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In search of an appropriate mix of taxes and subsidies on nutrients and food: A modelling study of the effectiveness on health-related consumption and mortality

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A B S T R A C T

Taxes and subsidies on foods and nutrients have the potential to promote healthier diets and thereby reduce mortality. In this study, we examine the effects of such policy instruments on Swedish public health. Specifically, we estimate the effects of food and nutrient taxes and subsidies on mortality averted and postponed in Sweden, using both demand system estimations and simulation models. We evaluate different Value Added Tax (VAT) reforms. The VAT is raised on food products that are particularly rich in saturated fat or salt and lowered on fruit and vegetables. Our models predict that an increase in the current VAT of 12% on food, to 25% VAT on products rich in saturated fat plus a 0% VAT on fruits and vegetables would result in almost 1100 deaths (95% CI: −832; −1363) averted or postponed in a year in Sweden, while the combination of a 34.4% VAT on products rich in saturated fat and a −10.4% VAT (i.e. a subsidy) on fruits and vegetables would result in almost 2100 (95% CI: −1572; −2311) deaths averted or postponed corresponding to a 4.8% reduction in diet-related annual death. Most of the deaths averted or delayed from this reform would be deaths from coronary heart disease (−1,148, 95% CI: −728; −1586), followed by stroke −641 (95% CI: −408; −887) and diet-related cancer deaths (−288, 95% CI: −11; −435). We find that health-related food taxes and subsidies improve dietary habits as well as reduce the mortality of the Swedish population. However, the effect of these reforms on different socioeconomic classes and which reforms provide the best value for money, i.e., cost-effectiveness of these reforms needs to be established first before implementation.

Credit author statement

Sanjib Saha: Conceptualization, Methodology, Model, Formal analysis, Writing – original draft preparation, Writing – review & editing, Funding acquisition, Jonas Nordström: Conceptualization, Methodology, Model, Formal analysis, Writing – original draft preparation, Writing – review & editing, Funding acquisition, Peter Scarborough: Writing – original draft preparation, Writing – review & editing, Funding acquisition, Linda Thunström: Methodology, Writing – original draft preparation, Writing – review & editing, Ulf-G. Gerdtham: Methodology, Writing – original draft preparation, Writing – review & editing.

1. Background

Non-Communicable Diseases (NCDs) constitute considerable challenges to public health, as they are some of the most important determinants of mortality and morbidity, as well as individual suffering due to reduced quality of life from ill-health. Focusing on mortality

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alone, cardiovascular diseases (CVDs), including ischemic heart disease and stroke, are the leading cause of mortality in the world(GBD, 2018) as well as in Sweden (GBD, 2017). Globally, unhealthy diets are now responsible for more deaths than tobacco use (GBD, 2019), and, in Sweden, poor diet is the second largest risk factor for death and disability, closely following tobacco use (GBD, 2017). The dietary habits of the Swedish population deviate substantially from the recommended food consumption, suggesting that significant health gains might be harvested from policies that incentivize the Swedish population to follow the dietary recommendations provided by the Swedish National Food Agency (Saha et al., 2019a).

Here, economic policy reforms such as incorporation of taxes and subsidies, or a combination of both, on unhealthy and healthy foods and nutrients might improve public health, as suggested by the World HealthWHO (2016) For example, a meta-analysis showed (Afshin et al., 2017) that 10% decreases in price (by subsidies) increased the consumption of healthy foods by 12% and a 10% increase in price by taxes or other means decreased the consumption of unhealthy foods and beverages by 6%. However, to learn how these reforms translate to public health improvements, changes in consumption need to be linked to health data. A few studies that have estimated the health benefits due to taxes and subsidies. For instance, the implementation of a tax on saturated fat in Denmark in 2011 (DKK 16 (€2.24) per Kilogram saturated fat) resulted in a 0.4% reduction in all NCD-related deaths in a year (Smed et al., 2016a). The tax was applied to butter, milk, cheese, pizza, meat, oil and processed food that contained more than 2.3% saturated fat; the tax resulted in a 20% price increase for butter. Further, a simulation study based on data from New Zealand suggests that a 20% subsidy of fruits and vegetables would result in a gain of 935,000 health-adjusted life years and would save more than $2 billion over the population's remaining lifetime (Blakely et al., 2020). The authors used a linear almost ideal -demand system which assumes linear expenditure patterns - a conservative assumption. In another study, a combination of taxes on unhealthy nutrients and subsidies of fruits and vegetables was predicted to avert 470,000 disability-adjusted life years in the Australian population of 22 million and save 3.4 billion Australian dollars (Cobiac et al., 2017). There are few studies that evaluated the health benefits of salt tax (Federici et al., 2019), subsidies on fruits and vegetables (Dallongeville et al., 2010), taxes on sugar and sweetened beverages (Powell et al., 2013), sales tax (Kalamov, 2020) and taxes on calory (Okrent and Alston, 2012) on obesity reduction. However, these studies do not use household consumption of all non-durable goods due to a lack of information on household's purchasing behavior.

