The effect of food price changes on consumer purchases: a randomised experiment

Wilma E Waterlander, Yannan Jiang, Nhung Nghiem, Helen Eyles, Nick Wilson, Christine Cleghorn, Murat Genç, Boyd Swinburn, Cliona Ni Mhurchu, Tony Blakely

Summary

Background Most evidence on health-related food taxes and subsidies relies on observational data and effects on single nutrients or foods instead of total diet. The aim of this study was to measure the effect of randomly assigned food price variations on consumer purchasing, where sets of prices emulated commonly discussed food tax and subsidy policies, including a subsidy on fruit and vegetables, a sweetened beverage tax, and taxes on foods according to sugar, sodium, and saturated fat content.

Methods In this study, adult participants (≥18 years) in New Zealand completed up to five weekly shops in a virtual supermarket. Each shopping occasion was randomly allocated to control (no change in prices) or one or more pricing options simulating the following: a fruit and vegetable subsidy (20%), a sweetened beverage tax (20% or 40%), a saturated fat tax (NZ$2 per 100 g or $4 per 100 g saturated fat), a salt tax ($0·02 per 100 mg or $0·04 per 100 mg sodium), or sugar tax ($0·40 per 100 g or $0·80 per 100 g sugar). The primary outcome was the healthiness of the total shopping basket for each weekly shop (% of total unit food items defined as healthy). Low and high price change options were combined in analyses (eg, results for a saturated fat tax are an average of $2 per 100 g or $4 per 100 g).

Findings Between Feb 1, and Dec 1, 2016, we randomly assigned 1132 shoppers, of whom 1038 (91·7%) completed at least one shop and 743 (71·6%) completed all five shops. Overall, data from 4258 shops were included in the analysis, including 645 control shops, 2545 shops where one policy was activated, and 1068 shops with two (or more) policies activated. In the control condition, 67·90% (SD 13·01) of food purchases were classified as healthy. Three of the five policies increased this proportion by a small, but significant amount (saturated fat tax mean absolute difference 1·77%, 95% CI 1·03 to 2·52, p<0·0001; sugar tax 1·09%, 0·26 to 1·91, p=0·0099; and salt tax 1·31%, 0·50 to 2·13, p=0·0016). The sweetened beverage tax and fruit and vegetable subsidy resulted in non-significant increases of 0·18% (95% CI –0·49 to 0·85, p=0·60) and 0·41% (–0·26 to 1·07, p=0·23), respectively. Both the saturated fat tax and salt tax resulted in the following important substitution effects: an increase in fruit and vegetable purchases as a percentage by weight of all food purchases (saturated fat tax 4·0%, 0·9 to 7·1; salt tax 4·3%, 0·9 to 7·7); but also an increase in sugar as a percentage of total energy (saturated fat tax 5·0%, 2·1 to 7·9; salt tax 3·2%, 0·0 to 6·5). Interaction terms for combined policies were mostly non-significant, consistent with additive effects of policy combinations.

Interpretation Price changes representing saturated fat, sugar, and salt taxes increased total healthy food purchases. As we observed important substitution effects, a combination of different tax and subsidy policies might be the most effective way to improve diets and decrease diet-related chronic diseases.

Funding Health Research Council of New Zealand.

Lancet Public Health 2019; 4: e394–405

See Comment page e363

National Institute for Health Innovation (W E Waterlander PhD, Y Jiang PhD, H Eyles PhD, Prof C N Mhurchu PhD) **and Department of Epidemiology and Biostatistics** (Prof B Swinburn PhD)**, School of Population Health, University of Auckland, Auckland, New Zealand; Department of Public Health, Amsterdam UMC, University of Amsterdam, Amsterdam, Netherlands** (W E Waterlander)**; Department of Public Health, University of Otago, Wellington, New Zealand** (N Nghiem PhD, Prof N Wilson MBChB, C Cleghorn PhD, Prof T Blakely PhD)**; Department of Economics, University of Otago, Dunedin, New Zealand** (M Genç PhD)**; and Melbourne School of Population and Global Health, University of Melbourne, VIC, Australia** (Prof T Blakely)

Correspondence to: Dr Wilma Waterlander, Department of Public Health, Amsterdam UMC, University of Amsterdam, 1105 AZ Amsterdam, Netherlands **w.waterlander@amsterdamumc.nl**

Introduction

Health-related food taxes and subsidies are a topic of growing public health importance. The evidence base for these policies is rapidly expanding[1] and numerous jurisdictions have introduced various fiscal food policies. Mexico and Hungary have implemented junk food taxes and a number of jurisdictions have soft drink taxes, including France, Mexico, Chile, Catalonia (Spain), Saudi Arabia, United Arab Emirates, Portugal, multiple US cities and, more recently, the UK and Ireland.[2–5] Emerging evidence shows that such policies (mostly sweetened beverage taxes) are effective in reducing consumption of the targeted foods or beverages. In Philadelphia, short-term effects showed that the odds of daily regular soft drink consumption were 40% lower (odds ratio 0·6, 95% CI 0·37–0·97) and the odds of bottled water consumption were 58% higher (1·58, 1·13–2·20) relative to comparison cities.[6] An evaluation of the Mexican sweetened beverage tax revealed that, after introduction of the tax, purchases of taxed beverages decreased by 5·5% in 2014 and 9·7% in 2015.[7]

A 2017 systematic review and meta-analysis[8] also supported the efficacy of taxes and subsidies in altering food and beverage consumption. This review concluded that subsidies combined with multicomponent interventions would be most effective[8] and supportive evidence

Research in context

Evidence before this study

Health-related food taxes and subsidies are increasingly the focus of research. Several systematic reviews and meta-analyses published in the last decade have assessed the effect of such taxes and subsidies in different types of studies (randomised controlled trials, simulation modelling studies, and natural experiments). To our knowledge, all systematic reviews and meta-analyses to date have concluded that food taxes and subsidies are effective, but have also highlighted important methodological limitations in studies, including a paucity of experimental studies on taxes (as opposed to subsidies) and limited generalisability (eg, in randomised controlled trials), absence of a high-quality control group (eg, in some natural experiments), and, importantly, restricted insight into the effects on the total diet because studies to date have largely been limited to changes in purchasing of single foods or nutrients targeted by the tax or subsidy.

Added value of this study

This study used a novel setting of a virtual supermarket, with shoppers randomly assigned to varying price sets that emulated a range of tax and subsidy options, allowing the generation of robust data on consumer responses to changing food prices. The study design also allowed quantification of the effect of price changes on total diet as opposed to single foods or nutrients. We found that increases in the price of foods high in saturated fat, sugar, and salt led to marked reductions in purchases of the targeted nutrients, and significantly improved the healthiness of the overall shopping basket and food purchases. However, we also observed some important substitution effects, including for the saturated fat and salt taxes, which both resulted in significant increases in fruit and vegetable purchases as a percentage by weight of all food purchases and sugar as a percentage of total energy. We could not detect an effect of beverage taxes on the healthiness of total food purchases, probably because sweetened beverages are a small component of the diet, but we did find that the most comprehensive beverage tax (including sweetened beverages, energy drinks, and fruit juices) led to significantly reduced purchases of the targeted drinks.

