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Adjusting VAT rates to promote healthier diets in Norway: A censored quantile regression approach

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ABSTRACT

The effects of health-related taxes and subsidies on food and beverages have mainly been investigated using models that assume identical price responses among high- and low-consuming households. Diet-related health problems are, however, more likely among households with high intakes of unhealthy foods or low intakes of healthy foods than in households with average intakes. In this article, we focus on purchases of healthy and unhealthy foods among low-, median-, and high-purchasing households. The effects of an increase in the Norwegian value-added tax (VAT) on some unhealthy foods and a removal of the VAT on some healthy foods are investigated. Using censored quantile regressions, we reject equality of the own-price elasticities for eight of nine food and beverage groups. We find that a VAT increase is more effective in reducing purchases of unhealthy foods among high-purchasing households than a VAT removal is in increasing the purchases of healthy foods among low-purchasing households.

Introduction

Norwegian obesity rates are on par with those of the other Nordic countries, and approximately 15–20% of Norwegians aged 40–45 are obese (Folkehelseinstituttet, 2010).[1] Obesity leads to increased risk of diseases such as coronary heart disease, type 2 diabetes, and cancer (National Task Force on the Prevention and Treatment of Obesity, 2000). The costs associated with obesity have been estimated to be 0.5–1% of the gross domestic product (Departementene, 2007: 9), and most of those costs are paid publicly. These public costs may justify market interventions such as taxes on unhealthy foods and subsidies for healthy foods.[2] Food taxes and subsidies may also be motivated by people's self-control problems, as discussed by O'Donoghue and Rabin (2006). They argue that food taxes may help people who currently consume large quantities of food without considering the future health costs of such consumption. Furthermore, some studies suggest that certain foods that are high in sugar or fat content could be addictive for some people (e.g., Gearhardt et al., 2009). Some individuals also lack sufficient knowledge about the health effects of their diets (e.g., Cash and Lacanilao, 2007), and taxes and subsidies may provide incentives for dietary changes among such groups, including children and young people.

The effects of health-related food taxes and subsidies have been investigated in controlled experiments, natural experiments, and simulation exercises based on models. Systematic reviews of some of these studies are provided by Thow et al. (2010) and Mytton et al. (2012). As discussed in Mytton et al. (2012), significant effects have been found in controlled experiments; however, the validity of these results outside the controlled environment may be questioned. Natural experiments provide a higher degree of external validity; however, according to Mytton et al. (2012), there are few studies involving such experiments. They refer to two studies that find small effects of low taxes on the prevalence of obesity and one study that found an 11% decrease in the consumption of soft drinks for each 10% increase in the price. Most studies have been based on simulations of economic models, and the reported effects on consumption and obesity are mixed, suggesting that the effects are likely to be product- as well as country-specific. Several studies report small effects of taxes (e.g., Chouinard et al., 2007; Miljkovic et al., 2008; Powell and Han, 2011) and subsidies (e.g., Nordström and Thunström, 2009) on consumption of different foods and beverages or on body weight. Other studies report larger effects of taxes, especially on sugar-sweetened beverages. For example, Zhen et al. (2011) found substantial reductions in store purchases, while Dharmasena and Capps (2011) found that a 20% tax on

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[1] An adult with a body mass index (BMI) between 25 and 29.9 is considered to be overweight; an adult with a BMI of 30 or higher is considered to be obese.

[2] The average household is likely to over-consume nutrients such as sugar and fats. We refer to energy-dense food and beverage groups with little nutritional value as unhealthy foods. However, it should be noted that for households who consume small quantities of these foods, an increased intake is not considered to be unhealthy.

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sugar-sweetened beverages would reduce the US average body weight by between 1.5 and 2.6 lb per year.

The risks of obesity and diet-related diseases are likely to be higher among households with high intakes of unhealthy foods or low intakes of healthy foods, and the distribution of consumption among households is therefore important. The simulation studies discussed above estimated conditional mean effects of price changes on purchases or obesity. The effects may, however, be different among households with high and low intakes of a food group, and estimation of the conditional mean effect may be insufficient for determination of targeted price interventions. For example, a price reduction for vegetables may increase the consumption of vegetables substantially among households who already consume a large quantity of vegetables, while the effect on the consumption of vegetables among low-consuming households may be small. A model that predicts the conditional mean effect would, however, predict a small average increase for all households.

Our objective is to investigate the effects of taxes and subsidies on purchases in different parts of the purchase distributions of different groups of food. Quantile regressions have previously been used to study distributional issues in food consumption (e.g., Auld and Powell, 2009). In our sample, many households did not purchase some food groups, and the data are censored, so we estimate censored quantile regressions (CQR). CQR have been used to investigate the effects of income changes on expenditures on fruits and vegetables in the US (Stewart et al., 2003). Furthermore, the effects of a subsidy on purchases of vegetables (Gustavsen and Rickertsen, 2006), the effects of a tax on purchases of ice cream (Gustavsen et al., 2008), and the effects of a tax on sugar-sweetened carbonated soft drinks (Gustavsen and Rickertsen, 2011) in Norway have been estimated. This work is an extension of these Norwegian studies. However, in the previous studies, no statistical tests for different price and expenditure elasticities among high- and low-purchasing households were conducted. We demonstrate through a bootstrapping test that the elasticities differ across the quantiles. Furthermore, we include six new food and beverage groups: milk, juice, candy, fruits, meat, and fish. We also use one algorithm, identical quantile points, and an updated sample.

We follow the method used in our previous studies and implement the taxes and subsidies through changes in the value-added tax (VAT). This type of change is well adjusted to the current VAT regime that operates with a reduced VAT for food and beverages, compared with most other products. We investigate the effects of increasing the current VAT rate, from 14% to 25%, for some groups of energy-dense foods and beverages with little nutritional value, removing the VAT for some healthy food groups, and maintaining the current rate for the remaining food groups.

