of 0·98 for the fruit and vegetable subsidy to 1·80 for the salt tax; appendix p 11). Reductions in health expenditure over the remaining lifespan reflected patterns of health gain. Using a 3% discount rate, health expenditure savings during the remainder of the lifespan ranged from $2170 million (95% UI 1470–3060 million) for the junk food tax to $9530 million (6480–13 800 million) for the sugar tax (table 3). About a third of cost savings were realised in the first 20 years after the intervention. When health expenditure savings are expressed per capita at the 3% discount rate, they ranged from $492 (334–694) per person during the remaining lifetime for the junk food tax to $2164 (1472–3122) per person for the sugar tax (figure 2). The health gains from all food tax and subsidy policies simulated in this paper were greater than those from 10% per annum increases in tobacco tax from 2011 to 2025 in New Zealand (figure 3), as simulated using a similar model structure and methods (275 000 HALYs gained; 0% discount rate), and most of the policies created greater health gains than a sinking lid on tobacco (ie, linear reduction in all tobacco sales to 0% from 2011 to 2025; figure 3).

Discussion

All of the modelled scenarios achieved changes in their target foods and nutrients. Substitution effects that were potentially deleterious to health were not severe, as manifested by net improvements in disease incidence and HALYs gained across all scenarios. Most of the health impact of the tax policies was through changes in BMI; energy intake changes are more important than substitution effects between foods and therefore nutrient-specific effects (eg, polyunsaturated *vs* saturated fats). Marked changes in diabetes incidence rates occurred for all food tax scenarios. The tax on sugar (across all foods, not just sugary drinks) produced the greatest health gain, increasing the HALYs over the remaining lifespan of the population by 1·91% compared with BAU, or 581 HALYs