Implications of all the available evidence

This study adds further support to existing evidence that food taxes are an effective policy to improve population diets, particularly taxes on foods high in sugar, saturated fat, and salt. However, we also observed some important substitution effects, suggesting that a combination of different tax and subsidy policies is probably the most effective strategy for improving population diets.

for subsidies was found in multiple trials.[9,10] Nevertheless, this review[8] also identified important gaps in the evidence base. Although most studies of subsidies have been found to have a strong interventional design with objective and rigorous assessment of both price changes and dietary changes, most studies of taxation used observational cohorts in which external databases on average price changes were linked with separate information on (subjective) self-reported dietary intakes.[8]

In contrast to the evidence on subsidies, there is no supporting evidence from large randomised studies for food taxes. There have been few intervention studies at the consumer level. A non-randomised intervention study by Block and colleagues[11] showed that sales of sweetened beverages declined by 26% during a 35% price increase phase in a hospital cafeteria. Two small randomised experiments in a Dutch virtual supermarket found no significant effects of price increases (by 5%, 10%, and 25%) on unhealthy foods[12] but did find significant effects for a 13% price increase on sweetened beverages.[13] Epstein and colleagues[14] did an experiment in a laboratory setting using image cards with healthy and less healthy food and beverages and observed that taxing less healthy foods (at 12·5% or 25%) reduced overall dietary energy purchases.[14]

In addition to the growing evidence base from jurisdictions that have introduced food taxes, most evidence to date comes from econometric estimates of price elasticities of demand[15–18] and simulation of the future health effects (eg, gains in quality-adjusted life-years) of taxes and subsidies, usually using these price elasticities.[4,19–21] Although these econometric studies provide important evidence, they have some limitations, particularly because the food purchase data used to calculate price elasticities of demand are not specifically designed for public health outcomes (eg, sugar-sweetened and non-sugar-sweetened drinks are often combined in a single category) and these estimates are generally obtained from observational data with minimal price variation. Furthermore, these data often lack cross-price elasticity estimates of a change in one food's price on consumption of another,[21] and therefore cannot provide a robust estimation of the effect of food taxes and subsidies on total dietary intake.[8,15] A systematic review and meta-analysis by Cornelsen and colleagues[15] specifically reviewing evidence on cross-price elasticities of demand, showed how crucial such data are because they can reinforce, undermine, or alleviate the direct effect of a price change. For example, a tax on sweets (including sweetened beverages) was associated with less consumption of sweets, but an increase of consumption in all other food groups except fat and oils (based on 37 studies).[15] This review also found that there were insufficient studies reporting cross-price elasticities by income group, meaning it was not possible to analyse effects on socioeconomic inequalities in health.[15] Other systematic reviews[22,23] also highlighted the need for insight into the effects of health-related food taxes and subsidies on low-income groups.

Therefore, although the evidence on health-related food taxes and subsidies is increasing, there have been insufficient randomised controlled intervention studies examining taxes beyond sweetened beverages, effects on total diet, including substitution effects, and low-income groups. There is also a paucity of studies examining how different pricing scenarios could be combined for optimal results.

Therefore, the aim of this study was to measure the effect of randomly assigned food price variations on consumer purchasing, where sets of prices emulated commonly discussed food tax and subsidy policies, including a subsidy on fruit and vegetables, a sweetened beverage tax, and taxes on foods according to sugar, sodium, and saturated fat content. Our specific objectives were to measure the effect of separate health-related food taxes and subsidies on healthy food purchases and on specific nutrients and to determine whether combined food taxes and subsidies had a statistically significant effect on outcomes.

Methods

Study design and participants

A full description of the price experiment and modelling (Price ExaM) study methods has been published previously.[24] Briefly, Price ExaM used an experimental study design in which participants were exposed to random varying food prices during weekly simulated shopping occasions (shops) in a virtual supermarket setting. The study was done in New Zealand between Feb 1, and Dec 1, 2016.

Eligible participants were adults (≥18 years) with access to a computer or laptop with an internet connection and an email address, and who were confident in basic computer skills, could speak and read English, contributed to household grocery shopping, and were available during the study period. Only one person per household could participate. Participants were recruited from the general New Zealand population[24] and stated they heard about the study via social media (1193 participants), email lists (469 participants), personal communication (182 participants), internet (153 participants), newspaper or magazine (110 participants), newsletter (59 participants), participation in a previous study (51 participants), or other (radio or flyer; 77 participants). Our social media recruitment consisted of a paid Facebook advertisement that we ran multiple times. The first Facebook post resulted in 128 145 unique views with 1224 website clicks. The entire study was completed online, where participants registered, were checked for eligibility, and provided informed consent. Before commencing virtual shopping, participants had to successfully complete a tutorial in which they had to locate six products in the virtual supermarket. Participants received a NZ$10 voucher after completion of their first shop and a further $30 after completing their fifth.

Ethics approval was received from the University of Auckland Human Participants Ethics Committee on Nov 10, 2015 (reference 016151).

The virtual supermarket

The New Zealand virtual supermarket is a realistic three-dimensional computer simulation of a supermarket mirroring the instore environment of a leading national supermarket brand. Unlike online shopping, participants did not receive the purchases they made; this was a virtual experience only. Nevertheless, validation against real shopping data found the virtual supermarket to accurately represent participants' real-world shopping behaviour. The Price ExaM virtual supermarket contained 1412 unique food items on supermarket shelves with clearly marked prices that popped up when participants hovered their computer mouse over a product image. An average New Zealand supermarket contains 9000 nutritionally unique food products; we selected the top-selling products using the Australian Grocery Guide Annual Report 2010 sales data,[25] as detailed more fully elsewhere.[26] A set of checkouts was located at the end of the supermarket where participants virtually paid. All packaged products were linked to a database of brand-specific nutrition information for New Zealand packaged food products.[27] Food composition data for fresh foods and alcohol were derived from the New Zealand Food Files, a generic food composition database.[28]

For a **brief video clip of the virtual supermarket** see https://www.youtube.com/watch?v=Se0VZkhcUvk&t=11s

Randomisation and masking

Participants were randomly allocated to a different price set for each shopping occasion, using a random number generator. Randomisation was neither stratified nor conditional on a shopper's previously allocated price sets, meaning that participants were exposed to different policy conditions across their five shopping occasions. The online registration and randomisation procedure was developed by an information technology specialist and data manager who had no involvement in the rest of the trial, analysis of the data, or assessment of outcomes. Participants were masked to the nature of price sets they were assigned to (although they were obviously exposed to the prices in the virtual supermarket) and they were not aware that the study aimed to evaluate food taxes and subsidies (they were told the study was about shopping behaviour in general).

Procedures

We generated 5000 different price sets (ie, the intervention). Participants were asked to complete five household shops in the virtual supermarket (one per week), where they were exposed to a different randomly selected price set for each shopping experience (1000 participants with five shops each equals 5000 price sets). We designed price sets to resemble New Zealand usual shopping prices (control), and one or more of five different price change options (with low and high tax

	Completed shops
Four beverage taxes (20% and 40% options)*	
Sweetened beverage tax	302 (152/150)
Sweetened beverage+: sweetened beverage plus sweetened fruit drinks, sweetened energy drinks, and sweetened sports drinks tax	328 (167/161)
Sweetened beverage++: sweetened beverage plus sweetened fruit drinks, fruit juices, sweetened energy drinks, and sweetened sports drinks tax	308 (158/150)
Carbonated drink tax	331 (178/153)
Total drinks taxes (as included in analysis)	1269 (655/614)
Total drinks tax only, with no other tax or subsidy	651 (331/320)
Total drinks tax with fruit and vegetable subsidy or one of three other taxes	618 (324/294)
Fruit and vegetable subsidy (20%)*	
Fresh fruit and vegetables only	660
Fresh and frozen fruit and vegetables	625
Total fruit and vegetable subsidy (as included in analysis)	1285
Total fruit and vegetable subsidy only	636
Total fruit and vegetable subsidy with one of four taxes	649
Saturated fat tax (NZ$2 per 100 g or $4 per 100 g†)	
Saturated fat tax	904 (447/457)
Saturated fat tax only	424 (214/210)
Saturated fat tax with fruit and vegetable subsidy or one of three other taxes	480 (233/247)
Sugar tax ($0·4 per 100 g or $0.8 per 100 g†)	
Sugar tax	718 (379/339)
Sugar tax only	418 (207/211)
Sugar tax with fruit and vegetable subsidy or one of three other taxes	300 (172/128)
Salt tax ($0·02 per 100 mg sodium or $0·04 per 100 mg sodium†)	
Salt tax	718 (350/368)
Salt tax only	416 (211/205)
Salt tax with fruit and vegetable subsidy or one of three other taxes	302 (139/163)
Other	
Control shops (no taxes and no subsidies)	645
Total shops assigned to just one tax or subsidy option	2545
Total shops assigned to two or more taxes or subsidies	1068
Total shops	4258

Data are n (low tax option/high tax option) or n. *Scenarios within beverage taxes and fruit and vegetable subsidies were mutually exclusive. †To set the amount of price increase ($2 or $4 per 100 g of saturated fat, $0·4 or $0·8 per 100 g of sugar, and $0·02 or $0·04 per 100 mg of sodium), we set the lower option for each of these three taxes to approximate doubling the price of butter, doubling the price of raw sugar, and quadrupling the price of raw salt. The high tax scenario was double the low tax scenario.