Given consumer preferences and price sensitivity differ substantially across countries, effectiveness of policies aimed at modifying dietary patterns will also likely differ across countries. It is therefore important to rely on country-specific studies when deciding on the implementation of policies aimed at improving public health.

In this study, we examine the effectiveness of a broad range of economic policy reforms designed to improve the diet of the average Swede. We compare the impact on public health measures from a tax on food that is generally over-consumed (such as food with a high content of salt or saturated fat), to a reform that entails both the tax and a subsidy of food that is under-consumed (such as fruit and vegetables).

While this study is not the first to examine the effects of food tax reforms aimed at encouraging a healthier national Swedish diet, it substantially expands upon previous studies. Nordström and Thunström, 2009, 2011a, 2011b examine the impact of tax reforms in Sweden to increase the intake of food products that Swedes generally under-consume. However, the household consumption data in these studies contained detailed information for grain products only, while other food categories (such as meat and dairy products) were not included in the study. Nordström and Thunström (2011a) also conclude that it is difficult to compare net health benefits from different reforms in the absence of information about the link between changes to nutrient intake and health measures. In the current study we examine the effect of economic policy reforms using a highly detailed and rich Swedish data set that includes consumption of all food categories, as well as other types of consumption which is a major contribution to the international literatures. Further, we evaluate how various tax reforms will contribute to health benefits. To do so, we use PRIME (Scarborough et al., 2014), a model developed to estimate changes in cardiovascular and cancer related mortality due to changes in dietary intake. PRIME model is freely available with user guidance developed by the World Health Organization (WHO, 2019).

2. Materials and methods

We use two simulation models to estimate the effect of different tax/ subsidy reforms on CVDs and diet-related cancer deaths that could be prevented or delayed. Fig. 1 gives an overview of the analysis framework. In the first model, we estimate the impact on food and nutrient consumption from price changes, based on estimated behavioral parameters from a system of demand equations (see Fig. 2). In the second model, we estimate the number of deaths that could be prevented or delayed in a particular year due to the change in nutrient consumption.

2.1. *Tax and subsidy reforms*

We evaluate different Value Added Tax (VAT) reforms. The VAT is raised on food products that are particularly rich in saturated fat or salt and lowered on fruit and vegetables. The food categories that are considered to be rich in saturated fats are butter and margarine; cakes and biscuits; cheese, cream and milk (3% fat), pastry products, beef, lamb, pork and prepared, preserved, and processed meat. Food products rich in salt are bread and breakfast cereals; prepared, preserved and processed meat; beef, lamb, pork poultry; and takeaway foods. This classification is in line with Ni Mhurchu et al. (Ni Mhurchu et al., 2015). The reforms that we analyze are described in Table 1.

In VAT #1 to 5, we increase the VAT rate for food products rich in saturated fats or salt to 25% and lower the VAT for fruit and vegetables to zero percent, either for individual food categories or combined for several food categories. In line with previous research (Nordström and Thunström, 2009; Brännlund and Nordström, 2004), we assume that the tax burden falls entirely on consumers. In Sweden, the VAT on food is 12%, while the standard VAT rate is 25%. VAT #1 to 5 therefore imply that consumer prices on food rich in saturated fats or salt increase by 11.61%, while consumer prices for fruit and vegetables decrease by 10.71%.

In VAT #6 to 10 we further increase the difference in the relative prices between healthy and less healthy food products. Specifically, we follow Ni Mhurchu et al. (Ni Mhurchu et al., 2015) and increase consumer prices on food rich in saturated fat or salt by 20%, while decreasing prices for fruit and vegetables by 20%. To accomplish these price changes, the VAT is raised to 34.4% on food rich in saturated fat or salt and lowered to negative 10.4% for fruit and vegetables.

2.2. *Consumption of the average swede*

To determine Swedes' average dietary intake, we use data from the latest large-scale dietary survey, i.e., "Riksmaten-vuxna 2010–11", which was conducted by the Swedish National Food Agency (Livsmedelsverket). A representative sample of 5003 Swedish individuals of 18–80 years was invited to participate in the survey, resulting in a final sample size of 1797 individuals. Using a web-based food questionnaire, participants self-reported their total food and beverage consumption during four consecutive days. For this study, we used age and sex-stratified information about energy intake, fiber, salt, total fats, saturated fats, poly unsaturated fatty acids (PUFA), monounsaturated fatty acids (MUFA), cholesterol, as well as consumption of fruits and vegetables. We find that the average Swede consumes less fruits and vegetables than recommended (Livsmedelsverket, 2012) and more total fat,