Food groups and data

The main goals of the Norwegian Government's Action Plan on Nutrition 2007–2011 are the following: (a) to change people's diets, in line with recommendations of the health authorities and (b) to reduce social inequalities in diet (Departementene, 2007). The Action Plan has defined general and quantitative goals for dietary changes. According to these goals, the average consumption of fruits, vegetables, whole grain bread, fish, and seafood should be increased, and the average consumption of saturated fats, sugar, and salt should be reduced. Some distributional targets concerning consumption are also specified. The distributional targets aim to increase the number of people who consume vegetables and fruits daily and who consume fish weekly by 20%. The number of children who consume sweets and candies daily and the number of people who consume sugar-sweetened soft drinks daily should also be reduced by 20%.

Table 1
Distribution of annual per capita purchases.

	Positive purchases[a]	Quantile			Mean	Trend[b]
		0.25	0.50	0.75		
Milk (l)	97	61	104	156	115	−4.2
CSD (l)	79	7	37	78	56	2.0
Juices (l)	73	0	20	43	32	1.1
Candy (kg)	83	1	4	9	7	0.2
Ice cream (kg)	52	0	0	7	5	0.0
Fruits (kg)	89	13	31	56	42	0.2
Vegetables (kg)	93	14	29	50	38	0.6
Meat (kg)	97	19	34	57	47	0.1
Fish (kg)	84	3	10	22	19	−0.3

[a] Percentage of households with positive purchases in survey period.
[b] Trend is a regression coefficient in a linear regression, with the mean purchases in each year as the dependent variable and the year as the independent variable.

To investigate the effects on purchases of a tax on energy-dense foods with little nutritional value, we increase the VAT rate for carbonated soft drinks (CSD), candy, and ice cream to 25% in our simulation.[3] To investigate the effects of a subsidy on purchases of fruits, vegetables, and fish, we remove the VAT for these groups. In addition, milk, fruit juices, and meat are included in the analysis. However, the health effects of these food groups are mixed, and we maintain their present VAT rate. Although whole milk is high in saturated fat, it is a good source of high-quality protein, calcium, and essential micronutrients and is recommended for small children, while low-fat milk is recommended for adults. Meat is also a heterogeneous group. Certain cuts of red meat are high in saturated fat, but other cuts, as well as poultry, are low in fat. In addition, meat contains healthy proteins and other important nutrients. Finally, fruit juices provide most of the nutrients of their natural sources, but have high energy contents.[4]

The data used are from the consumer expenditure surveys of Statistics Norway from 1986 to 2005 and are described in Statistics Norway (1996). Each year, 2200 persons were selected for participation. The non-response rate varied between 33% and 52%, and our total sample consists of 25,023 cross-sectional observations. The data are described in more detail in Gustavsen et al. (2008).

The distribution of purchases in the sample is shown in Table 1. The table shows the average percentage of households reporting positive purchases of each good during the 2-week survey period; the distribution of per capita purchases, in litres, of milk, CSD, and juices, and, in kilograms, of items from the other food groups; the mean purchases; and trends in purchases.[5] Some goods, such as milk and meat, were purchased by almost all households. However, more than 20% of the households did not purchase CSD or juices, and nearly half did not purchase ice cream. We also note a substantial variation in purchases. For example, the annual per capita purchase of fish was less than 3 kg in 25% of households, 50% of households

[3] The current Norwegian VAT system has four rates. The VAT is 25% for most goods and services, 14% for food and beverages (it was increased to 15% on January 1, 2012), 8% for some services, and zero for some products such as books.

[4] Most of the CSD group consists of sugar-sweetened CSD, and we treat CSD as one beverage group because the data only distinguish between sugar-sweetened CSD and sugar-free CSD after 1989. In our sample, sugar-sweetened CSD purchases vary between 82% and 91% of total CSD purchases. In addition, it is not obvious that sugar-sweetened CSD and diet CSD are substitutes. Zhen et al. (2011: 187), rather surprisingly, report a complementary relationship. Furthermore, milk is treated as one group because of high censoring of some milk types such as non-fat milk, which only 23% of the households purchased in some of the years. The juices group also includes mineral water and light beer. Fats and oils are not included as a specific group in the analysis because most fats and oils are consumed as a part of other products such as meat and milk that also contain healthy components. Some types of fats are also healthier than other types of fats.

[5] In our household expenditure survey data, the per capita purchases of each household are multiplied by 26 to approximate annual per capita consumption.

Table 2
Variable definitions and description of the sample.