Table 1: Price ExaM policy scenarios and affected food groups

options) emulating a beverage tax (comprising four mutually exclusive subtypes, each at either 20% or 40%), a saturated fat tax ($2 per 100 g and $4 per 100 g), a salt tax ($0·02 per 100 mg and $0·04 per 100 mg sodium), a sugar tax ($0·20 per 100 g and $0·40 per 100 g), and a 20% fruit and vegetable subsidy (with a fresh fruit and vegetable option and one also including frozen and canned).[24] An overview of the products that were taxed or subsidised and the rationale is provided in table 1 and the appendix (p 1); a price set might have had two or more tax or subsidy options affecting food prices to allow subsequent statistical testing of interactions between policies. We also recorded how pricing policies affected the price changes for different food groups (appendix p 1).

See Online for appendix

Within each of the 5000 price sets, the price of every product in the virtual supermarket was set to fluctuate at random, with some correlation between food categories.[24] For the food taxes or subsidy scenarios, the prices were increased for the tax policies (decreased for the subsidy policies) by a random draw with mean, for example, of 20% or 40% for the sweetened beverage tax options and SD of 30% about these means. The reason for having this element of random variation was that, in addition to the analyses in this paper, the study was also designed to allow Bayesian estimates of price elasticities of demand.[24]

On each of five shops, participants were instructed to buy the groceries for their household for the coming week just as they would in real life. Shopping occasions were roughly 1 week apart. Before their first shop, participants were asked to estimate their average weekly household shopping budget. Their allocated budget for each shop was then set to between 50% and 125% of this self-nominated budget to help ensure a valid shop (ie, participants could not just buy one item and quit the experiment) and to allow for overspending in response to higher food prices because of the taxes.

Outcomes

The primary outcome was the healthiness of the total shopping basket for each weekly shop (% of total unit food items defined as healthy). 41% of all food items were classified as healthy, namely all fresh fruit and vegetables, fresh fish, and packaged foods eligible to carry a health claim based on a government-endorsed nutrient profiling system (Nutrient Profiling Scoring Criterion[29]). Fresh red meat was not classified as healthy given its probable causal association with colorectal cancer.[30] The Nutrient Profiling Scoring Criterion system allocates an overall score to food products on the basis of a balance of both so-called positive and negative nutrients including energy, saturated fat, total sugars, sodium, fibre, protein, and percentage of fruit, vegetables, nuts, and legumes.

Secondary outcomes were total food and drink purchases (in kg), total food purchases (in kg), total energy (MJ), energy density of food (MJ/kg), energy density of drinks (MJ/kg), sugar (g and % of total energy), saturated fat (g and % of total energy), unsaturated fat (g and % total energy), sodium (mg and % by total weight of food and drink), and fresh fruit and vegetables (kg and % by total weight of food and drink).

Statistical analysis

We determined our study power based on the subsequent modelling stage of the Price ExaM study,[24] in which we aimed to recruit 1000 participants to complete a total of 5000 shops. As per protocol and to maximise power, the main analysis aimed to compare the five broad policy options with the control (ie, the 645 control shops in table 1). Therefore, we combined the different levels of tax scenario into a single policy meaning that, for example, the saturated fat tax ($2 per 100 g and

$4 per 100 g) effect corresponds to around $3 per 100 g and that we have 904 shops for the total saturated fat tax, instead of 424 shops or 480 shops for the separate sub-policies. For the sweetened beverage tax and fruit and vegetable subsidy, we present effects pooled across the four (beverage taxes) and two (fruit and vegetable subsidies) scenarios. Separate effects by low and high level of tax are shown in the appendix (p 2).

All statistical tests were two-sided at a 5% significance level, accompanied by inspection of confidence intervals. Random effects linear regression models included all randomised shops, with each shop dummy coded for the tax and subsidy options (with no assignment of any tax or subsidy option as the reference group). We accounted for repeated shopping data collected for the same participant with a random cluster effect. We estimated model-adjusted mean differences compared with the control condition for each intervention policy with associated 95% CIs and p values, adjusted for other possible policies also assigned (as participants could be exposed to multiple policies at the same time; table 1). We tested the interaction effects between intervention policies (ie, departure from additivity of separate policy effects on the outcome) and the interaction of policies with income using the log of the midpoint of each shopper's income category treated as a continuous variable (as a sensitivity analysis about socioeconomic variation of effects).

Statistical analyses were done with SAS version 9.4 and R version 3.4.4.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Between Feb 1, and Dec 12, 2016, we randomly assigned 1132 shoppers, of whom 1038 (91·7%) completed at least one shop and 743 (71·6%) completed all five shops (figure 1). Overall, data from 4258 shops were included in the analysis, including 645 control shops, 2545 shops where one policy was activated, and 1068 shops with two (or more) policies activated (table 1).

Most participants were female (79·2%), and the mean age was 32·9 years (SD 12·5; table 2). The Indigenous population (Māori) comprised 11·4% of the sample (compared with 15% of the general population at the 2013 census),[31] the median gross household income was $77 015 (compared with $63 800 for the total 2013 census population), and 71·3% had post-school qualifications (compared with around half at the 2013 census).

The proportion of food purchased that was categorised as healthy (by unit or item) in the control scenario was 67·90% (SD 13·07; table 3; appendix p 3). Three of the five policies increased this proportion by a small, but significant amount (saturated fat tax mean absolute difference 1·77%, 95% CI 1·03 to 2·52, p<0·0001; sugar tax 1·09%, 0·26 to 1·91, p=0·0099; and salt tax 1·31%, 0·50 to 2·13, p=0·0016). Looking at percentage of total energy and percentage of total weight, we also found significant differences for these policies (saturated fat tax mean absolute difference 2·6%, 1·5 to 3·7, p<0·0001; sugar tax 1·6%, 0·4 to 2·8, p=0·0090; salt tax 1·9%, 0·7 to 3·1, p=0·0020; figure 2). The sweetened beverage tax and fruit and vegetable subsidy resulted in

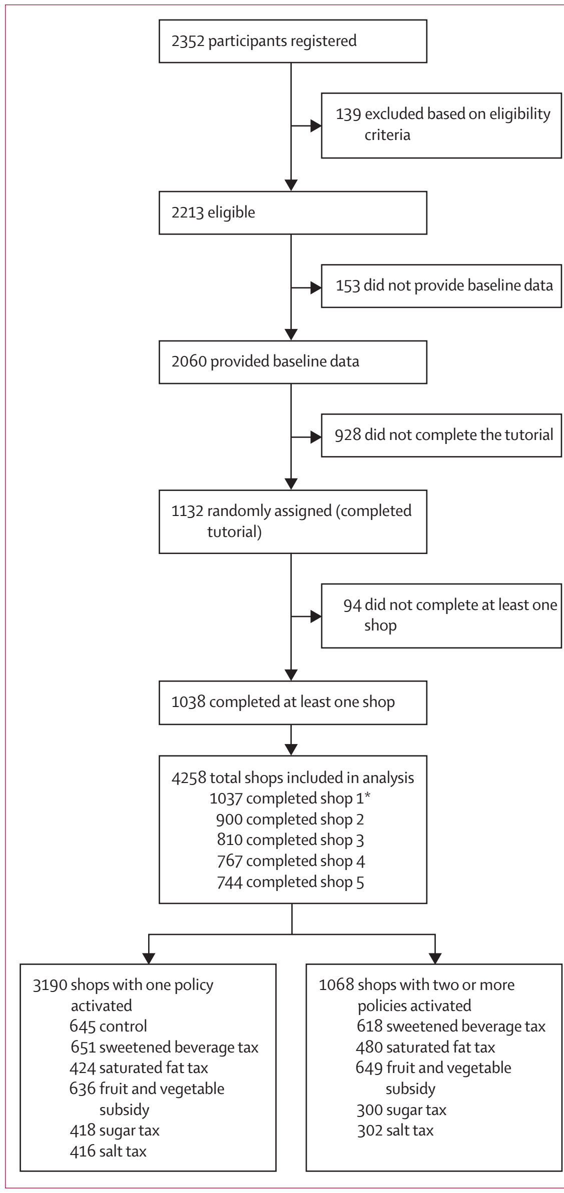

***Figure 1:* Study flow diagram**
The total number of shops for each of the policy scenarios (ie, control plus sweetened beverage tax plus saturated fat tax plus salt tax plus sugar tax plus fruit and vegetable subsidy) is larger than the total shops included in analysis because in some cases multiple policies were turned on. *For one participant, data from shop 1 were registered as shop 2.

