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The effect of using consumption taxes on foods to promote climate friendly diets – The case of Denmark

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ABSTRACT

Agriculture is responsible for 17–35% of global anthropogenic greenhouse gas emissions with livestock production contributing by approximately 18–22% of global emissions. Due to high monitoring costs and low technical potential for emission reductions, a tax on consumption may be a more efficient policy instrument to decrease emissions from agriculture than a tax based directly on emissions from production. In this study, we look at the effect of internalising the social costs of greenhouse gas emissions through a tax based on CO_2 equivalents for 23 different foods. Furthermore, we compare the loss in consumer surplus and the changed dietary composition for different taxation scenarios. In the most efficient scenario, we find a decrease in the carbon footprint from foods for an average household of 2.3–8.8% at a cost of 0.15–1.73 DKK per kg CO_2 equivalent whereas the most effective scenario led to a decrease in the carbon footprint of 10.4–19.4%, but at a cost of 3.53–6.90 DKK per kg CO_2 equivalent. The derived consequences for health show that scenarios where consumers are not compensated for the increase in taxation level lead to a decrease in the total daily amount of kJ consumed, whereas scenarios where the consumers are compensated lead to an increase. Most scenarios lead to a decrease in the consumption of saturated fat. Compensated scenarios leads to an increase in the consumption of added sugar, whereas uncompensated scenarios lead to almost no change or a decrease. Generally, the results show a low cost potential for using consumption taxes to promote climate friendly diets.

Introduction

Greenhouse gas (GHG) mitigation has increasingly been put on the political agenda as global climate change can lead to comprehensive global problems if GHG emissions are not limited in the near future. Most effort has so far been directed toward reducing emissions of carbon dioxide from the energy and transport sectors by means of policies such as subsidies for substitution towards renewable energy, energy efficiency policies, CO_2 emission trading schemes and emission taxes. Even though CO_2 emissions from the energy and transport sectors are still the largest contributors to GHG emissions, contributions from agricultural land-use, energy use on farms and in fertiliser production and methane and nitrous oxide emissions from meat and dairy production are considerable (IPCC, 2007a). On a global scale, agriculture has been estimated to contribute to 17–35% of total GHG emissions (IPCC, 2007b; Houghton, 1999; Steinfeld et al., 2006; McMichael et al., 2007), while the livestock production alone is estimated to contribute by approximately 18–22% of global GHG emissions (Steinfeld et al., 2006; McMichael et al., 2007). For a comparison, the Danish agriculture is assumed to contribute to 16% of total Danish GHG emissions (Olesen, 2010) while the total emission of GHG from food consumption (export subtracted and import added) is estimated to constitute 19 million tons of CO_2 equivalents annually, which corresponds to approximately 27% of total GHG emissions (Olesen, 2010). On a global scale meat and dairy products currently supply about one-third of the dietary energy intake globally in high income populations, but they contribute far more than one third of GHG emissions from food consumption (McMichael et al., 2007). Hence due to the climatic impact of the dietary composition, dietary changes may lead to reductions in emissions (Aiking et al., 2006; McMichael et al., 2007). Friel et al. (2008) conclude, in an article describing the link between meat consumption and global warming, that there is a need to reduce the average daily meat consumption from about 100 g to 90 g per day per person if the world community is to meet its target of reducing greenhouse gas emissions to the 2005 level by 2050. Furthermore dietary changes may not only be attractive from a climate perspective, the impacts they might have on human health are also of great interest from a public health perspective. In recent decades, there has been a marked increase in the prevalence of lifestyle related illnesses due to excess consumption of saturated fats and sugar and the consumption of red meats as beef and pork are assumed to increase the risk of intestinal cancer (WHO, 2003; WCRF and AICR, 2007; Sinha et al., 2009; Li et al., 2005; Ding, 2006). This implies that major possible

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gains exist in terms of GHG mitigation and in terms of health effects from a reduction in the consumption of meat and dairy products in favour of vegetable based products.