Variable	Definition	Mean	Std. dev.
Beverages			
Y_1	=Milk purchases (litres/capita) in 2-week period	4.43	3.02
Y_2	=CSD purchases (litres/capita) in 2-week period	2.16	3.14
Y_3	=Juice purchases (litres/capita) in 2-week period	1.22	1.71
$\ln(P_1/P_4)$	=Price of milk deflated by CPI	−2.47	0.11
$\ln(P_2/P_4)$	=Price of CSD deflated by CPI	−1.92	0.29
$\ln(P_3/P_4)$	=Price of juice deflated by CPI	−1.73	0.30
Snacks			
Y_1	=Candy purchases (kg/capita) in 2-week period	0.25	0.30
Y_2	=Ice cream purchases (kg/capita) in 2-week period	0.18	0.32
Y_3	=Fruit purchases (kg/capita) in 2-week period	1.62	1.97
$\ln(P_1/P_4)$	=Price of candy deflated by CPI	0.19	0.26
$\ln(P_2/P_4)$	=Price of ice cream deflated by CPI	−0.33	0.36
$\ln(P_3/P_4)$	=Price of fresh fruits deflated by CPI	−1.75	0.26
Dinner items			
Y_1	=Vegetable purchases (kg/capita) in 2-week period	1.46	1.54
Y_2	=Meat purchases (kg/capita) in 2-week period	1.81	2.61
Y_3	=Fish purchases (kg/capita) in 2-week period	0.73	1.48
$\ln(P_1/P_4)$	=Price of vegetables deflated by CPI	−1.28	0.33
$\ln(P_2/P_4)$	=Price of meat deflated by CPI	−0.17	0.30
$\ln(P_3/P_4)$	=Price of fish deflated by CPI	−0.59	0.39
All blocks			
$\ln(\text{EXP}/P_4)$	=Expenditure deflated by CPI	3.24	0.55
$\ln(\text{EXP}/P_4)^2$	=Squared expenditure deflated by CPI	10.81	3.62
$\ln\text{AGE}$	=Log of age of the head of the household	3.78	0.33
$\ln T$	=Log of trend variable	2.05	0.82
D_1	=1 If household consists of one person	0.15	0.35
D_2	=1 If household consists of couple without children	0.23	0.42
D_3	=1 If household consists of couple with children	0.47	0.50
D_4	=1 If household consists of single parent	0.05	0.21
D_5	=1 If other household type	0.10	0.30
D_6	=1 If household lives in a rural area	0.22	0.41
D_7	=1 If household lives in a non-major city	0.60	0.49
D_8	=1 If household lives in a major city	0.18	0.38
D_9	=1 If household lives in east central	0.19	0.40
D_{10}	=1 If household lives in rest of east	0.27	0.45
D_{11}	=1 If household lives in south	0.14	0.35
D_{12}	=1 If household lives in west	0.18	0.38
D_{13}	=1 If household lives in central	0.10	0.30
D_{14}	=1 If household lives in north	0.11	0.31
D_{15}	=1 If household is surveyed during Christmas	0.03	0.18
D_{16}	=1 If household is surveyed in 1st quarter	0.24	0.42
D_{17}	=1 If household is surveyed in 2nd quarter	0.27	0.44
D_{18}	=1 If household is surveyed in 3rd quarter	0.22	0.41
D_{19}	=1 If household is surveyed in 4th quarter	0.27	0.45

purchased less than 10 kg of fish per capita annually, and the mean annual per capita purchase was 19 kg. We also note a negative trend in purchases of milk, which shows that per capita purchases of milk fell during the study period by 4.2 l per year. In contrast, per capita purchases of CSD increased by 2 l per year. All of the trends in purchases are significantly different from zero at the 5% level, except for ice cream and meat. It should be noted that the data exclude purchases away from home.

Variable definitions and summary statistics for the sample are provided in Table 2. Three main groups of food and beverages are specified. In each group, we include foods that are assumed to be substitutes or complements. Furthermore, in each group, at last one healthy and/or one unhealthy food or beverage is included. In total, these nine foods and beverages comprise approximately 60% of the value of Norwegian at-home food and non-alcoholic beverage purchases. The non-alcoholic beverage group includes milk, CSD, and juices. The snack group consists of candy, ice cream, and fresh fruits, and the dinner group consists of vegetables, meat, and fish. Our reference household lived in the east central region, in a non-major city, was surveyed during the winter but not at Christmas, and consisted of a couple with children. Approximately 47% of the households were couples with children, approximately 60% lived in a non-major city, approximately 24% were surveyed during the winter, and approximately 19% lived in the east central region.

Empirical model

Following Gustavsen and Rickertsen (2006), Gustavsen et al. (2008), and Gustavsen and Rickertsen (2011), the semi-logarithmic demand equation

$$Y_i^h = \beta_{i0} + \sum_{j=1}^{3}\beta_{ij}\ln\left(\frac{P_{jt}}{P_{4t}}\right) + \beta_{i4}\ln\left(\frac{EXP^h}{P_{4t}}\right) + \beta_{i5}\left\{\ln\left(\frac{EXP^h}{P_{4t}}\right)\right\}^2 + \beta_{i6}\ln AGE^h + \beta_{i7}\ln T_t + \sum_{j=1}^{J}\gamma_{ij}D_j^h + \varepsilon_i^h \quad (1)$$

is estimated for each good, using CQR.[6] In this model, Y_i^h is household h's per capita quantity purchases of good i; P_{jt} is the price of good j in survey period t; P_{4t} is the consumer price index (excluding the prices for durable goods); EXP^h is the total per capita expenditure on nondurable goods and services; AGE^h is the age of the head of the household; T_t is an annual trend variable that takes a value of 1 in 1986 and 20 in 2005; D_j^h are dummy variables representing region, season, and household type; and ε_i^h is an error term. The socioeconomic variables included are partly given by the available data. For example, potentially important variables such as income, education, and ethnicity are not recorded in our data. In each demand equation, the prices of the three foods that belong to the relevant group are included.[7]

The total expenditure elasticity for the ith good in the θ-conditional quantile is calculated as

$$E_{\theta i} = \frac{1}{Y_i}(\hat{\beta}_{i4} + 2\hat{\beta}_{i5}\,\overline{EXP})\cdot \Pr(Y_i > 0) \quad (2)$$

where $\overline{EXP}$ is the mean value of $\ln(EXP^h/P_{4t})$ in the sample, Y_i is the mean of the positive predicted purchases of good i in the θ quantile,