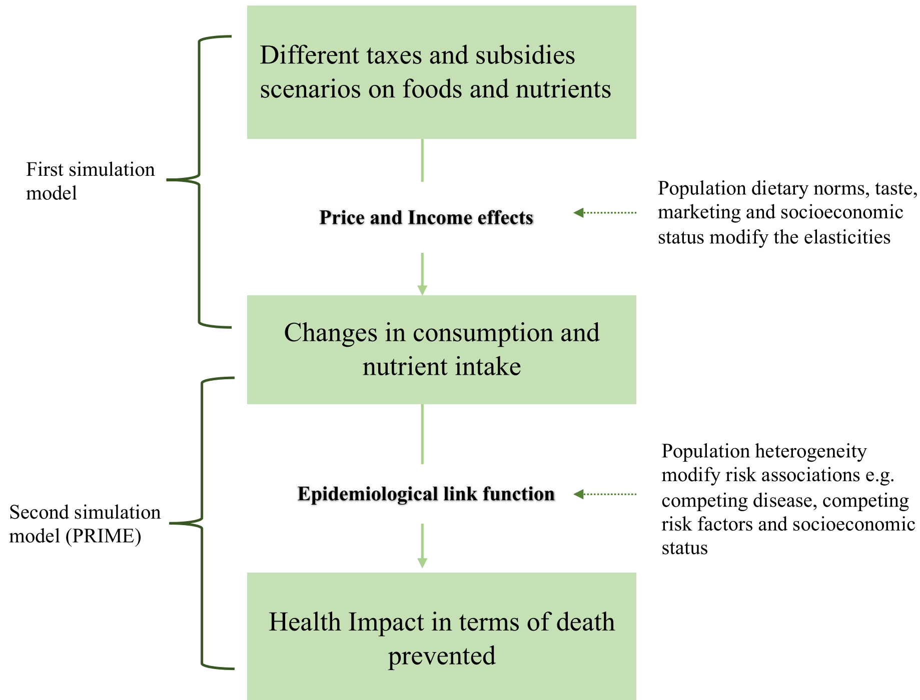

Fig. 1. A causal diagram of effect of food taxes/subsidies on health (adapted from Eyles H et al. (Eyles et al., 2012b)).

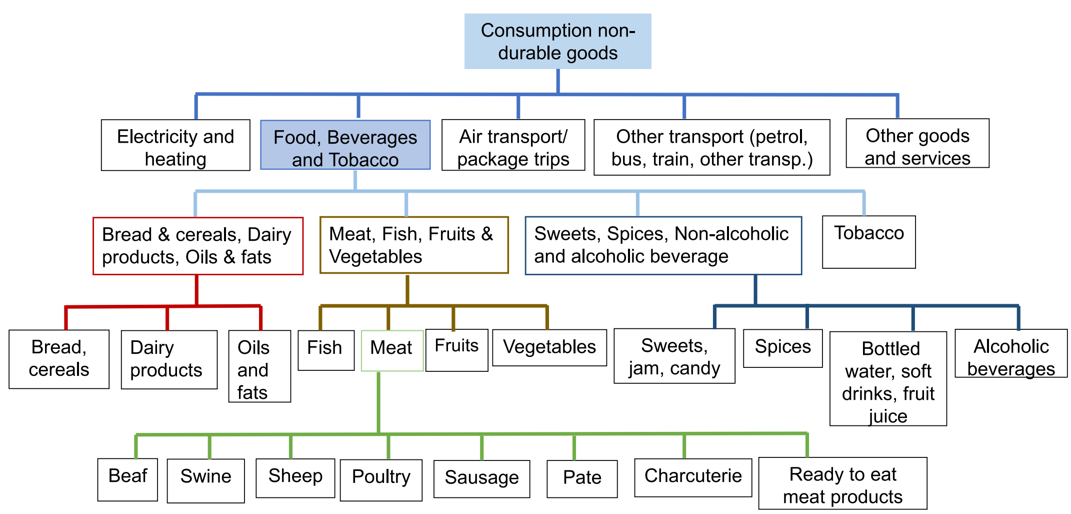

Fig. 2. Household demand.

saturated fat and salt than recommended. Further, there are significant gender differences in consumption – we find that men consume more salt and fiber than women. Detailed information on consumption of nutrients and food groups is available in the supplementary materials.

2.3. First simulation model

To be able to calculate the change in food and nutrient intake due to changes in relative prices, we need information about the households' behavioral response as a result of price changes. These parameters are estimated based on demand system estimation, and then used in the first simulation model. Since non-linear expenditure patterns (income expansion paths) are likely to be important in our analysis, as are substitution patterns between different food products resulting from changes in the relative prices, we use the Exact Affine Stone Index (EASI) implicit Marshallian demand system (Lewbel and Pendakur, 2009). Unlike the AID system, EASI builds around the Stone price index which facilitates the simulations of the tax reforms (Lewbel and Pendakur, 2009).

We use cross-sectional data for the years 2003–2009, and in the modelling, we include households' consumption of all non-durable goods. The advantage of including all non-durable goods in the demand system, and not just the food products that we include in the second simulation model to study the health effects, is that we avoid unnecessary restrictive assumptions on individual preferences. For example, we do not need to assume that consumption of food and alcohol is separable (independent) from other non-durable consumption, such as clothes and transportation. In doing so, we reduce a source of bias to our results. Models that impose erroneous separability assumptions will likely generate biased results. A subsidy of e.g., fruit and vegetables will, for example, result in a higher household real income, which may then be allocated across any types of consumption. In the

Table 1
Different tax and subsidy reform models and their description.