Overall, policymakers with the aim of regulating food consumption have the choice between command and control instruments, information provision and price-based approaches (Lorek et al., 2008). In relation to the adverse effects of food consumption command and control instruments are economically inefficient and have mainly been used in relation to cases where there is an acute threat to the life and health of citizens (Reich et al., 2011). Information campaigns have been widely used to improve general health, such as to decrease smoking or to increase consumption of fruits and vegetables, but in relation to GHG emission information campaigns are considered to have a limited effect since the consumption of meat and dairy is deeply rooted in our culture (Olesen, 2010). The lack of suitability of the two former policy instruments leaves price based instruments as the most appropriate to reduce GHG emissions from food consumption. In terms of reducing emissions, a tax placed directly on the source is theoretically preferable since it directly address the discrepancy between the private and social cost. However, when monitoring costs are high, there are limited options for cutting back on emissions apart from output reduction and when there are a considerable number of output substitution possibilities emission taxes may be less cost-effective than taxes on either outputs or inputs (Schmutzler and Goulder, 1997). All three conditions are assumed to be fulfilled concerning GHG emissions from agriculture in countries with a technologically fairly advanced agricultural sector, since the GHG mitigation potential of improving agricultural productivity or technological enhancements is considered to be small (Wirsenius et al., 2010).[1] Furthermore, according to Wirsenius et al. (2010), there is a limited potential in agriculture for dedicated mitigation measures due to the fact that most of the GHG emissions are related to the intrinsic characteristics of the agricultural system as e.g. nitrous oxide from fertilised soils or methane from enteric fermentation in ruminants. The exact level of these emissions varies considerably with a number of factors and has a non-point source character. In addition, a wide range of substitution possibilities exist at the output level, e.g. the substitution of red meat with either white meat or vegetables such as beans resulting in large reductions in GHG emissions. This implies in the case of GHG mitigation taxes on food that the conditions for the cost-effective use of output taxes compared to input taxes or emission taxes are fulfilled.

Regulation of consumer behaviour through taxation is not new in relation to food consumption. Taxes on stimulants like alcohol, tobacco and soft drinks have been used in many countries during the last decades. Recently a controversial tax on consumption of saturated fat has been introduced in Denmark with the aim of increasing health, a tax which was accompanied by increased taxes on sugar products, soft drinks and cigarettes (Smed, 2012). This tax was removed again 1st of January 2013. Furthermore a planned increase in the taxation of several sugar products that was planned to take place from January 2013 (Skat 2012). The tax on saturated fat was the object of a huge debate concerning the justification for public intervention in food consumption (Smed, 2012) and the issue has attracted huge attention worldwide.

The purpose of this paper is to estimate the magnitude of the GHG mitigation potential of implementing consumption taxes on foods differentiated with respect to average GHG emission per kg of each type of food product consumed in Denmark. This issue has still only been quantified to a limited extent in the literature. Furthermore, we consider the welfare economic losses measured as the change in consumer surplus of each of the proposed scenarios, which implies that we can approximate the costs for consumers of a changed diet. Finally, we quantify the changes in daily intake of energy, saturated fat and sugar per person to assess the health consequences of the implied dietary changes. The remainder part of this paper is organised as follow. In section "Model and data", we describe the model and the data used. In section "Simulation scenarios", we consider the simulation scenarios, whereas in section "Results" we discuss the results from these simulations. Section "Discussion and conclusion" is dedicated to a discussion and the conclusion.

Model and data

Model

Emissions of greenhouse gases from agricultural food production impose externalities on society as the damage costs caused by the emissions are not reflected in the price of foods. This leads to excess production and consumption from a societal perspective. GHGs from food production can, in the same manner as other forms of pollution, be subject to taxation in the form of a "Pigouvian tax" (Pigou, 1957), which internalises the externalities. According to regulation theory, the cost-efficient reductions of greenhouse gas emissions are achieved by taxing production according to the level of emissions per unit of food for the individual producers multiplied by the social cost of emitting 1 kg GHG.

In reality, this is not possible due to the cost of information and administration implied in this form of monitoring so instead, the imposed taxes are based on the average emission levels for each food category representing all food producers in the entire market rather than individual producers' specific emission levels. The bias introduced here is minor since the variation in GHG emissions between individual food producers of the same product is generally much smaller than the difference between food categories (Wirsenius et al., 2010). In addition, according to Wirsenius et al. (2010), a tax should be imposed on consumers rather than producers in order to avoid a so-called "carbon leakage", meaning that CO_2 emissions in a country increase because of another country's effort to reduce its CO_2 emissions. If producers are taxed in Denmark based on their products' emissions, it will reduce the Danish producers' competitiveness. This will give the producers an incentive to move production abroad and an incentive for consumers in Danish supermarkets to choose some now relatively cheaper foreign products. This would not only hurt Danish agriculture and the Danish trade balance, but would probably just move the GHG emissions caused by Danish food consumption abroad, which would not be beneficial for the global climate. If consumers are taxed instead of producers, the competitiveness of Danish producers would not be affected, since the products in the supermarket are taxed equally hard regardless of where they are produced. Furthermore, it is worth noting that as markets for food products are characterised by near-perfect competition, one must assume that the tax burden between food producer and consumer does not depend on whether it is the producer or the consumer who is taxed since, on a long term basis, the tax in both cases is likely to end at the consumer. This implies that the modelling framework used in this paper is a tax on consumer level based on the average emission coefficient for the particular food in question in CO_2 equivalents per kg and the social cost of CO_2 emissions.