[6] Quantile regressions cannot be estimated as a system of demand equations with across-equation restrictions, such as symmetry, because different households belong to different quantiles for different foods. Therefore, nine separate demand equations are estimated. Furthermore, as pointed out by a reviewer, the demand may be affected by dynamic behaviour that is not captured by the trend or the quarterly dummy variables. We acknowledge this weakness; however, it is impossible to estimate a dynamic model using CQR because it is not given that a specific household will belong to the same quantile in several time periods. Furthermore, in our pooled cross-sectional data, each household was recorded just once, and it is therefore impossible to estimate any dynamic model. A second issue raised by the reviewer relates to the choice of quantity rather than expenditure share as a dependent variable. We are interested in the distribution of purchased quantities rather than the distribution of expenditure shares, and it seems reasonable to use quantity as the dependent variable. Furthermore, the law of iterated expectations (Cameron and Trivedi, 2005: 955) does not hold for quantile regressions. Consequently, we cannot use the expenditure share as the dependent variable and transform it into a quantity in the purchase distribution. A third question raised by the reviewer was the choice of a semi-logarithmic functional form. Given that many households do not purchase each good, we cannot estimate a double logarithmic model. Furthermore, it seems reasonable to allow for price responses that are nonlinear. Finally, it should be noted that there are no tests available for functional misspecification for quantile regressions.

[7] As pointed out by a reviewer, we use per capita quantities purchased and per capita expenditures on nondurable goods and services. For many foods children consume less than adults, an alternative would be to adjust purchases and expenditures using adult equivalence scales. However, the results in Gustavsen and Rickertsen (2011) and Gustavsen et al. (2008) indicate that families with children are overrepresented in the higher quantiles and underrepresented in the lower quantiles of the purchase distributions of carbonated soft drinks and ice cream, suggesting that children are likely to consume more of several unhealthy foods than adults. Given these results, we have chosen not to use equivalence scales. Finally, note that the head of the household is defined as the household member with the highest income.

and Pr $(Y_i > 0)$ is the probability of purchasing the good. The price elasticities are calculated as

$$e_{\theta ij} = \frac{\hat{\beta}_{ij}}{Y_i} \cdot \Pr(Y_i > 0) \tag{3}$$

The calculated elasticities must be interpreted with some caution. As explained in Buchinsky (1998), a household that is in the θ quantile before a price or income change will not necessarily remain in that quantile after the change.

To construct the prices, we follow the three-step procedure of Cox and Wohlgenant (1986) as described in more detail in Gustavsen et al. (2008).

Censored quantile regressions

The quantile regression model was introduced by Koenker and Bassett (1978) and can be written as

$$Q_\theta(y_i|x_i) = x_i'\beta_\theta \tag{4}$$

where $Q_\theta(y_i|x_i)$ denotes the θ-conditional quantile of the dependent variable y_i, x_i is the vector of independent variables, β_θ is the vector of parameters, and the conditional quantile of the error term is zero. The estimator of β_θ is found by solving

$$\min_{\beta_\theta} \frac{1}{N}\left\{ \sum_{y_i \geqslant x_i'\beta_\theta} \theta|y_i - x_i'\beta_\theta| + \sum_{y_i < x_i'\beta_\theta} (1-\theta)|y_i - x_i'\beta_\theta| \right\}. \tag{5}$$

This minimisation problem can be solved by linear programming for the different quantiles of the dependent variable, as described in Koenker (2005).

As discussed above, the data are censored, and censored quantile regressions are estimated. The CQR estimator suggested by Powell (1986) is found by solving

$$\min_{\beta_\theta} \frac{1}{N}\sum_{i=1}^{N}\left[\{\theta - I(y_i < \max\{0, x_i'\beta_\theta\})\}(y_i - \max\{0, x_i'\beta_\theta\})\right] \tag{6}$$

where I is an indicator function taking the value of one when the expression holds and zero otherwise. Powell (1986) showed that, under some weak regularity conditions, the CQR estimator is consistent, independent of the distribution of the error term, and that the error term is asymptotically normally distributed. Furthermore, median regressions are robust to outliers of the dependent variable (Cameron and Trivedi, 2005). CQR inherit this robustness in other parts of the distribution in addition to the median. Finally, CQR estimates are not based on an assumption of constant variance, and heteroscedasticity is not a problem (Buchinsky, 1998).

While Eq. (5) is a linear function, the expression $\max\{0, x_i'\beta_\theta\}$ in Eq. (6) is not linear and has no linear programming representation. To solve Eq. (6), we use the three-step algorithm proposed by Chernozhukov and Hong (2002), which is simple, robust, and performs well near the censoring point. Their algorithm is implemented in the following three steps.

First, the subsample of participants that purchased the good is predicted by a logit model. This subsample is defined as $J_0 = \{i : x_i^{*\prime}\hat{\gamma} > 1 - \theta + c\}$, where θ is the quantile level and c is a trimming constant between 0 and 1, set in our case to 0.05.[8] Second, the initial estimator, $\hat{\beta}_\theta^0$, is determined from Eq. (5) for the sample J_0. As shown by Chernozhukov and Hong (2002), the initial estimator $\hat{\beta}_\theta^0$ is consistent but inefficient. This initial estimator is used to select the subsample $J_1 = \{x_i^{*\prime}\hat{\beta}_\theta^0 > 0\}$. Third, the model is estimated with Eq(5) for the sample J_1. As shown by Chernozhukov and Hong (2002), this results in a consistent and efficient estimator of $\hat{\beta}_\theta$.

The standard errors of the parameter estimates are obtained with the CQR bootstrapping procedure described by Bilias et al. (2000), who also showed that the distribution of the CQR bootstrap estimator converges to the CQR estimator. Our program is based on the "qreg" command in Stata (StataCorp, 2007).[9]

Table 3
P-values of *t*-tests for equality of elasticities in 0.25 and 0.75 quantiles.