Reforms	Description
Imposing 25% or 0% VAT from 12% baseline VAT ≈ price change of 11.61% or −10.71%	
VAT #1	25% VAT on products rich in Salt
VAT #2	25% VAT on products rich in Saturated fat
VAT #3	Zero VAT on F&V
VAT #4	25% VAT on products rich in Saturated Fat and zero VAT on F&V
VAT #5	25% VAT on Saturated Fat and Salt and zero VAT on F&V
Imposing 20% price change for taxed and subsidized products ≈ imposing 34.4% VAT or −10.4% VAT from 12% baseline VAT	
VAT #6	34.4% VAT on products rich in Salt
VAT #7	34.4% VAT on products rich in Saturated fat
VAT #8	−10.4% VAT on F&V
VAT #9	34.4% VAT on products rich in Saturated Fat and −10.4% VAT on F&V
VAT #10	34.4% VAT on products rich in Saturated Fat and Salt and −10.4% VAT on F&V

Abbreviations: F&V, Fruits and Vegetables; SEK, Swedish Krona; VAT, Value Added Tax; ≈, equals to.
Note: 1 Euro = 10.21 SEK, 2018 price year.

food tax literature very few studies account for this fact, i.e., most studies assume that changes to real income from food tax reforms affect consumption of food only (Eyles et al., 2012a).

To estimate the behavioral parameters, we use consumption data on food products, tobacco, alcohol and other non-durable goods from Statistics Sweden's Household Expenditure Surveys (HES). Information about food consumption in the HES is detailed and reported on a four-digit Classification of Individual Consumption According to Purpose (CICOP) level. The HES contain e.g., information about household expenditures on different kinds of meat products (red meat, pork, lamb, poultry, sausage, processed meat products, ready meals) dairy products, fruit and vegetables, sweets etc. The expenditure surveys also contain information about household characteristics and socioeconomic status which allows us to control for these factors in the estimation of the demand system. For the years 2003–2009, the HES contain consumption and household characteristics data from about 15,000 households.

The expenditure data is matched with market prices from Statistic Sweden and Nielsen's scanner data which is exogenous aggregated price data (not self-reported price data). Furthermore, the nutritional content in the food products, e.g., fiber, fat, saturated fat, salt, sugar, added sugar and energy are also matched with the expenditure data for the specific food products. The knowledge of nutrient intakes enables us to examine the impact of the tax reforms on the prevalence of diet related diseases. A change in total intake of dietary fiber affects the prevalence of CHDs, stroke, and colorectal cancer. Changes in the intake of total fat and total saturated fat have an effect on total serum cholesterol, whereas a change in the intake of salt affects the systolic blood pressure. The changes in the mediating variables blood cholesterol, blood pressure, and body weight are then related to the probability of developing different diseases in simulation model 2.

To calculate the nutritional content in the different food categories we use product-specific information and the product's EAN code (European Article Number), which is a specific code for each product from Nielsen scanner database (Nielsen, 2021). This scanner data contains all sales of food products that are sold in Swedish supermarkets. To determine the nutritional content in the food products we use several data bases and sources, so that the nutritional information is as detailed and specific as possible. Where possible, we use data bases that match the EAN code of the food product to its nutritional content. This ensures that the information is as product specific as possible. For more homogenous product groups with little variation in the nutritional content, such as different kinds of flour and lettuce, we use information about standard products in nutritional data bases (e.g., the National Food Agencies data base, the Fabrikant database, FINELI, the producer's own homepages, etc.). Based on the products with the highest sales value, we calculate the nutritional content of 80–90% of the products sold in each food category.

The EASI demand function is estimated using Generalized Method of Moments (GMM), which is a distribution-free estimator that allows us to control for endogeneity of real expenditures (Lewbel and Pendakur, 2009). Based on the estimated parameters, this simulation model allows us to examine the effects of taxes/subsidies on consumption and food/nutrients intake. For a description of this procedure, see Nordström and Thunström (2009). In Fig. 2, we present the household demand system that is used in this study and in the supplementary materials we present the specification of demand system together with estimated coefficients, standard errors and p-value together with own price elasticities for the goods used in Fig. 2.

2.4. *The second simulation model*

The next step is to convert the estimated effects on consumption from the first simulation model to mortality which is accomplished in the second simulation model. Here, we use a comparative risk assessment macrosimulation model, PRIME (Preventable Risk Integrated ModEl) (Scarborough et al., 2014). This model simulates the effect of changes in consumption of foods (fruits and vegetables) and nutrients (dietary fiber, salt and fatty acids) on risk factors, such as serum cholesterol, blood pressure and overweight/obesity to diet-related mortality from CVDs and diet-related cancers.