Data

To predict the assumed tax induced changes in food consumption, GHG emissions as well as consumption of health related nutrients such as saturated fat and sugar a number of different

[1] On a global scale it is assumed that mitigation technologies could reduce emission per unit of animal product by up to 20% at a reasonable cost, and that reductions above that level are unreasonably expensive (DeAngelo et al., 2006).

Table 1
The food groups used in the model.

Food group	
Beef	Margarine
Biscuits and cakes	Milk
Butter	Other dairy products
Canned and marinated fish	Other foods
Cheese	Other meats (mainly lamb)
Curdled milk products	Pork
Eggs	Potatoes
Fish	Poultry
Flour and bread	Rice and pasta
Fresh vegetables	Sliced processed meat
Frozen vegetables	Sugar
Fruit	

datasets are needed. First we need an estimate for the initial consumption of the different foods as well as the initial consumption of energy in kilojoules and saturated fat and sugar in grams. We need CO_2 equivalents for the relevant food groups to determine the size of the tax and the following changes in GHG emissions. Furthermore we need price-elasticities to predict the changes in food consumption due to the new prices.

Elasticities

The elasticities used to predict changes in consumer behaviour are mainly based on the elasticities estimated in Smed et al. (2007). The model estimated in that paper is based on the Almost Ideal Demand System (AIDS) model (Deaton and Muellbauer, 1980) in its linear form (LA-AIDS) (Moschini, 1995). The model is estimated with dynamics in consumer behaviour (e.g. habit formation or storage effects) introduced as lagged budget shares in the AIDS model, as suggested by, for example, Alessie and Kapteyn (1991) and Assarson (1991). Furthermore, a trend variable is used to reflect changes in preferences not captured by the explanatory variables. Dummies for seasonality reflect seasonal differences in demand. The model is estimated to satisfy the properties of adding-up, linear homogeneity and Slutsky symmetry and the elasticities are then calibrated to be in accordance with the concavity restriction following Jensen (2007). The elasticities are presented in Appendix D. There are a number of uncertainties regarding the applied elasticities. According to Smed et al. (2007), the data is from a representative panel of 2000 households, but with the continuous record of prices and quantities, participation in the panel can lead to increased price sensitivity, which may contribute to an overestimation of the price sensitivity. Furthermore, the price elasticities are based on monthly observations, which imply that the estimated demand parameters describe consumer behaviour in relation to short-term changes in prices (Smed et al., 2007). This implies that the consumer reaction to prices, as we see in this paper, is considered to be in the upper end. Despite this, it is assumed that the general trends are representative of the overall behavioural change among consumers. These elasticities cover the 23 different foods shown in Table 1. For a further explanation of the content of each of these groups see Smed (2008).

As the elasticities used to predict changes in consumer behaviour due to GHG-based taxes are the main determinants of the observed results, we repeat the analysis by elasticities estimated on yearly national accounting data which to a larger extent represent long term behaviour (Jensen and Toftkær, 2002). The latter unconditional elasticities are calculated based on parameters estimated within a dynamic version of the AIDS system.[2] The data based on Smed et al. (2007) are more disaggregated than the data based on the national account data, hence the former capture to a larger degree substitution within groups. As substitution (and thereby elasticities) tend to increase as products are disaggregated we choose to show the results from the consumption data in detail, however all main results are compared across both datasets. Finally to assure that results are not solely driven by cross-price elasticities the analyses are repeated by the use of own-price elasticities from Smed et al. (2007).