	Participants (n=1038)
Age (years)	32·9 (12·5)
Number of shops completed	4·1 (1·5)
1	138 (13·3%)
2	90 (8·7%)
3	43 (4·1%)
4	24 (2·3%)
5	743 (71·6%)
Household size (adults and children)	3·0 (1·8)
1	173 (16·7%)
2	296 (28·5%)
3	202 (19·5%)
4	203 (19·6%)
5	97 (9·3%)
>5	67 (6·5%)
Gender	
Female	822 (79·2%)
Male	198 (19·1%)
Other	18 (1·7%)
Income* (NZ$)	
<10 000	61 (5·9%)
10 001–20 000	67 (6·5%)
20 001–30 000	63 (6·1%)
30 001–40 000	58 (5·6%)
40 001–50 000	48 (4·6%)
50 001–60 000	72 (6·9%)
60 001–70 000	59 (5·7%)
70 001–100 000	175 (16·9%)
100 001–150 000	152 (14·6%)
>150 000	95 (9·2%)
Prefer not to answer or missing	188 (18·1%)
Education (highest completed)	
None	14 (1·3%)
Secondary school	191 (18·4%)
Trade	43 (4·1%)
Undergraduate	354 (34·1%)
Postgraduate	344 (33·1%)
Other	57 (5·5%)
Prefer not to answer or missing	35 (3·4%)
Prioritised ethnicity	
Māori (Indigenous)	118 (11·4%)
Pacific	29 (2·8%)
Asian	151 (14·5%)
New Zealand European	740 (71·3%)

Data are mean (SD) or n (%). *Gross household income.

Table 2: **Participant characteristics**

non-significant increases of 0·18% (95% CI –0·49 to 0·85, p=0·60) and 0·41% (–0·26 to 1·07, p=0·23), respectively (figure 2, table 4). These results were also not significant for percentage of total energy or percentage of total weight (figure 2).

For a weekly household shop, the effects on the targeted nutrient or product compared with the control were –131·67 g saturated fat (95% CI –148·88 to –114·47) and –2·57% total energy from saturated fat (–2·99 to –2·16) for the saturated fat tax on saturated fat purchases per shop; –118·79 g sugar (–171·84 to –65·74) and –0·92% total energy from sugar (–1·50 to –0·33) for the sugar tax on sugar purchases; –10·68 g salt (–13·81 to –7·56) for the salt tax on total sodium in purchases; 0·33 kg (0·17 to 0·48) fruit and vegetables for the fruit and vegetable subsidy on fruit and vegetable purchases; and –2·22 mL (–53·66 to 49·22) for the sweetened beverage tax on sugar-sweetened beverage purchases (table 4). For all policies, we generally observed a dose-response effect, in which a higher tax or subsidy resulted in a pattern of larger change in purchases of the targeted food or nutrient compared with the control versus a lower tax or subsidy (appendix p 2).

The significant increases in healthy food purchasing (the primary outcome) for the saturated fat tax, sugar tax, and salt tax suggest a net overall benefit for these policies. However, we observed substantial effects on total spending and the total weight of food purchased, and substitution between nutrients. First, the saturated fat tax and salt tax resulted in significant reductions in the total weight of food purchased and an increase in expenditure (table 4). By contrast, the fruit and vegetable subsidy increased the total kg of food purchased. Relative shifts within purchases should be considered as well as the absolute changes. We analysed these relative shifts for the fruit and vegetable subsidy and the saturated fat, sugar, and salt tax, using percentage changes in each metric (figure 2). For example, we calculated the proportion of healthy diet as the absolute percentage point change from control (1·77%, 95% CI 1·03–2·52; table 4) divided by the baseline value for controls (mean 67·90% healthy food purchasing, SD 13·07; table 3) to give a 2·6% relative increase (95% CI 1·5–3·7) under the saturated fat tax. We also calculated the equivalent values, scaling by the control group values (table 4), for all other outcome measures and across all four price manipulations (figure 2). We found that only the fruit and vegetable subsidy had a significant impact on fruit and vegetable purchases, and not on other outcomes. Second, in addition to a large effect on saturated fat itself and a net benefit on the proportion of healthy foods purchased, the saturated fat tax also resulted in a 4·0% (95% CI 0·9–7·1) increase in fruit and vegetables as a percentage by weight of all food purchases, but also a 5·0% (2·1–7·9) increase in sugar as a percentage of total energy (figure 2). Third, the sugar tax did not have significant substitution effects on the amount of sodium purchases or fruit and vegetables by weight, nor on saturated fat or non-saturated fat (ie, total fat) by percentage of total energy (figure 2). Fourth, the salt tax resulted in a 4·3% (95% CI 0·9–7·7) increase in fruit and vegetables as a percentage by weight of all food purchases, but also a 3·2% (0·0–6·5) increase in sugar as a percentage of total energy (figure 2).

	Control (n=645)	Any of four beverage taxes (n=651)	Fruit and vegetable subsidy (n=636)	Saturated fat tax (n=424)	Sugar tax (n=418)	Salt tax (n=416)
Proportion healthy (%)	67·90 (13·07)	67·93 (13·29)	68·11 (12·22)	68·90 (13·15)	68·45 (12·18)	68·98 (12·73)
Total expenditure (NZ$)	156·54 (87·44)	157·67 (83·84)	158·07 (82·49)	167·27 (90·69)	156·86 (87·72)	160·09 (88·33)
Food and drink purchases (kg)	19·57 (10·94)	19·53 (10·31)	20·63 (10·92)	19·59 (11·08)	19·25 (11·48)	18·79 (10·61)
Food purchases (kg)	17·58 (9·94)	17·66 (9·40)	18·58 (9·84)	17·46 (9·81)	17·32 (10·04)	16·77 (9·50)
Total energy (MJ)	126·38 (79·35)	125·87 (72·89)	130·54 (76·50)	120·54 (74·73)	123·62 (77·85)	118·76 (71·11)
Total saturated fat (g)	549·74 (404·88)	536·52 (359·67)	552·71 (379·38)	425·02 (321·47)	523·50 (383·80)	499·53 (343·89)
Saturated fat (% total energy)	15·91 (6·41)	15·61 (6·20)	15·44 (5·89)	12·87 (5·82)	15·32 (5·99)	15·40 (6·11)
Total non-saturated fat (g)	768·93 (581·34)	773·16 (528·93)	798·01 (563·34)	700·31 (518·60)	758·01 (557·77)	725·39 (493·66)
Non-saturated fat (% total energy)	22·25 (8·90)	22·49 (8·14)	22·33 (8·20)	21·27 (8·04)	22·35 (7·86)	22·42 (7·34)
Total sugar (g)	1325·54 (999·56)	1325·80 (975·65)	1398·19 (974·19)	1348·02 (1020·24)	1256·85 (935·17)	1286·21 (962·37)
Sugar (% total energy)	17·87 (7·57)	17·87 (7·58)	18·43 (7·57)	19·17 (7·78)	17·79 (7·46)	18·45 (7·75)
Total sodium (g)	44·01 (50·09)	43·59 (46·08)	44·26 (48·07)	43·07 (46·60)	45·08 (50·23)	32·27 (23·42)
Sodium as % weight of food and drink (kg)	0·22 (0·19)	0·22 (0·19)	0·21 (0·17)	0·22 (0·22)	0·23 (0·24)	0·17 (0·10)
Fresh fruit and vegetables (kg)	4·18 (3·43)	4·27 (3·61)	4·55 (3·47)	4·37 (3·64)	4·12 (3·12)	4·07 (3·37)
Fruit and vegetables as % weight of total food and drink (kg)	21·88 (12·64)	22·28 (13·19)	22·56 (12·90)	22·84 (13·73)	22·75 (12·91)	21·88 (12·64)
Sweetened soft drinks (ml)	286·22 (914·88)	245·73 (792·83)	350·97 (1051·70)	305·35 (993·75)	269·59 (858·54)	295·60 (906·34)
Sweetened soft drinks as % weight of total food and drink (kg)	1·24 (3·97)	1·17 (3·67)	1·47 (4·22)	1·36 (4·27)	1·09 (3·38)	1·29 (3·85)