	Milk	CSD	Juices	Other goods	Expenditure
Milk	0.32	0.40	0.42	0.36	0.00
CSD	0.36	0.00	0.85	0.00	0.00
Juices	0.43	0.26	0.00	0.03	0.00
	Candy	Ice cream	Fruits	Other goods	Expenditure
Candy	0.00	0.99	0.07	0.00	0.00
Ice cream	0.00	0.00	0.02	0.00	0.00
Fruits	0.87	0.00	0.00	0.00	0.00
	Vegetables	Meat	Fish	Other goods	Expenditure
Vegetables	0.00	0.23	0.12	0.00	0.00
Meat	0.19	0.00	0.02	0.00	0.00
Fish	0.01	0.42	0.00	0.00	0.00

Note: For juices and ice cream the elasticities are not calculated for the 0.25 quantile. Hence, for these goods the *t*-tests are performed as differences between the 0.50 and the 0.75 quantiles.

Results

The goodness of fit for our CQR is measured by pseudo R^2 values, as described in StataCorp (2007: 31). The pseudo R^2 values are highest in the 0.75 quantile and lowest in the 0.25 quantile. They range from 0.04 for fish to 0.11 for meat in the 0.25 quantile, from 0.10 for ice cream to 0.22 for milk in the 0.50 quantile, and from 0.21 for ice cream to 0.34 for milk in the 0.75 quantile.[10]

Estimated elasticities

First, we test for equality of the price responses in the different parts of the purchase distributions by bootstrapping *t*-tests for equality of the elasticities in the 0.25 and 0.75 quantiles. The *p*-values of these tests are reported in Table 3. Except for milk, equality of the own-price elasticities is rejected at the 5% level of significance. Equality of the total expenditure elasticity is also rejected for each of the groups. Several of the cross-price elasticities are significantly different. These results demonstrate the usefulness of estimating demand functions for different parts of the purchase distribution.

The price and expenditure elasticities in the 0.25, 0.50, and 0.75 quantiles are reported in Table 4. For juices and ice cream, the censoring point is above the 0.25 quantile and purchases in this quantile are not estimated.

With the exception of milk in the 0.25 quantile, all of the estimated own-price elasticities are statistically significant at the 5% level. The demand for CSD, candy, ice cream, and meat is price-elastic in all of the quantiles. In the 0.25 quantile, the demand is price-elastic for CSD, juices, candy, ice cream, meat, and fish. With the exception of milk, the own-price elasticities are more elastic in the lower quantiles than in the higher quantiles, suggesting that low-purchasing households are more price-sensitive than high-purchasing households. For example, a 1% increase in the price of candy will reduce candy purchases by approximately 2.5% in the 0.25 quantile, 1.6% at the median, and 1.1% in the

[8] The choice of the trimming constant may affect the results. However, Buchinsky and Hahn (1998) used a propensity score together with a trimming constant to choose the subsample, with observations above the quantile line, to be included in the second step of their two-step CQR. They found that varying the trimming constant between 0.005, 0.05, and 0.1 had little effect on the results.

[9] The program is available from the authors upon request.

[10] The estimated coefficients with standard errors from the quantile regressions are included in Tables 1–9 in the Supplementary appendix to this article.

0.75 quantile. Finally, the differences between own-price elasticities in the 0.25 and 0.75 quantiles appear to be larger for unhealthy foods than for healthy foods.

Most of the cross-price elasticities are low, and most of the food groups are gross substitutes. The cross-price elasticities between the "other goods" group and each of the various food groups are positive and significant, except for milk in the 0.25 quantile. The cross-price elasticities between CSD, candy, ice cream, and fish and the "other goods" group are elastic in the 0.25 quantile. The total expenditure elasticities range between 0.01 and 0.58, and most are significantly different from zero.[11]

Effects on purchases

Following the approach taken in Gustavsen et al. (2008), we first simulated Eq. (1) for each of the conditional quantiles. In this simulation, the observed values of the independent variables for each household were inserted into Eq. (1) and multiplied by the estimated parameters, and the product was multiplied by the probability of a positive purchase. The resulting value is the predicted per capita purchase for each household, and the mean effects for the households in each quantile were calculated. Second, the same simulation was conducted after the VAT changes, and finally, the differences in purchases with and without VAT changes were calculated. The current VAT rate is 14% for food and beverages, and the suggested VAT rate of 25% corresponds to a price increase of 9.6% for CSD, candy, and ice cream. The removal of VAT for healthy foods corresponds to a price reduction of 12.3% for fresh fruits, fresh vegetables, and fish. The VAT rate for milk, juices, meat, and other goods remains unchanged in the simulation.[12] Some of the households with positive purchases before the price changes are predicted to have negative purchases after the changes. The purchases for these households are set to zero.

Table 5 shows the predicted annual average per capita purchases before the VAT change, Y_{before}, after the VAT change, Y_{after}, the predicted change measured in litres of beverages or kilograms of food, ΔY, the corresponding percentage change $\Delta Y\%$, and the calculated change in body weight in kilograms, ΔBW. The associated standard errors are reported in parentheses. We note that all the simulated changes for groups with changed VAT rates are significantly different from zero.