Price of CO_2

There are numerous problems associated with determining the cost to society of GHG emissions. First, it requires knowledge of the initial concentration of greenhouse gases in the atmosphere, the degree to which a given emission affects the concentration of greenhouse gases in the atmosphere, as well as how a given change in concentration of GHG in the atmosphere affects present and future generations. Secondly, it is in fact misleading to put a fixed price on the social costs of GHG emissions, since the damage effects of emissions depends on the concentration of GHGs in the atmosphere, which continuously changes over time. Thus, the costs associated with a given level of emissions depend not only on past releases, but also on future emissions. Despite the high complexity associated with fixing a price of GHG emissions, a wide range of estimates exist for the social costs of GHG emissions. The comprehensive Stern Review on the Economics on Climate Change from 2006 calculated the social cost of carbon to be $85 per ton of CO_2 equivalents at 2000-prices, based on an average of estimates from several studies (Stern, 2006, p. 287). This is roughly equivalent to 756 DKK per ton of CO_2 equivalent in 2007-prices. Furthermore, Tol (2005) estimates the cost to be $29 per ton CO_2 equivalents, which equates to 260 DKK per ton CO_2 equivalents. However, according to Stern (2006), the different estimates in the scientific literature vary between under $0 to more than $400 per ton of CO_2 equivalents at 2000-prices. Another approach to determine the price of CO_2 equivalents could be to look at how the CO_2 tax has been priced in other contexts.[3]

Initial food consumption

The consumption data that we use to calculate the initial food consumption on which we base the estimated change in GHG emissions are from Statistics Denmark's consumer survey. The consumption data are constructed as a moving average, i.e. consumption in 2007 is collected over a period of three years from 2006 to 2008. Since the model we use is based on own and cross-price elasticities for 23 food groups, we reduced the original 55 categories in the consumption data to 23 equivalent groups. For a thorough description of how this is performed see Edjabou (2011). The consumption data are expenditure data measured in DKK per household. To translate this into consumption data in volumes, the expenditure data are divided by food prices in DKK. The used food prices are based on own calculations using data from GfK Consumer Tracking Scandinavia (presented in Appendix B).

CO_2 equivalents for food

The primary source for the used CO_2 equivalent is data from the Faculty of Agricultural Sciences at Aarhus University. Their CO_2 equivalents are published in the Ministry of Food's Climate Cookbook from 2009, "Climate at the table" and on the Ministry's website (Ministry of Food, Agriculture and Fisheries, 2009). The carbon footprints of specific food products are determined through life cycle assessments hence, besides the impact on the climate from

[2] For details see Jensen and Toftkær (2002).

[3] Thus, it can be noted for comparison that the price of CO_2 allowances in September 2009 was around 110 DKK per ton of CO_2 (www.nordpool.com). This corresponds to about $ 12.3 (2007 prices), which is well below both Stern's estimate and Tol's mean of the societal costs associated with CO_2 emissions. From this viewpoint, CO_2 quotas are sold too cheaply so that the marginal social cost of emissions is likely to exceed the marginal profit caused by emission from these allowances, whereby the socially optimal production is not reached.

the production itself, the impact of feed, fertiliser, transportation, processing, and packaging is also included. The calculated CO_2 equivalents from the Faculty of Agricultural Sciences have, however, proved to be insufficiently broad for the 23 food groups used in the model. Several adjustments have been made. One example is the missing equivalent for margarine where it was considered reasonable to use the CO_2 equivalent for rape and soya oil from LCA-Food (2010), since the principal ingredient of margarine is vegetable oil. For the food groups, fish, vegetables, fruit, rice and pasta the CO_2 equivalents are calculated as the weighted average according to the individual food's consumption share of the foods contained in these food groups. For example, the food group fish includes shrimp, which has a relatively high carbon footprint and the weighted CO_2 equivalent for fish is thus a weighted value for shrimp and other fish types with substantially lower carbon footprints respectively. Similarly, it is considered essential to include tomatoes and cucumbers in the weighted CO_2 equivalent for vegetables, since they also have a relatively high carbon footprint compared to other vegetables whilst they represent about one third of the consumption of vegetables. For tomatoes and cucumbers, CO_2 equivalents from the Environmental Protection Agency (2006) are used. A review as well as a calculation of the used carbon footprints can be seen in Appendix A. Apart when otherwise stated the used CO_2 equivalents are for Danish produced foods.