Data are mean (SD). n indicates the number of shops assigned only to this policy, corresponding to table 1. For data on all shops see appendix p 3. Appendix p 4 shows this table but with data divided by the number of people in the household and the number of days in the week to generate per person per day descriptive statistics.

***Table 3:* Descriptive summary of the results for the effects of the tax or subsidy policies per shop in the virtual supermarket**

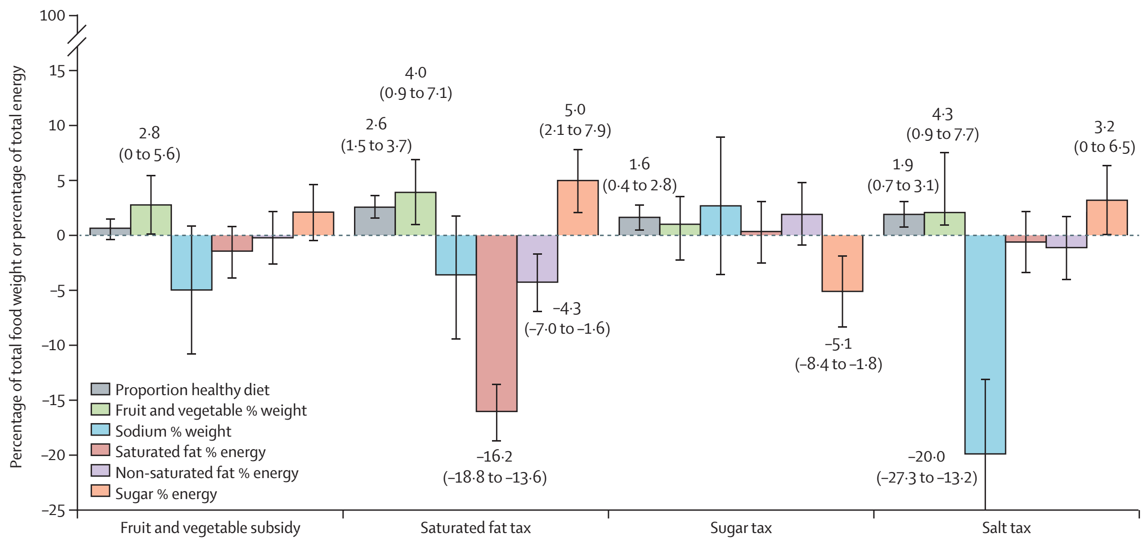

***Figure 2:* Percentage changes for intervention policies compared with control**
Data labels are for percentage changes (with 95% CI) if the shift was statistically significant, but 95% CI error bars are shown for all estimates. Results are averaged across the different subsidy tax levels tested under each policy.

Analysis of the effect of each of the four specific sweetened beverage tax policies on the targeted beverages revealed that the tax targeting the greatest number of items was most effective in reducing the volume of beverage purchased and was effective in significantly reducing purchases of targeted beverages by 170 mL per weekly household shop (95% CI 34–307; sweetened beverage++; table 1; appendix p 5). Furthermore, when comparing the different tax levels (20% to 40%) for these four policies, we found that for eight (72·7%) of 11 outcomes the effects of the 40% tax were larger than the effects of the 20% tax (appendix p 6). We recorded descriptive data for the results of each policy individually (separate from the other policies in the mixed model; appendix p 7).

	Beverage tax (n=1269)		Fruit and vegetable subsidy (n=1285)		Saturated fat tax (n=904)		Sugar tax (n=718)		Salt tax (n=718)	
	Δ	p value	Δ	p value	Δ	p value	Δ	p value	Δ	p value
Proportion healthy items (%)	0·18 (–0·49 to 0·85)	0·6000	0·41 (–0·26 to 1·07)	0·2311	1·77 (1·03 to 2·52)	<0·0001	1·09 (0·26 to 1·91)	0·0099	1·31 (0·5 to 2·13)	0·0016
Total (NZ$)	–1·01 (–2·87 to 0·86)	0·2918	–1·33 (–3·17 to 0·52)	0·1579	2·88 (0·8 to 4·95)	0·0066	–0·67 (–2·98 to 1·64)	0·5690	2·43 (0·16 to 4·69)	0·0358
Food and drink (kg)	–0·05 (–0·33 to 0·23)	0·7125	0·68 (0·41 to 0·96)	<0·0001	–1·06 (–1·37 to –0·75)	<0·0001	–0·41 (–0·75 to –0·06)	0·0211	–0·48 (–0·82 to –0·14)	0·0056
Food (kg)	0·02 (–0·25 to 0·28)	0·9056	0·60 (0·35 to 0·86)	<0·0001	–0·89 (–1·18 to –0·6)	<0·0001	–0·27 (–0·59 to 0·05)	0·1036	–0·52 (–0·83 to –0·2)	0·0014
Energy (MJ)	–1·21 (–3·59 to 1·18)	0·3204	2·06 (–0·29 to 4·42)	0·0854	–12·3 (–14·93 to –9·64)	<0·0001	–2·42 (–5·37 to 0·52)	0·1064	–5·78 (–8·67 to –2·89)	<0·0001
Energy density food (MJ/kg)	–0·06 (–0·16 to 0·04)	0·2577	–0·09 (–0·2 to 0·01)	0·0699	–0·39 (–0·5 to –0·27)	<0·0001	0·004 (–0·12 to 0·13)	0·9545	–0·12 (–0·25 to 0·002)	0·0532
Saturated fat (g)	5·32 (–10·19 to 20·83)	0·5010	8·05 (–7·26 to 23·35)	0·3029	–131·67 (–148·88 to –114·47)	<0·0001	–0·97 (–20·09 to 18·15)	0·9208	–32·17 (–50·97 to –13·37)	0·0008
Saturated fat (% total energy)	0·29 (–0·09 to 0·66)	0·1366	–0·24 (–0·62 to 0·13)	0·2005	–2·57 (–2·99 to –2·16)	<0·0001	0·05 (–0·41 to 0·52)	0·8161	–0·1 (–0·56 to 0·35)	0·6629
Non-saturated fat (g)	–1·64 (–27·89 to 24·6)	0·9023	16·06 (–9·87 to 41·98)	0·2247	–95·95 (–125·06 to –66·84)	<0·0001	11·98 (–20·33 to 44·3)	0·4673	–44·61 (–76·42 to –12·8)	0·0060
Non-saturated fat (% total energy)	0·13 (–0·41 to 0·67)	0·6326	–0·05 (–0·58 to 0·49)	0·8562	–0·96 (–1·56 to –0·36)	0·0016	0·44 (–0·22 to 1·1)	0·188	–0·25 (–0·91 to 0·4)	0·4514
Sugar (g)	–7·51 (–50·56 to 35·53)	0·7322	47·41 (4·92 to 89·9)	0·0288	–80·48 (–128·23 to –32·73)	0·0010	–118·79 (–171·84 to –65·74)	<0·0001	–23·28 (–75·46 to 28·89)	0·3816
Sugar (% total energy)	–0·14 (–0·62 to 0·33)	0·5559	0·38 (–0·09 to 0·85)	0·1129	0·9 (0·37 to 1·42)	0·0009	–0·92 (–1·50 to –0·33)	0·0021	0·58 (0·0003 to 1·16)	0·0499
Sodium (g)	–1·93 (–4·5 to 0·65)	0·1427	–1·43 (–3·97 to 1·12)	0·2723	–3·69 (–6·55 to –0·83)	0·0113	–0·67 (–3·83 to 2·49)	0·6771	–10·68 (–13·81 to –7·56)	<0·0001
Sodium as % weight of food and drink (kg)	–0·007 (–0·02 to 0·006)	0·2860	–0·011 (–0·024 to 0·001)	0·079	–0·008 (–0·022 to 0·006)	0·269	0·006 (–0·009 to 0·021)	0·4460	–0·044 (–0·06 to –0·029)	<0·0001
Fresh fruit and vegetables (kg)	0·1 (–0·05 to 0·26)	0·1979	0·33 (0·17 to 0·48)	<0·0001	–0·02 (–0·2 to 0·15)	0·8131	–0·03 (–0·22 to 0·17)	0·8011	0·14 (–0·05 to 0·33)	0·1476
Fresh fruit and vegetables as % weight of food and drink	0·46 (–0·16 to 1·07)	0·1444	0·61 (0·01 to 1·22)	0·0477	0·87 (0·19 to 1·55)	0·0123	0·23 (–0·52 to 0·99)	0·5465	0·94 (0·19 to 1·68)	0·0136
Sweetened soft drinks (ml)*	–2·22 (–53·66 to 49·22)	0·9326	63·46 (12·62 to 114·3)	0·0144	–0·39 (–57·44 to 56·66)	0·9894	–32·85 (–96·12 to 30·42)	0·3087	26·25 (–36·1 to 88·6)	0·4092
Sweetened soft drinks as % weight of food and drink (kg)	–0·06 (–0·28 to 0·17)	0·6300	0·15 (–0·08 to 0·37)	0·2028	0·03 (–0·22 to 0·28)	0·8073	–0·27 (–0·55 to 0·01)	0·0552	0·03 (–0·25 to 0·3)	0·8538