The VAT rate for milk and juices does not change; thus, purchases of these beverages are minimally affected. The purchases of CSD decrease from 9.7 l to 7.3 l in the 0.25 quantile, i.e., a reduction of 24.1%. Approximately 2% of this reduction is attributed to people who stopped purchasing CSD, while approximately 22% is attributed to reduced purchases by people still purchasing CSD.[13] In the 0.75 quantile, the VAT changes lead to a reduction in purchases of 8.7 l, or 11.1%. Most of this reduction is due to reduced purchases (11.0%), and only 0.1% is attributed to people who stopped purchasing CSD. These changes are in line with results reported in Gustavsen and Rickertsen (2011). Using corresponding data for the 1989–2001 period but a different estimation algorithm, they simulated the effects of a corresponding VAT increase. They predicted reductions in the purchases of sugar-sweetened carbonated soft drinks of 5.1, 6.8, 11.5, 13.9, and 19.2 l in the 0.35, 0.50, 0.75, 0.90, and 0.95 quantiles, respectively.[14]

Candy purchases are predicted to decrease from 1.4 to 1.1 kg in the 0.25 quantile, i.e., a 25.1% reduction. In the 0.75 quantile, the reduction in candy purchases is 0.9 kg, or 9.8%. In the 0.25 quantile, the quantity of purchased fresh fruit is predicted to increase from 12.5 to 13.5 kg per capita, i.e., an 8.1% increase. In the 0.75 quantile, the increase is 3.9 kg, or 6.2%. In our sample, 48% of the households did not purchase ice cream, and Eq. (1) was not estimated for the 0.25 quantile. In the 0.50 quantile, the annual reduction of purchases is 0.4 kg of ice cream, while the reduction is 1.1 kg in the 0.75 quantile. The changes for ice cream are in line with results reported in Gustavsen et al. (2008). Using corresponding data for the 1986–2001 period and simulating the effects of a corresponding VAT increase, they found reductions in the purchases of ice cream of 0.4, 0.6, 0.9, 1.4, and 1.8 kg in the 0.50, 0.60, 0.70, 0.80, and 0.90 quantiles, respectively.

In the 0.25 quantile, purchases of vegetables are predicted to increase by 1.6 kg, or 10.5%, while in the 0.75 quantile, purchases are predicted to increase by 4.7 kg, or 8.3%. The changes for vegetables are larger than the effects reported in Gustavsen and Rickertsen (2006), who used corresponding data for the 1986–1998 period but a different algorithm, and simulated the effects of a VAT removal for fresh vegetables. They found increases in purchases of 0.1, 0.6, 1.3, 1.9, and 3.3 kg in the 0.10, 0.25, 0.50, 0.75, and 0.90 quantiles, respectively. The price of meat does not change in the simulation; thus, meat purchases are minimally affected. Purchases of fish are predicted to increase from 3.7 to 4.5 kg in the lowest quantile and from 26.2 to 28.7 kg in the highest quantile.

Effects on body weight – an illustrative example

The energy content of one representative food item in each food group is used to illustrate the likely magnitudes of the predicted changes in purchases on body weight. We use the conversion factors published by the Norwegian Food Administration (2012)[15] and assume a linear and constant response of body weight to reduced caloric intake.[16]

[11] Our main focus is on price effects, with age, trend, season, and demographic variables treated as control variables. However, a few points may be noted. In all quantiles, the age variable is positive for milk, fruits, vegetables, meat, and fish, and negative for CSD, juices, candy, and ice cream. The trend variable is negative for all goods except candy. The coefficient for single-person households is negative for all goods except in the 0.75 quantile for milk, fruits, vegetables, and fish.

[12] As pointed out by one reviewer, the price of the group "other goods" is measured by the consumer price index, and this index is also affected by VAT changes. However, all the foods with VAT changes account for very small expenditure shares in the index, so these effects are neglected in the simulation.

[13] The contribution of households who stopped purchasing the product is calculated as the reduced purchases of households with a positive purchase before the tax increase and no purchase after the tax increase.

[14] As pointed out by a reviewer, it may be of interest to include the prices of all nine food and beverage items in each demand equation when the effects of VAT changes are simulated. When we reestimated all the models with all nine prices included and used the results in our VAT simulations, the results were similar to the results in Table 5. All the effects, except for CSD and fruits in the 0.25 quantile, fell within the 95% confidence intervals calculated from the standard errors in Table 5. For CSD, the effects were −2.8 l in the 0.25 quantile, 7.2 l in the 0.50 quantile, and 10.9 l in the 0.75 quantile. For fruits in the 0.25 quantile, the effect of a VAT change was 1.5 kg. The estimated coefficients with standard errors from the quantile regressions with all nine prices are presented in Tables 10–18 in the Supplementary appendix to this article.

[15] To convert the predicted changes in quantities of food and beverages to changes in body weight, we assume that each group consists of only one (representative) product. We use the following products: 3.5% milk containing 60 kcal per 100 g, CSD containing 40 kcal per 100 g, orange juice containing 40 kcal per 100 g, mixed candy containing 460 kcal per 100 g, ice cream containing 200 kcal per 100 g, apples containing 50 kcal per 100 g, carrots containing 40 kcal per 100 g, ground beef (14% fat) containing 200 kcal per 100 g, and an average of lean and fatty fish containing 150 kcal per 100 g. One kilogram of fat contains approximately 9000 kcal. Body fat contains approximately 20% water, and $9000 \times 0.8 = 7200$ kcal are required to gain 1 kg of body weight.

[16] A linear and constant response in body weight to a reduced intake of calories is a fairly common assumption in applied work. However, recent research suggests that the energy requirement of the body is a function of body weight and body composition, and as the body weight or body composition changes, this energy requirement changes. The body's self-regulatory mechanism also reduces the long-term effects of dietary changes on body weight as compared with those predicted by a model based on an assumption of a linear and constant response (Hall et al., 2011).

Table 4
Estimated elasticities across quantiles.