The food components included in the PRIME model have been shown to be associated with CVDs and cancer, or biological risk factors for these diseases, in meta-analyses of randomized trials or prospective cohort studies. The results from these meta-analyses are used to parameterize changes in nutritional risk factors and mortality as a result of the change in population intake of food items and nutrients via the calculation of Population Impact Fractions (Scarborough et al., 2014). PRIME estimates the differences in mortality in one single year between the baseline scenario (actual dietary intake, in this case) and the counterfactual scenario (changes in dietary intake caused by the tax reforms). Some key assumptions for the model are:

1. The counterfactuals are based on changing dietary variables that are continuous (e.g. fruit consumption (g/d)), rather than binary exposures (meet recommendations for fruit (yes/no)). Therefore, a distribution of each variable within the population is used as baselines for the model. For the counterfactuals, a shift of distribution is made so that the new mean level of consumption matches the changes due to policy reforms, but the variance in the population remains the same as for the baseline.
2. Combined changes in the risks for individuals are multiplicative. For instance, if reduction of salt intake by 1 g per day reduces the risk by 12% and one extra serving of vegetables reduces the risk of CVDs by 10% then both of these behaviour changes jointly reduce the risk of CVD death by 20.8% (1- (1–0.10) × (1–0.12)).
3. Changes in risk follow a log-linear, dose-response relationship whereas obesity follows a J-shaped curve. For example, the effect on relative risk is same if a person increases his consumptions of vegetables form 2 servings to 3 servings comparing to a change in consumption from 4 to 5 servings. Though, an upper threshold has been included, above which no additional health benefits could be achieved. The upper thresholds are established based on data from the metanalyses. It is unlikely that the effects of different food components are independent and additive. By combining parameters multiplicatively, the PRIME model estimates the overlap in estimated changes in risk of cause-specific mortality as they relate to changes in different dietary components (i.e., the outcome of changing several dietary components simultaneously is less than the sum of its parts and can never exceed 100% risk reduction).

The details regarding the underlying assumptions of the model are provided in technical reports (Scarborough et al., 2014; WHO, 2019).

2.5. Population statistics

The PRIME model entails age- and sex-specific population mortality for stroke (ICD-10: I60-69), coronary heart diseases (ICD-10: I20-25), and diet-related cancers (ICD-10: C00–14, C16, C23, and C33-34) for a given year, which we retrieved from the Swedish National Board of Health and Welfare (Socialstyrelsen) database (Socialstyrelsen. Statisti). Population statistics have been obtained from the Statistics Sweden database. We use the information of population and mortality data from 2018.

2.6. Uncertainty analysis

A Monte Carlo method was conducted to estimate the Uncertainty Intervals (UI) around the results. Each of the estimates in the PRIME model was allowed to vary according to the distribution reported in the accompanying literature. The 95% UI estimates are based on the 2.5th and 97.5th percentiles of results obtained from 5000 iterations of the model.

3. Results

3.1. Changes in food prices and consumer price index

Table 2 shows the effect on the Consumer Price Index (CPI) of the tax reforms. The changes in CPI vary from −1 to 2% for the VAT reforms. VAT #3, which combines a VAT of 25% for food rich in saturated fat with a VAT of 0% on fruit and vegetables, results in a modest increase in CPI with 0.57%. The price elasticities are included in the supplementary materials which are in line with similar literature (ref Basu).

3.2. Changes in food consumption and nutrient intake

In Table 2, we present percentage changes in the consumption of different nutrients and food items due to the different tax reforms presented in Table 1. As expected, our model predicts larger effects on consumption with larger changes to taxes and/or subsidies. However, our model suggests that even if we impose the larger VAT reforms (VAT#6 to VAT#9), the average Swede is unable to reach the dietary intake recommended by the Swedish National Food Agency. The results also reveal that a tax may result in unwanted side effects. For example, while a tax on products rich in salt (VAT #1 and #6) reduces salt consumption, it also increases consumption of saturated fat.

However, not all tax reforms generate meaningful negative side effects. Specifically, the VAT reform on products rich in saturated fat (VAT #2) does not generate a substantial negative side effect. The subsidy on fruits and vegetables (VAT #3) is also promising and results only in a modest increase in the intake of saturated fat. The VAT reforms that combine subsidies and taxes also seem promising, since they reduce the overall intake of saturated fat and salt and increase the intake of fruits and fiber to a fairly large extent. The results also reveal that the combined VAT reform (#5) that taxes both products rich in saturated fat and salt and subsidizes fruits and vegetables results in a lower intake of salt but a higher intake of saturated fat, compared to VAT reform (#4) that only taxes products rich in saturated fat and subsidizes fruits and vegetables. To evaluate which of the reforms has the best public health outcome, however, we need to add to our analysis the health effects of consuming different types of foods and nutrients.

3.3. Changes in public health outcomes

The number of deaths that can be prevented or averted in a year according to the PRIME model, can be subdivided according to different types of foods and nutrients, as well as disease-specific deaths, as shown

Table 2
Percentage changes in the consumer price index and consumption associated with each reform model.