Results from a regression model with all policies in the model, adjusted for the fact that sometimes multiple policies might have been turned on (and standard adjusted for multiple shops). *Sweetened beverages—ie, beverages that were taxed in all four beverage tax policies.

***Table 4:* Regression estimated mean differences in food purchases compared with control (n=645) per shop, for each policy independently**

We tested the possible interactive effects of the food taxes and subsidies on total and single nutrient purchases by examining whether there was a significant interaction for any of the two policies together (for example sugar tax and sweetened beverage tax together having an effect that was less or more than that expected based on their separate and independent effects) on any of the outcome measures. 1068 (25·1%) of 4258 total shops were exposed to a combination of two or three policies (table 1; figure 1). We found statistically significant interactions for only six (3·0%) of 200 possible interactions, consistent with these interactions being due only to chance (appendix p 8). Statistically significant interactions between policy effects and shoppers' log income were observed in only three (4·1%) of 74 possible tests, also consistent with chance.

Discussion

This study presents new evidence of the effects of food price changes by using an innovative design in which study participants were exposed to different price set scenarios in a virtual supermarket. Among participants who were randomly assigned to control price sets, 67·90% of purchased items were categorised as healthy.

Healthy purchasing increased significantly under the saturated fat tax, sugar tax, and salt tax. The sweetened beverage tax and fruit and vegetable subsidy had no significant effects on the total units of healthy food purchased.

Important findings were that the three policies that affected the price of multiple foods—the saturated fat tax, sugar tax, and salt tax—had significant positive effects on net healthy food purchasing (the primary outcome) and their target nutrient, with larger effects for larger price changes. However, for each policy there were important substitution or displacement effects, which are challenging to interpret. For example, on an absolute scale difference, the volume of fruit and vegetable purchases (in kg) only increased for the fruit and vegetable subsidy. However, as a percentage of the total weight of food and drink purchases, fruit and vegetable purchases also increased significantly for the saturated fat and salt taxes, as these policies substantially decreased the total weight of food and drink purchased. Although both measures are probably important, in the context of this study we place more emphasis on the relative changes (as shown in figure 2) for two reasons. First, relative changes within diet are commonly considered in nutrition research (eg, the percentage of energy derived from specific macronutrients). Second, relative changes in purchases are a standard measure to reflect changes in health outcomes from pricing policy instruments.[32,33] Moreover, when consumers are suddenly exposed to high prices (as in our study), changes in absolute purchases probably more closely reflect short-term shock changes in purchasing, leading for example to higher (fruit and vegetable subsidy) or lower (saturated fat and salt tax) total purchased food weight, which might not be sustained in the long term because of complex homeostatic, hedonic, and cognitive feedback mechanisms.[34] Over time, one would expect that consumers would tend to adjust to price changes and keep their energy intake constant. Therefore, relative shifts in nutrients might plausibly be stable over time with long-term adaptation. This observation has some important implications for our findings. First, the saturated fat tax was associated with an increase in sugar as a percentage of total energy intake. Whether a saturated fat tax would still result in a net improvement in healthy diet is dependant on two things—the relative effects of the different nutrients on diseases and population health (eg, as can be estimated by simulating quality-adjusted life-years gained); and how the food industry might respond to a saturated fat tax. There is substantial emerging evidence of food industry reformulation of sweetened beverages in response to taxes.[35,36] If the food industry substitutes non-saturated fats (eg, more vegetable oils) for saturated fats in foods in response to a saturated fat tax, this could avoid the reduction in non-saturated fats suggested by our results. However, if the food industry reformulated foods to include more sugar instead of saturated fat, the increase in sugar we observed for a saturated fat tax could be greater still. A sugar tax has a more focused effect solely on sugar as a percentage of total purchased energy but does not (in our study at least) increase fruit and vegetables as a percentage of total food weight, unlike the saturated fat and salt taxes. Our study provides improved information on probable nutrient substitution effects, which is crucial because these effects can reinforce, undermine, or alleviate the direct effect of a price change.[15] However, the net effect if applied in a real-world setting will depend greatly on how the food industry reformulates food, the food regulatory environment that such taxes and subsidies are introduced into, and any accompanying public health messaging (eg, improved nutrition labelling). Combinations of tax and subsidy options, accompanied by codes of practice with and regulation of the food industry (eg, to set maximum levels of hazardous nutrients, to improve nutrition labelling, and to constrain marketing) might yield the best improvements in population diets and mitigate potential unintended consequences.[8,21]

Our analyses did not find any pattern of statistically significant interactions between food tax and subsidy programmes for the primary or secondary outcomes. Although our study was probably underpowered to detect such interactions individually, we would have expected to see more than 5% of interactions overall being statistically significant if there truly were underlying important interactions. Similar findings were also obtained for interactions by shoppers' income. This finding does not necessarily mean that combined policies will not be more effective, but rather that, as best we can tell and putting aside food industry reformulation, the effects would be additive. Also, because lower socioeconomic groups might be more likely to have poorer diets and higher proportions of disease attributable to diet,[37] the net effect on population health would probably be greater for lower socioeconomic groups than for higher socioeconomic groups, a hypothesis that can be tested in population simulation models.