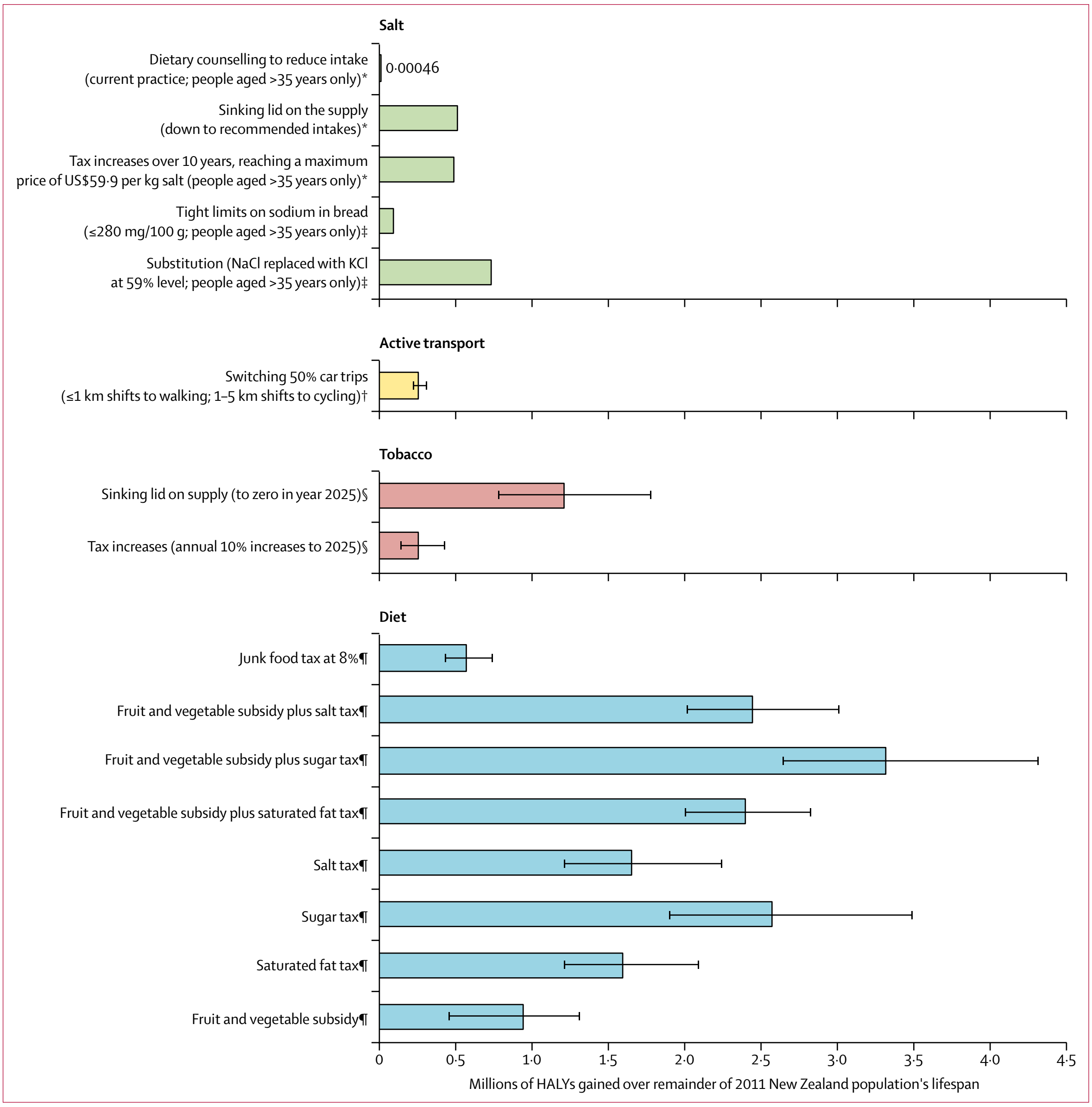

Figure 3: **Comparison of food tax and subsidy interventions with selected other interventions using the same model structure and disease inputs**
Error bars are 95% uncertainty intervals. Disease inputs include tobacco and active transport. We used a Markov model for people older than 35 years for salt interventions, which more than halves the HALYs gains because of halving the number of people included and because those older than 35 years gain less benefit than do those younger (because they have more time to accrue HALY gains with a longer life expectancy). Comparison with a greater range of interventions can be done using the Australia New Zealand-Health Intervention League Table. HALY=health-adjusted life-years. *Data from Nghiem and colleagues[22] (with 0% discount rates in the appendix). †Data from Mizdrak and colleagues.[23] ‡Data from Nghiem and colleagues[24] (with 0% discount rates in the appendix). §Data from Van der Deen and colleagues.[25] ¶Data from current paper.

per 1000 people (95% UI 429–792). The saturated fat and salt taxes each achieved about two-thirds of this gain, and the fruit and vegetable subsidy nearly 40%. An 8% junk food tax replicating that which was implemented in Mexico achieved the least gain, at 127 HALYs per 1000 people (96–167), although this was proportionate to the policy only causing a 0·9% increase in food prices compared with the 3·4% increase of the other nutrient taxes.

Disease prevention can lower health expenditure by reducing future disease incidence and hence prevalence. The policies we assessed produced estimated expenditure reductions ranging from $492 per person (for the junk food tax) to $2164 per person (for the combined fruit and vegetable subsidy and sugar tax) during the remaining lifespan of the population, even with a 3% annual discount rate.

Calculating the total fruit and vegetable subsidy cost and tax revenue intakes to governments from these

For more on the **Australia–New Zealand Health Intervention League Table** see https://league-table.shinyapps.io/bode3/bv

interventions is challenging. However, using published estimates of the total consumption in 2008–09 from the New Zealand National Nutrition Survey,[13] the daily intake of saturated fat was estimated at 36·5 g for men and 25·8 g for women. For our modelled saturated fat tax, factoring in the 10·3% decrease due to the tax, tax revenue is about $260 million per annum. Likewise, for a 20% subsidy on fruit and vegetables, allowing for increased purchasing in response to a subsidy and using New Zealand Household Expenditure Survey data for 2015–16 on fruit and vegetables, the cost to the Government would be about $145 million for fruit and $220 million for vegetables annually.

Many studies have assessed targeted taxes on sweetened sugary beverages,[26,27] but fewer have simulated the health impacts from taxes and subsidies that act on many foods. A 2007 study by Mytton and colleagues[28] raised concern that taxing saturated fat alone might create a net deleterious impact on cardiovascular disease through increased salt intake, but they did find health improvements for taxes on unhealthy foods. In 2009, Nnoaham and colleagues[29] estimated the effects of food taxes on cause-specific deaths and total deaths. They found that a saturated fat-only tax increased cancer and cardiovascular disease deaths (due to compensatory increases in salt intake), but that a package of taxing less healthy foods with all revenue used to subsidise fruits and vegetables could lead to large reductions in deaths. In 2017, Cobiac and colleagues[30] examined taxes on saturated fat, salt, sugar, and sugar-sweetened beverages, and a subsidy on fruits and vegetables. Their tax amounts were similar to those that we have used, but the taxes only applied to nutrients when they exceeded a threshold (eg, saturated fat tax only on products with more than 2·3% saturated fat), leading to lower per capita health gains. Moreover, they found that on its own, a fruit and vegetable subsidy generated health loss because of substitution effects. We suspect that if an expenditure constraint had been used (as we did with a food expenditure elasticity), this result might not have occurred.