Reforms		Changes in Consumer Price index	Changes in Consumption									
			Energy	Fruits	Vegetables	Fiber	Salt	Fat	Saturated fat	MUFA	PUFA	Cholesterol
Imposing 25% or 0% VAT from 12% baseline VAT ≈ price change of 11.61% or −10.71%												
VAT #1	25% VAT on products rich in Salt	0.90	−0.42	9.29	−2.06	−2.93	−2.32	2.14	2.33	2.38	3.16	0.60
VAT #2	25% VAT on products rich in Saturated fat	1.11	0.54	7.44	−2.10	4.06	−0.06	−3.20	−3.69	−2.89	−2.22	−3.76
VAT #3	Zero VAT on F&V	−0.55	0.61	11.80	0.81	2.45	−0.21	0.19	0.12	0.26	1.19	−0.52
VAT #4	25% VAT on products rich in Saturated Fat and zero VAT on F&V	0.57	1.20	20.24	−1.48	6.63	−0.25	−2.99	−3.60	−2.58	−0.90	−4.28
VAT #5	25% VAT on Saturated Fat and Salt and 0% VAT on F&V	0.90	0.46	21.55	−2.04	2.83	−2.51	−1.36	−1.54	−1.00	0.88	−3.21
Imposing 20% price change for taxed and subsidized products ≈ imposing 34.4% VAT or −10.4% VAT from 12% baseline VAT												
VAT #6	34.4% VAT on products rich in Salt	1.55	−0.52	15.93	−3.54	−4.59	−3.70	3.73	4.02	4.13	5.52	1.04
VAT #7	34.4% VAT on products rich in Saturated fat	1.92	1.08	12.73	−3.58	6.95	0.02	−5.08	−5.90	−4.60	−3.42	−6.08
VAT #8	−10.4% VAT on F&V	−1.01	1.27	24.71	1.39	4.97	−0.37	0.43	0.24	0.62	2.55	−0.98
VAT #9	34.4% VAT on products rich in Saturated Fat and −10.4% VAT on F&V	0.90	2.53	41.04	−2.94	12.33	−0.25	−4.58	−5.72	−3.75	−0.39	−7.03
VAT #10	34.4% VAT on products rich in Saturated Fat and Salt and −10.4% VAT on F&V	1.47	1.20	43.53	−3.93	5.90	−4.10	−2.01	−2.45	−1.25	2.41	−5.33

Abbreviations: F&V, Fruits and Vegetables, MUFA, Monounsaturated fatty acids; PUFA, Polyunsaturated fatty acids, VAT, Value Added Tax.

in Table 3 and Table 4, respectively.

The PRIME model predicts that the VAT #4 reform, with 25% VAT on products rich in saturated fat plus 0% VAT on fruits and vegetables, would result in −1093 deaths (95% CI: −832; −1363) averted or postponed (see Table 3). This reform is thus better from a public health perspective than the broader VAT reform #5 that taxes products rich in saturated fat and products rich in salt and subsidizes fruits and vegetables. Due to the larger changes in the relative prices between healthy and less healthy food in VAT reform #9 and #10, these reforms generate larger benefits to public health. For instance, VAT #9, (a combination of VAT on saturated fat and subsidies on fruits and vegetables), results in −2089 (95% CI: −1572; −2311) deaths averted or postponed, according to our model. This corresponded to a 4.8% reduction in diet-related annual deaths.

In terms of disease-specific deaths prevented, the model predicts that for the VAT reform with the highest benefits to public health (VAT #9), most deaths that are prevented or averted are those due to coronary heart disease (−1,148, 95% CI: −728; −1586), followed by deaths from stroke (Table 4). This reform also prevents the highest number of diet-related cancer deaths (−288, 95% CI: −11; −435). It is noteworthy that any taxes imposed on products rich in salt, or salt directly (VAT #1 and #6), seems to increase the number of deaths from coronary heart disease, although the increase is not statistically significant.

4. Discussion

We used two complementary simulation models to predict health benefits (in terms of reduced mortality) of food and nutrients taxes and subsidies on unhealthy/healthy food in Sweden. We found that taxes on unhealthy foods and nutrients, subsidies of healthy foods, and the combination of these could avert or postpone substantial numbers of deaths. Of the VAT reforms we examine, the combinations of taxes and subsidies generate the highest public health benefits, where most prevented or delayed deaths are those from coronary heart disease.

All of the reforms modelled in this study illustrate that it is possible to avert or postpone deaths in Sweden using economic policies on foods and nutrients. For the VAT reforms we find that the best public health outcome can be achieved through a combination of taxes and subsidies, which is echoed in the findings from New Zealand (Ni Mhurchu et al., 2015) and the UK (Nnoaham et al., 2009). However, we find that the effectiveness of a salt tax is higher in New Zealand than in Sweden, while the effectiveness of subsidies on fruits and vegetables is higher in Sweden than in New Zealand in terms of percentage of annual deaths prevented. Potential explanations for these differences, aside from variations in methodology, are that the baseline intake of fruits, vegetables and salt differs for New Zealanders and Swedes, or/and that own and cross price elasticities differ across the two countries. For instance, reducing salt consumption will also reduce the intake of fiber and the effects of the latter will outweigh the benefits obtained from reduced salt intake (Ni Mhurchu et al., 2015). Other possible explanations are differences in country-specific mortality and the diet of the population. The differences in health outcomes from the reforms across countries highlight the need for country-specific analyses.