Our results are in line with previous studies showing that taxes resulted in a significant change in purchasing for the targeted nutrient, except for the sweetened beverage tax.[1,8,38] However, the sweetened beverage tax policy included in our main analysis was a combined policy that averaged different types of drinks (eg, carbonated drinks only) and different tax levels (20% and 40%), and, with sweetened beverage purchases accounting for only a small amount of household food purchases, our study power is limited. The latest New Zealand household economic survey showed that 3·5% of total household food shopping was spent on soft drinks, waters, and juices,[39] compared with 0·13% in our study. However, when examining the sweetened beverage tax subpolicies we found that the beverage tax option that targeted the greatest range of beverages was effective in significantly reducing purchases of these beverages. Furthermore, we generally found greater effects of higher price changes compared with lower price changes, suggesting that to be demonstrably effective, a beverage tax should target many sugary beverages (including fruit drinks) and be substantial (ideally 40% or more), which is in line with a study by Blake and colleagues.[40] Nevertheless, while a sweetened beverage tax is a potentially important way to reduce purchases of such products, this would target only one dietary category. Further policies might be needed, including those tested in this study, to obtain substantial benefits from changes in total population diets.

A key strength of this study was the randomised repeated measures design, which is rare in this area of research. Furthermore, existing experimental and randomised studies in this field are often relatively small (a few hundred participants), whereas we used shopping data from 4258 shops where the food prices differed (representing five tax or subsidy options or control) in each of the shops. From this design, we could show results on total diet (as opposed to single nutrients only), thereby including substitution effects.

However, a limitation of our design is that the price changes tested in this study might not be directly translatable to the effects of taxes and subsidies in the real world—eg, the price changes were not communicated to participants. With real-world policies, there would probably be signalling in the mass media that a tax or subsidy was going to be introduced, alongside the rationale that certain food products were being taxed or subsidised because the government (and its science advisers) considered these foods or nutrients to be unhealthy or healthy. Therefore, the real-world effects might be greater than those seen in our study, as was observed in a study showing that signposting could be an important complementary nudge policy to enhance the effect of taxes.[41] Likewise, pricing strategies could be combined with health education strategies, as there is evidence that diet education could strengthen the effects of food subsidies.[10] Furthermore, our intervention price changes were substantial, and whether responsiveness to smaller price changes will be proportional is uncertain (although this is what most price elasticity studies assume). Our study deliberately selected non-trivial price changes that presumably would be in line with any deliberate policy on food taxes and subsidies. Finally, our policy options assumed exact concordance with changes in food prices; if taxes are not passed on to the consumer by the food industry or retailers (or conversely, prices are increased more than tax) then our results will either overestimate or underestimate the real-world effects.

Another limitation of this study is that a virtual supermarket is not the same as a real supermarket, and virtual food purchases might not reflect outcomes for actual consumption. Nevertheless, the external validity of the software has been tested in a validation study, which confirmed that virtual supermarket purchases were a good representation of real-life purchases. Regarding the link between purchases and consumption, we have seen in previous studies that both fruit and vegetable purchases and consumption increased following fruit and vegetable subsidies.[10] Also, measures of purchases have an advantage over consumption surveys because the data are objective and unaffected by recall bias.[10] All participants had to complete a tutorial before being randomly assigned, so there would have been some selection towards more motivated participants (but also to participants incentivised by financial inducement). In addition to external validity for the New Zealand population, there is likely to be some generalisability of this New Zealand trial to other countries and contexts. Humans respond to price changes across all contexts, to the point where meta-analyses of price elasticities generated in different countries are being done.[15] However, responses to price changes will vary by cultural norms (eg, what is considered a staple food, with less responsiveness to price, varies by country), differing pre-tax and subsidy prices, and viable substitute food sources. Therefore, it would be valuable to repeat this study in different countries and contexts.

Our study required participants to carry out five subsequent shops, which we consider a more efficient design than recruiting five times as many participants each for one shop. We do not expect any bias because most participants provided five shops and because the price sets were randomly allocated to each shop.

We found positive effects for the nutrient taxes that affect many foods, but these taxes can be more challenging to implement in terms of policy detail compared with, for example, a narrowly-targeted tax on sweetened beverages, and might lead to negative spill-over effects as reported in this study. We were only able to test a selection of policy options in this study. There are further possible options, such as combining the three nutrient taxes (salt, sugar, and saturated fat) into a junk food tax (as used in Mexico with some evidence of success, or perhaps using a nutrient profile score), adopting an ultra-processed food tax,[42] or combining taxes with subsidies or higher welfare benefit payments, which would probably have more political support.[43] This study was also specifically designed to allow the calculation of price elasticities (under review elsewhere) as an alternative output that can be used to estimate the health effects of any kind of tax and subsidy amount or combination. Nevertheless, we can conclude at this point that the net health gains are probably from food taxes and subsidies, but also dependent on political and societal support, policy design and implementation, and accompanying incentives and regulations for the food industry to reformulate.[44]

In conclusion, this study examined the effects of five different policy options (sweetened beverage tax, saturated fat tax, sugar tax, salt tax, and fruit and vegetable subsidy) on total household food purchases and on specific nutrient or product purchases. Three policies showed significant positive effects on total healthy purchases—the sugar tax, salt tax, and saturated fat tax—but we noted important substitution effects of all policies to other foods and nutrients. These results suggest that a combination of policies might yield the best results, accompanied by monitoring and (probable) regulation of food industry reformulation in response to the taxes to prevent unintended harm and maximise healthiness of processed foods. In general, we observed stronger effects for higher taxes or subsidies compared with lower taxes or subsidies.

Contributors

WEW, NW, BS, CNM, and TB conceived and designed the project. WEW and HE designed the experiment. WEW, HE, and CNM designed the virtual supermarket software. WEW led the data collection and analysis. WEW, NN, CC, and TB drafted the manuscript. NN, CC, MG, and TB designed the economic and simulation modelling methods, which contributed to the design of the study. NN, YJ, and TB analysed the data and interpreted the results. YJ designed the statistical analyses. YJ, HE, MG, NW, BS, and CNM revised the manuscript critically for important intellectual content. HE analysed the nutrition data. HE and CC interpreted the results. CNM advised on the experimental design of the project. All authors read, provided input to, and approved the final version of the manuscript.

Declaration of interests

CNM and CC report grants from the Health Research Council of New Zealand during the conduct of the study.

Data sharing

Requests for de-identified individual participant data or study documents will be considered where the proposed use aligns with public positive purposes, does not conflict with other requests or planned use by the trial steering committee, and the requestor is willing to sign a data access agreement. Contact is though the corresponding author. Consent for data sharing was not obtained but the presented data are anonymised and the risk of identification is low. The original protocol is available from the corresponding author on request.

Acknowledgments

This study was funded by a Health Research Council of New Zealand programme grant (grant no 13/724). We would like to acknowledge our study team, including our project manager (Rachel Carter), research assistant (Rita George), virtual supermarket software developer (Tijs de Kler), our information technology specialist (Debra Warren), and data manager (John Fa'atui).

References

1 Wright A, Smith KE, Hellowell M. Policy lessons from health taxes: a systematic review of empirical studies. *BMC Public Health* 2017; **17:** 583

2 Mytton OT, Clarke D, Rayner M. Taxing unhealthy food and drinks to improve health. *BMJ* 2012; **344:** e2931.

3 WHO. Tackling NCDs: 'best buys' and other recommended interventions for the prevention and control of noncommunicable diseases. Geneva: World Health Organization, 2017.

4 Briggs ADM, Mytton OT, Kehlbacher A, et al. Health impact assessment of the UK soft drinks industry levy: a comparative risk assessment modelling study. *Lancet Public Health* 2017; **2:** e15–22.

5 Backholer K, Blake M, Vandevijvere S. Sweetened beverage taxation: an update on the year that was 2017. *Public Health Nutr* 2017; **20:** 3219–24.

6 Zhong Y, Auchincloss AH, Lee BK, Kanter GP. The short-term impacts of the Philadelphia beverage tax on beverage consumption. *Am J Prev Med* 2018; **55:** 26–34.

7 Colchero MA, Rivera-Dommarco J, Popkin BM, Ng SW. In Mexico, evidence of sustained consumer response two years after implementing a sweetened beverage tax. *Health Aff (Millwood)* 2017; **36:** 564–71.