To contextualise these results, the health gains from all food tax and subsidy policies simulated in this paper were greater than those projected for a 10% per annum increases in tobacco tax from 2011 to 2025 in New Zealand and, apart from the fruit and vegetable subsidy alone and the 8% junk food tax, the health gains across all interventions were greater than a sinking lid on tobacco.[25] This does not mean that tobacco interventions do not reap large health gains (especially for those people prevented from taking up smoking or quitting), but rather highlights that population-wide food interventions affect everyone in the population. A suite of New Zealand and Australian dietary evaluations were published in 2019–20 using similar methods.[31,32] The health gains for food taxes and subsidies in this paper greatly exceeded those for dietary interventions, such as restricted marketing or package size limits on sugary drinks, but they are roughly equivalent to substantial alcohol taxes and food reformulation (eg, major reductions of sodium). Further comparisons can be made using the Australia–New Zealand Health Intervention League Table.

Modelling health impacts is a balance of data requirements, data availability, and model parsimony, with validity assessable at two levels: uncertainty about the model structure and about the input parameters. Concerning our model structure, first of all, it did not include the impact of food reformulation. When a tax or subsidy is imposed, new incentive structures are created that the food industry is likely to respond to. For example, when the UK introduced a tiered levy on sugary soft drinks, the industry (as the policy intended) reformulated drinks to contain lower levels of sugar and introduced lower sugar products. One estimate is that two-thirds of the total health gain from sugary drinks tax is via the reformulation pathway.[33] Would this apply to food taxes and subsidies that are broader than just the specific category of drinks? The answer is almost certainly yes, but the change would probably not be as marked as with drinks, which are easily reformulated. A second aspect of our model is that it included key risk factors (eg, salt, BMI, fruits and vegetables), but future models could extend the range to include nuts and legumes, processed and red meat, and fibre. Third, and relatedly, one could include additional causal links in the model, such as directly from sugar to diabetes, given the evidence that some of the effect of sugar is through mechanisms other than bodyweight.[34] Fourth, our modelling explicitly allowed for substitution effects between foods, but not, for example, how physical activity or other risk factors impacting on the same diseases might change with a change in energy intake.

Regarding the input parameters, dietary intake was sourced from the most recent national nutrition survey,[13] which had a weighted response rate of 61%, similar to those achieved in population nutrition surveys in Australia, the UK, and Ireland.[20] Rate ratios associating risk factors to disease rates came from the GBD 2013[19] and are of comparatively high quality. Nevertheless, determining the associations of individual dietary components with disease rates is notoriously difficult; for example, measurement error and residual confounding across many, if not all of the separate studies included in meta-analyses will be present. Although we used uncertainty intervals about the inputs, this difficulty is a source of uncertainty beyond confidence intervals. For many risk factors, there is uncertainty about the threshold above or below which health harm occurs. However, we explicitly allowed for this by including uncertainty about the theoretical minimum risk exposure level in the probabilistic uncertainty analyses. A second concern with input parameters is the obvious uncertainty about future disease rates. We partially addressed this by extending past trends out to 2026, and then allowing no further change. Third, there is inevitable uncertainty about price elasticities and the extent to which they can predict future changes in purchasing. The price elasticities matrix that we used was generated from a New Zealand prior, with a Bayesian amalgamation with experimental data that was deliberately designed for assessing food tax and subsidy effects.

There have been concerns about the unintended substitution effects of food taxes and subsidies, whereby, for example, a sugar tax might lead to increased saturated fat consumption and limit health gains, or even lead to health harm. Our simulations suggest that although there will be substitution, the net health gains are still highly likely (eg, our 95% uncertainty intervals all excluded the null), at least for the specific fiscal policies modelled in this particular high-income country. Whether the same patterns would be observed in countries with markedly different dietary patterns remains to be investigated, and models such as ours provide a mechanism for doing so.

Decisions on food taxes and subsidies should not be made based only on simulation modelling studies. There are multiple other considerations, such as political and social acceptability, food industry perspectives, deadweight costs of any tax or subsidy, added complexity and bureaucracy in administering taxes and subsidies, and intervention options other than taxes or subsides (eg, mandatory reformulation of food). However, our study and those before it[23,29,30] clearly point to the probably large and positive health gains that could arise from changing the price signals. Moreover, taxes could prompt food industry product reformulation to avoid tax, further enhancing health gains over and above the direct effects that we modelled.

Contributors

TB led the conceptualisation and design of the study. CC, BS, NW, and CNM contributed to the conceptualisation and design of the study. CC and AM contributed to building models, WW led and NN contributed to the conceptualisation and design of the virtual supermarket that generated the price elasticities. TB oversaw the analysis and led the interpretation, CC and AM contributed to the analysis, and all other authors contributed to the interpretation. TB led, and all other authors contributed to the drafting and revision of the manuscript.

Declaration of interests

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