	Milk		CSD		Juices		Other goods		Expenditure	
Milk										
0.25	−0.12	(−1.72)	0.05	(1.05)	0.04	(0.89)	0.03	(0.45)	0.01	(0.37)
0.50	−0.19	(−3.72)	0.01	(0.22)	0.02	(1.01)	0.15	(2.60)	0.01	(0.84)
0.75	−0.16	(−3.19)	0.03	(1.44)	−0.00	(−0.08)	0.10	(1.90)	0.03	(2.29)
CSD										
0.25	0.71	(9.03)	−2.57	(−26.15)	0.16	(4.42)	1.50	(13.83)	0.19	(8.40)
0.50	0.17	(2.57)	−1.63	(−40.65)	0.10	(3.18)	0.92	(12.62)	0.43	(22.46)
0.75	0.09	(1.91)	−1.19	(−38.89)	0.08	(3.23)	0.58	(9.02)	0.44	(25.37)
Juices										
0.50	0.36	(5.11)	0.16	(3.59)	−1.57	(−33.17)	0.59	(6.35)	0.45	(15.87)
0.75	0.27	(3.71)	0.12	(3.28)	−0.95	(−36.27)	0.19	(2.48)	0.37	(16.68)
	Candy		Ice cream		Fruits		Other goods		Expenditure	
Candy										
0.25	−2.52	(−32.79)	0.10	(3.15)	0.14	(3.83)	1.83	(19.39)	0.45	(18.58)
0.50	−1.55	(−39.31)	0.07	(2.32)	0.03	(0.71)	0.87	(15.50)	0.58	(32.79)
0.75	−1.08	(−34.65)	0.02	(0.86)	−0.01	(−0.27)	0.58	(13.57)	0.48	(33.07)
Ice cream										
0.50	−0.10	(−6.09)	−2.66	(−37.06)	0.03	(1.53)	2.66	(33.67)	0.07	(6.59)
0.75	−0.16	(−7.01)	−1.82	(−44.88)	0.06	(2.23)	1.65	(28.23)	0.26	(15.12)
Fruits										
0.25	0.03	(0.52)	−0.33	(−9.60)	−0.83	(−18.17)	0.82	(9.29)	0.31	(9.30)
0.50	−0.02	(−0.50)	−0.18	(−7.85)	−0.58	(−21.03)	0.52	(9.82)	0.26	(10.17)
0.75	0.00	(0.08)	−0.12	(−5.05)	−0.55	(−15.90)	0.46	(9.12)	0.21	(12.35)
	Vegetables		Meat		Fish		Other goods		Expenditure	
Vegetables										
0.25	−0.75	(−17.53)	−0.06	(−1.55)	−0.04	(−1.40)	0.53	(7.11)	0.33	(11.13)
0.50	−0.64	(−26.92)	−0.00	(−0.11)	−0.00	(−0.11)	0.39	(8.89)	0.25	(12.46)
0.75	−0.63	(−28.70)	−0.01	(−0.34)	0.00	(0.03)	0.41	(11.02)	0.23	(13.54)
Meat										
0.25	0.02	(0.85)	−1.20	(−35.63)	0.05	(2.10)	0.83	(18.10)	0.30	(17.76)
0.50	0.02	(1.11)	−1.10	(−46.70)	0.06	(3.94)	0.76	(22.82)	0.26	(21.55)
0.75	0.02	(0.91)	−1.01	(−47.50)	0.07	(4.49)	0.67	(19.17)	0.25	(19.09)
Fish										
0.25	−0.11	(−3.24)	−0.01	(−0.43)	−1.39	(−28.84)	1.41	(22.36)	0.10	(3.63)
0.50	−0.04	(−1.60)	−0.05	(−1.47)	−0.82	(−32.22)	0.79	(14.57)	0.13	(4.79)
0.75	−0.00	(−0.09)	−0.02	(−0.48)	−0.72	(−30.94)	0.57	(12.40)	0.17	(9.43)

Note: t-Values are reported in parentheses. The estimated coefficients with standard errors from the quantile regressions are included in Tables 1–9 in the Supplementary appendix to this article.

The predicted changes in body weight are, for several reasons, rough calculations that represent the upper bounds of the effects of VAT changes within a 1-year period. First, the estimates do not account for product substitution within the household. A household in the 0.75 quantile of the purchase distribution for one food is not necessarily in the 0.75 quantile of the purchase distribution for another food; thus, the estimated changes cannot be added together to calculate the total effect for an average person in the given quantile. Second, the analysis does not include all food and beverage purchases. For example, food purchased away from home is not included in the analysis. Third, we have assumed that any changes in the VAT rates are fully passed onto consumers. However, the extent to which these changes are actually passed on depends largely on the retail industry.

As Table 5 shows, the predicted effects on body weight of the predicted changes in purchases are small for many foods. However, the effects are larger for high-purchasing households for CSD, candy, ice cream, fruits, and fish. The reduced purchases of CSD result in an annual reduction of approximately 0.5 kg in body weight among people in the 0.75 quantile. The effect in the 0.50 quantile is approximately 0.3 kg. These weight effects are somewhat lower than the results reported in Dharmasena and Capps (2011), who found that a 20% tax on sugar-sweetened beverages would reduce the per capita body weight between 0.7 and 1.2 kg per year in the US. However, their proposed tax rate is approximately twice as high as our proposed tax rate. Reduced candy purchases result in an annual reduction in body weight of 0.4 and 0.6 kg among people in the 0.50 and 0.75 quantiles, respectively. In the 0.75 quantile, reduced purchases of ice cream result in a reduction in body weight of approximately 0.3 kg per year. The suggested VAT removal for vegetables, fruits, and fish is not motivated by high obesity rates. However, increased fruit consumption results in an increase in the body weight of 0.3 kg per year in the 0.75 quantile, and increased purchases of fish result in an annual increase in body weight of approximately 0.5 kg among people in the 0.75 quantile.

Conclusions

The effects of health-related taxes and subsidies on food and beverages have usually been investigated using models that assume identical price responses among high- and low-purchasing households. We reject the assumption of equality of own-price elasticities for eight of nine food and beverage groups, and we find that several of the cross-price elasticities are also significantly different. These results demonstrate the usefulness of estimating demand functions for different parts of the purchase distribution.