8 Afshin A, Peñalvo JL, Del Gobbo L, et al. The prospective impact of food pricing on improving dietary consumption: a systematic review and meta-analysis. *PLoS One* 2017; **12:** e0172277.

9 Ni Mhurchu C, Blakely T, Jiang Y, Eyles HC, Rodgers A. Effects of price discounts and tailored nutrition education on supermarket purchases: a randomized controlled trial. *Am J Clin Nutr* 2010; **91:** 736–47.

10 Waterlander WE, de Boer MR, Schuit AJ, Seidell JC, Steenhuis IHM. Price discounts significantly enhance fruit and vegetable purchases when combined with nutrition education: a randomized controlled supermarket trial. *Am J Clin Nutr* 2013; **97:** 886–95.

11 Block JP, Chandra A, McManus KD, Willett WC. Point-of-purchase price and education intervention to reduce consumption of sugary soft drinks. *Am J Public Health* 2010; **100:** 1427–33.

12 Waterlander WE, Steenhuis IH, de Boer MR, Schuit AJ, Seidell JC. Introducing taxes, subsidies or both: the effects of various food pricing strategies in a web-based supermarket randomized trial. *Prev Med* 2012; **54:** 323–30.

13 Waterlander WE, Ni Mhurchu C, Steenhuis IH. Effects of a price increase on purchases of sugar sweetened beverages. Results from a randomized controlled trial. *Appetite* 2014; **78:** 32–39.

14 Epstein LH, Dearing KK, Roba LG, Finkelstein E. The influence of taxes and subsidies on energy purchased in an experimental purchasing study. *Psychol Sci* 2010; **21:** 406–14.

15 Cornelsen L, Green R, Turner R, et al. What happens to patterns of food consumption when food prices change? Evidence from a systematic review and meta-analysis of food price elasticities globally. *Health Econ* 2015; **24:** 1548–59.

16 Ni Mhurchu C, Eyles H, Schilling C, et al. Food prices and consumer demand: differences across income levels and ethnic groups. *PLoS One* 2013; **8:** e75934.

17 Nghiem N, Wilson N, Genç M, Blakely T. Understanding price elasticities to inform public health research and intervention studies: key issues. *Am J Public Health* 2013; **103:** 1954–61.

18 Sharma A, Hauck K, Hollingsworth B, Siciliani L. The effects of taxing sweetened beverages across different income groups. *Health Econ* 2014; **23:** 1159–84.

19 Briggs AD, Kehlbacher A, Tiffin R, Garnett T, Rayner M, Scarborough P. Assessing the impact on chronic disease of incorporating the societal cost of greenhouse gases into the price of food: an econometric and comparative risk assessment modelling study. *BMJ Open* 2013; **3:** e003543.

20 Cobiac LJ, Tam K, Veerman L, Blakely T. Taxes and subsidies for improving diet and population health in Australia: a cost-effectiveness modelling study. *PLoS Med* 2017; **14:** e1002232.

21 Eyles H, Mhurchu CN, Nghiem N, Blakely T. Food pricing strategies, population diets, and non-communicable disease: a systematic review of simulation studies. *PLoS Med* 2012; **9:** e1001353.

22 Mizdrak A, Scarborough P, Waterlander WE, Rayner M. Differential responses to food price changes by personal characteristic: a systematic review of experimental studies. *PLoS One* 2015; **10:** e0130320.

23 Niebylski ML, Redburn KA, Duhaney T, Campbell NR. Healthy food subsidies and unhealthy food taxation: a systematic review of the evidence. *Nutrition* 2015; **31:** 787–95.

24 Waterlander WE, Blakely T, Nghiem N, et al. Study protocol: combining experimental methods, econometrics and simulation modelling to determine price elasticities for studying food taxes and subsidies (The Price ExaM Study). *BMC Public Health* 2016; **16:** 601.

25 Australian Grocery Guide. Retail World Annual Report. Rydalmere, NSW: Retail Media, 2010.

26 Waterlander WE, Jiang Y, Steenhuis IH, Ni Mhurchu C. Using a 3D virtual supermarket to measure food purchase behavior: a validation study. *J Med Internet Res* 2015; **17:** e107.

27 Eyles H, Neal B, Jiang YN, Mhurchu CN. Estimating population food and nutrient exposure: a comparison of store survey data with household panel food purchases. *Brit J Nutr* 2016; **115:** 1835–42.

28 New Zealand Food Composition Database. Foodfiles. 2016. http://www.foodcomposition.co.nz/foodfiles (accessed June 12, 2019).

29 Food Standards Australia New Zealand. Short guide for industry to the Nutrient Profiling Scoring Criterion in Standard 1.2.7—nutrition, health and related claims. May, 2016. http://www.foodstandards.gov.au/industry/labelling/Documents/Short-guide-for-industry-to-the-NPSC.pdf (accessed June 12, 2019).

30 Domingo JL, Nadal M. Carcinogenicity of consumption of red meat and processed meat: a review of scientific news since the IARC decision. *Food Chem Toxicol* 2017; **105:** 256–61.

31 Statistics New Zealand. 2013 Census QuickStats about Māori. Dec 3, 2013. http://archive.stats.govt.nz/Census/2013-census/profile-and-summary-reports/quickstats-about-maori-english/population.aspx (accessed July 12, 2019).

32 Andreyeva T, Long MW, Brownell KD. The impact of food prices on consumption: a systematic review of research on the price elasticity of demand for food. *Am J Public Health* 2010; **100:** 216–22.

33 Powell LM, Chaloupka FJ. Food prices and obesity: evidence and policy implications for taxes and subsidies. *Milbank Q* 2009; **87:** 229–57.

34 Hall KD, Hammond RA, Rahmandad H. Dynamic interplay among homeostatic, hedonic, and cognitive feedback circuits regulating body weight. *Am J Public Health* 2014; **104:** 1169–75.

35 Goiana-da-Silva F, Cruz-e-Silva D, Gregório MJ, Miraldo M, Darzi A, Araújo F. The future of the sweetened beverages tax in Portugal. *Lancet Public Health* 2018; **3:** e562.

36 Public Health England. Sugar reduction and wider reformulation programme: report on progress towards the first 5% reduction and next steps. London: Public Health England, 2018.

37 Petrovic D, de Mestral C, Bochud M, et al. The contribution of health behaviors to socioeconomic inequalities in health: a systematic review. *Prev Med* 2018; **113:** 15–31.

38 Alagiyawanna AMAAP, Townsend N, Mytton O, Scarborough P, Roberts N, Rayner M. Studying the consumption and health outcomes of fiscal interventions (taxes and subsidies) on food and beverages in countries of different income classifications; a systematic review. *BMC Public Health* 2015; **15:** 887.

39 Statistics New Zealand. Household expenditure statistics: year ended June 2016—corrected. Dec 1, 2016. https://www.stats.govt.nz/information-releases/household-expenditure-statistics-year-ended-june-2016 (accessed July 15, 2019).

40 Blake MR, Lancsar E, Peeters A, Backholer K. The effect of sweetened beverage price increases and educational messages on beverage purchasing behavior among adults. *Appetite* 2018; **126:** 156–62.

41 Zizzo D, Parravano M, Nakamura R, Forwood S, Suhrcke ME. The impact of taxation and signposting on diet: an online field study with breakfast cereals and soft drinks. York: Centre for Health Economics, University of York, 2016.

42 Taillie LS, Rivera JA, Popkin BM, Batis C. Do high vs low purchasers respond differently to a nonessential energy-dense food tax? Two-year evaluation of Mexico's 8% nonessential food tax. *Prev Med* 2017; **105:** S37–42.

43 Caraher M, Cowburn G. Guest commentary: fat and other taxes, lessons for the implementation of preventive policies. *Prev Med* 2015; **77:** 204–06.

44 World Cancer Research Fund International. Building momentum: lessons on implementing a robust sugar sweetened beverage tax. London: World Cancer Resarch Fund International, 2018.