Our models suggest that a tax on salt (VAT #1) will increase the consumption of saturated fat by 2.3% which is line with the study from New Zealand (Ni Mhurchu et al., 2015), where the fat-containing products purchase increased by 3%. It is also interesting to note that our analysis suggests taxing food products based on their salt content, either as an increased VAT on food products rich in salt, will increase the intake of saturated fat (Table 2). This is a common risk with any food pricing policy, where a shift in the intake of one type of unhealthy food, may lead to increased consumption of an equally, or more, unhealthy food. However, in all reforms, the overall effects on population mortality were beneficial.

While not examined here, it is worth noting that changing consumer behavior due to taxes and subsidies may also have an effect on the supply of food products. For example, reformulation of products rich in specific nutrients, as a means to evade taxes. In the UK, the tax led to a 33.8 percentage points drop in the number of eligible soft drinks with sugar over the lower threshold for the tax (5 gm sugar per 100 ml) (Scarborough et al., 2020). Furthermore, imposing additional VAT rates gives rise to considerable costs, both to the public authorities, food producers and retailers. For example, at present Sweden has three VAT rates and the administrative cost of having three VAT rates instead of one is 13% of total administrative cost (Nordström and Thunström, 2009).

We have also assumed full pass-through of these policies which are in line with other (Caro et al., 2020) but also opposed with other literatures (Salgado and Ng, 2019)(Delipalla and Keen, 1992) (Anderson et al., 2001)(Bonnet and Réquillart, 2013). It is probable that the pass-through

Table 3
Number of deaths averted in a year due to each reform model, according to food items and nutrients.

		Fruits and vegetables	Fiber	Fats	Salt	Total	% of annual death*
Imposing 25% or 0% VAT from 12% baseline VAT ≈ price change of 11.61% or −10.71%							
VAT #1	25% VAT on products rich in Salt	−248 (−154; −343)	155 (88; 218)	56 (39; 75)	−118 (−48; −186)	−154 (−19; −292)	0.35
VAT #2	25% VAT on products rich in Saturated fat	−188 (−111; −267)	−213 (−125; −306)	−106 (−77; −137)	−3 (−1; −5)	−514 (−389; −642)	1.18
VAT #3	Zero VAT on F&V	−403 (−288; −521)	−128 (−75; −186)	−1 (−3; 1)	−11 (−4; −17)	−547 (−416; −676)	1.26
VAT #4	25% VAT on products rich in Saturated Fat and zero VAT on F&V	−613 (−417; −812)	−349 (−199; −499)	−107 (−80; −139)	−12 (−5; −20)	−1093 (−832; −1363)	2.51
VAT #5	25% VAT on Saturated Fat and Salt and 0% VAT on F&V	−639 (−435; −850)	−148 (−85; −214)	−56 (−43; −72)	−128 (−52; −203)	−978 (−753; −1222)	2.25
Imposing 20% price change for taxed and subsidized products ≈ imposing 34.4% VAT or −10.4% VAT from 12% baseline VAT							
VAT #6	34.4% VAT on products rich in Salt	−248 (−155; −343)	153 (87; 221)	56 (38; 75)	−119 (−50; −189)	−156 (−21; −289)	0.36
VAT #7	34.4% VAT on products rich in Saturated fat	−320 (−186; −453)	−366 (−207; −526)	−170 (−124; −222)	1 (0; 1)	−862 (−644; −1083)	1.98
VAT #8	−10.4% VAT on F&V	−820 (−584; −1064)	−260 (−148; −377)	−2 (2; −6)	−19 (−8; −30)	−1113 (−848; −1394)	2.56
VAT #9	34.4% VAT on products rich in Saturated Fat and −10.4% VAT on F&V	−1208 (−827; −1612)	−643 (−368; −923)	−173 (−127; −223)	−13 (−6; −21)	−2089 (−1572; −2611)	4.80
VAT #10	34.4% VAT on products rich in Saturated Fat and Salt and −10.4% VAT on F&V	−1252 (−842; −1688)	−311 (−178; −445)	−91 (−70; −115)	−209 (−87; −331)	−1893 (−1435; −2380)	4.35

Abbreviations: F&V, Fruits and Vegetables, VAT, Value Added Tax; ≈, equals to. Note: *The annual death is the total number of deaths in a year due to the diseases incorporated in the PRIME model.

Table 4
Number of deaths averted in a year due to each reform model, according to food items and nutrients.