Different price responses are important when the effects of taxes and subsidies are evaluated. A VAT increase from the current

Table 5
Predicted annual effects of VAT changes in different quantiles.

	$\widehat{Y}_{before}$		$\widehat{Y}_{after}$		$\Delta\widehat{Y}$		$\Delta\widehat{Y}\%$		ΔBW
Milk									
0.25	59.4	(0.6)	59.6	(0.2)	0.3	(0.6)	0.4	(0.9)	0.0
0.50	100.9	(0.9)	100.9	(0.4)	0.0	(0.7)	0.0	(0.7)	0.0
0.75	155.6	(1.2)	156.0	(0.7)	0.5	(0.9)	0.3	(0.6)	0.0
CSD									
0.25	9.7	(0.2)	7.3	(0.1)	−2.3	(0.2)	−24.1	(1.6)	−0.1
0.50	33.2	(0.5)	28.6	(0.2)	−5.2	(0.5)	−15.5	(1.3)	−0.3
0.75	78.2	(1.1)	69.5	(0.4)	−8.7	(1.0)	−11.1	(1.1)	−0.5
Juices									
0.50	18.8	(0.4)	19.1	(0.1)	0.3	(0.4)	1.6	(2.1)	0.0
0.75	46.6	(0.6)	47.1	(0.3)	0.5	(0.6)	1.1	(1.3)	0.0
Candy									
0.25	1.4	(0.0)	1.1	(0.0)	−0.3	(0.0)	−25.1	(1.5)	−0.2
0.50	4.1	(0.1)	3.5	(0.0)	−0.6	(0.1)	−14.4	(1.2)	−0.4
0.75	9.0	(0.1)	8.1	(0.1)	−0.9	(0.1)	−9.8	(1.2)	−0.6
Ice cream									
0.50	1.2	(0.0)	0.9	(0.0)	−0.4	(0.0)	−31.1	(1.1)	−0.1
0.75	5.6	(0.1)	4.5	(0.0)	−1.1	(0.1)	−19.8	(1.5)	−0.3
Fruits									
0.25	12.5	(0.3)	13.5	(0.1)	1.0	(0.2)	8.1	(2.1)	0.1
0.50	33.2	(0.5)	35.1	(0.2)	1.9	(0.4)	5.8	(1.3)	0.1
0.75	62.6	(0.8)	66.5	(0.4)	3.9	(0.6)	6.2	(1.1)	0.3
Vegetables									
0.25	15.0	(0.3)	16.6	(0.1)	1.6	(0.3)	10.5	(2.1)	0.1
0.50	32.9	(0.4)	35.7	(0.2)	2.8	(0.4)	8.4	(1.3)	0.2
0.75	56.2	(0.6)	60.9	(0.4)	4.7	(0.6)	8.3	(1.1)	0.3
Meat									
0.25	20.8	(0.4)	20.6	(0.1)	−0.2	(0.3)	−1.0	(1.6)	−0.1
0.50	37.6	(0.4)	37.2	(0.2)	−0.4	(0.4)	−1.1	(0.9)	−0.1
0.75	61.2	(0.7)	60.5	(0.4)	−0.7	(0.6)	−1.1	(0.9)	−0.2
Fish									
0.25	3.7	(0.1)	4.5	(0.0)	0.8	(0.1)	23.0	(2.7)	0.2
0.50	12.4	(0.2)	13.8	(0.1)	1.4	(0.2)	11.8	(1.8)	0.3
0.75	26.2	(0.4)	28.7	(0.2)	2.5	(0.3)	9.6	(1.4)	0.5

Note: Standard errors are reported in parentheses. Column headings: $\widehat{Y}_{before}$ = predicted purchases before the VAT changes in litres of beverages and kilograms of food per capita per year, $\widehat{Y}_{after}$ = predicted purchases after the VAT changes in litres/kilograms per capita per year, $\Delta\widehat{Y}$ = predicted differences in litres/kilograms per capita per year, $\Delta\widehat{Y}\%$ = predicted differences in percent, ΔBW = calculated change in body weight in kilograms.

level of 14–25% on some energy-dense foods and beverages is predicted to reduce annual per capita purchases by 8.7 l of CSD, 0.9 kg of candy, and 1.1 kg of ice cream in the 0.75 quantile. In the 0.25 quantile, the corresponding predicted reductions are 2.3 l of CSD, 0.3 kg of candy, and 0.4 kg of ice cream. The predicted effects of VAT removal for healthy foods are minor among low-purchasing households. In the 0.25 quantile, the removal is predicted to result in increases of 1.0 kg in purchases of fruits, 1.6 kg in purchases of vegetables, and 0.8 kg in purchases of fish. The effects are substantially higher in the 0.75 quantile; however, the expected health benefits of increased purchases among high-purchasing households are small.

The larger quantity changes among high-purchasing households indicate that the suggested VAT increase is well targeted to reduce obesity. In contrast, subsidies will only result in minor increases in purchases of healthy foods among low-purchasing households; thus, the subsidies are less targeted. Furthermore, increased taxes on unhealthy foods will mainly be paid by the households that consume large quantities of unhealthy foods, i.e., those who should be encouraged to change behaviour have the strongest incentives. This is in contrast to the effects of subsidies: the households that already consume large quantities of healthy foods receive the most subsidies, i.e., those who should be encouraged to change behaviour receive the weakest incentives.

Our calculations illustrates that VAT changes may affect body weight. Relatively small annual weight changes will be added over several years and can affect the prevalence of obesity. Data for 2002 show that 31.5% of Norwegians over 15 years of age are overweight (WHO, 2009). Over 80% of these overweight individuals are not obese, suggesting that most are at weights at which small changes in diet could shift them into either healthy or unhealthy weight categories.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodpol.2013.07.001.

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