		Coronary heart disease	Stroke	Heart failure	Hypertensive disease	Diet-related cancer
Imposing 25% or 0% VAT from 12% baseline VAT ≈ price change of 11.61% or −10.71%						
VAT #1	25% VAT on products rich in Salt	42 (−57; 143)	−113 (−56; −169)	−16 (−7; −27)	−30 (−12; −48)	−33 (−67; 0)
VAT #2	25% VAT on products rich in Saturated Fat	−318 (−208; −430)	−130 (−77; −185)	0 (−1; 0)	−1 (−1; 0)	−64 (−36; −93)
VAT #3	Zero VAT on F&V	−283 (−177; −389)	−180 (−119; −245)	−1 (−2; −1)	−3 (−4; −1)	−78 (−38; −117)
VAT #4	25% VAT on products rich in Saturated Fat and zero VAT on F&V	−617 (−398; −837)	−325 (−204; −447)	−2 (−3; −1)	−3 (−5; −1)	−148 (−78; −220)
VAT #5	25% VAT on Saturated Fat and Salt and zero VAT on F&V	−467 (−284; −648)	−323 (−211; −441)	−18 (−7; −28)	−33 (−13; −52)	−133 (−63; −202)
Imposing 20% price change for taxed and subsidized products ≈ imposing 34.4% VAT or −10.4% VAT from 12% baseline VAT						
VAT #6	20% tax on Salt	43 (−56; 142)	−113 (−58; −168)	−16 (−7; −27)	−30 (−13; 49)	−33 (−1; −66)
VAT #7	20% tax on saturated Fat	−530 (−337; −727)	−223 (−133; −316)	0	0	−111 (−61; −160)
VAT #8	20% subsidy on F&V	−570 (−355; −791)	−373 (−245; −506)	−3 (−1; −4)	−5 (−2; −8)	−160 (−77; −241)
VAT #9	20% tax on Saturated Fat and 20% subsidy on F&V	−1148 (−728; −1586)	−641 (−408; −887)	−2 (−1; −3)	−3 (−1; −5)	−288 (−11; −435)
VAT #10	20% tax on Saturated Fat and Salt and 20% subsidy on F&V	−901 (−540; −1281)	−639 (−417; −869)	−29 (−12; −48)	−54 (−22; −85)	−256 (−118; −406)

Abbreviations: F&V, Fruits and Vegetables, VAT, Value Added Tax; ≈, equals to.

of subsidies and/or taxes might not be complete. One possible implication of full pass-through is that the findings might be overestimated as producers might offset some of the price increase due to taxes. We are not able to consider the substitution effect for non-processed food which is driven by both the market prices and cooking-time costs (Kalamov, 2020; Xiang et al., 2020). However, for the taxes scenarios, it seems reasonable to assume that the time for cooking will be unchanged due to reforms.

Our study has several strengths. We used the actual household purchase data of foods items together with consumption of other commodities, e.g., transportation and clothes. It also estimated behavioural response parameters due to price changes. These aspects were missing in the previous literatures in this field (Blakely et al., 2020; Cobiac et al., 2017). Furthermore, the population statistics such as number of population and disease-specific mortality stratified by age, sex comes from the National Statistic of Sweden, an agency that maintains highly detailed register data. PRIME is a transparent and open-access model in which risk equations are related to diets and mortality, based on outcomes of meta-analyses (Scarborough et al., 2014). Moreover, PRIME has repeatedly been used in studies of other countries, for example for the UK (Briggs et al., 2013a, 2013b; Scarborough et al., 2011, 2012), Ireland (Briggs et al., 2013c), New Zealand (Ni Mhurchu et al., 2015), France (Irz et al., 2015), Canada (Bélanger et al., 2014), Denmark (Smed et al., 2016b), Sweden (Saha et al., 2019a) and as well as a comparison among the Nordic countries (Saha et al., 2019b).

Our study also has shortcomings. It likely substantially underestimates health effects from the tax reforms. For instance, the model provides a cross-sectional analysis of deaths prevented in a particular year and does not provide estimates for a longer time period, for example deaths prevented in five- or ten-year intervals as presented in other literatures (Colchero et al., 2017; Basto-Abreu et al., 2019; Lal et al., 2017) since the public health effects of taxes and/or subsidies are expected to have effect over the long-term. Moreover, the model only considers health gains (or costs) from deaths prevented or delayed and not from prevention of NCDs incidence. Future research might quantify public health gains using a measure that captures not only deaths, but also reduction of the incidences of these diseases, changes in health-related quality of life, such as through Quality-Adjusted Life Years (QALY). In addition, in future studies, we will also consider the cost-effectiveness of the reforms (Basto-Abreu et al., 2019; Lal et al., 2017) as well as the distributional effect of these reforms in various socioeconomic groups (Dogbe and Gil, 2020; Tiffin and Salois, 2015). Future research may consider not only the impact on the government budget from the reforms, but also the effects on other social costs and benefits from changes to public health, such as productivity gains associated with a healthier labour force and/or reduced mortality.

4.1. *Policy relevance*

Our findings have important policy implications. At present, the VAT rate on food in Sweden is 12% and it would be feasible to increase the VAT to 25% on unhealthy food products, the same level as the general VAT in Sweden, and reduce the VAT to zero percentage for fruits and vegetables from an administrative perspective. We find such a reform would have substantial benefits to public health. Other reforms give even higher benefits to public health but are more demanding from a tax administrative perspective.

Declaration of competing interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2021.114388.

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