As about 25% of the Danish food is imported the use of CO_2 equivalents for Danish produced foods is a possible source of inaccuracy in the calculations. When considering how important this is in calculation of the climatic impact of carbon taxes three issues are of major importance: (1) The extent to which the climatic impact of production methods differ between Denmark and the other countries, (2) the climatic impact of transportation of the food to Denmark and finally (3) there might be differences in the method of calculation of the climatic impact (Mogensen et al., 2009). Considering the first issue the impact of this on the final results depend on the magnitude of import of the foods for which largest changes in consumption are observed and the extent to which CO_2 equivalents for Danish produced foods differ from foreign produced foods. This will be discussed in the results section. Concerning the second issue the climatic impact of imported versus locally produced foods a comparison of the climatic impact of foods produced in an outside the UK has been made by Williams et al. (2007). The impact of transportation is estimated to be between 0.3 and 0.7 kg CO_2 equivalents/kg foods. Consequently, the transportation has a relatively large climatic impact for foods like potatoes or apples which have a low climatic impact from production alone, but a relatively small impact when considering a product as e.g. beef. In the above mentioned study this implies, e.g. that the transportation contribute with less than one percent of the total climatic impact from beef and up to 50% for vegetables. These numbers are supported by, e.g. Dalgaard et al. (2007) and Ligthart et al. (2005). All in all these sources of inaccuracy implies that the used CO_2 equivalents for certain food groups should be considered as being roughly representative because they are not based on an actual life-cycle analysis of the goods, but rather approximations and weighted CO_2 equivalents for these categories. Thus, the calculated changes in climate impacts as a result of changes in consumption are considered to be estimates that describe the general effects, rather than accurate results.

Simulation scenarios

Scenario description

Two different types of scenarios are chosen to illustrate the effect of a tax on GHG emissions and each of these is estimated with the two different prices for the social cost of CO_2 emissions. The A scenarios are based on Tol's estimate of 0.26 DKK per kg, whereas the B scenarios are based on Stern's estimate of 0.76 DKK per kg. All four scenarios are based on the idea that the climate-related costs of food consumption for society should be internalised and hence the price of specific food products should be increased based on their climate impact. In scenarios 1A and 1B, a tax is imposed on all foods, which is equivalent to the climatic impact of the food (uncompensated), whereas scenarios 2A and 2B are designed so that the total tax revenue derived from food taxation is unaltered (compensated). This is achieved by reducing the current level of VAT of 25% on all food in parallel with the introduction of the differentiated climate taxes on food so that the resulting tax is revenue neutral. The tax Δp_i imposed on food in uncompensated scenarios calculated as:

$$\Delta p_{ik} = k_i \cdot p_k \tag{1}$$

where k_i is the used CO_2 equivalent for food group i and p_k is the price of CO_2 used in scenario k calculated as the social cost of releasing 1 kg of GHG measured in CO_2 equivalents.

The compensated scenarios have one more element than the uncompensated scenarios since it is revenue-neutral for the authorities i.e. the original VAT is reduced by a fixed percentage of all the foods. The result is that the price change in compensated scenarios is positive overall for the most climate-damaging food groups, while it is negative for the more climate-friendly food groups. The price change Δp_i for food is then calculated as:

$$\Delta p_{ik} = k_i \cdot p_k - x \cdot p_{i0} \tag{2}$$

where x is a consistently positive factor and p_{i0} is the original price with VAT on food included. The resulting price change is then composed of an environmental tax, as in scenario 1, and a reduction of the original price, which can be achieved by a reduction in the rate of VAT on food. The associated x values for each of the scenarios are determined by entering the expression for the price change for all 23 categories in the model and then by letting x in the function refer to a fixed constant.[4] The value of x is then determined as the value where the total tax revenue after the price change equals the tax revenue before the price change. Using this method, the two x-values that just make Scenario 2A and 2B tax revenue-neutral are: $x_A = 0.026134$ and $x_B = 0.071305$ corresponding to overall reductions in the original prices including VAT of approximately 2.61% and 7.13% respectively. The resulting price changes for each of the scenarios are shown in Table 2.

Post-scenario calculations

This section describes the calculations carried out in relation to the tax scenarios. Based on the described data and a number of functions, the results of the used price changes appear simultaneously. The calculation of the new consumption after the tax requires a set of own and cross-price elasticities in addition to data on initial consumption, original prices and new prices.

By rewriting the elasticity expression, as shown in Appendix C, the new consumption is calculated as:

$$q = \exp\left(\ln(q_0) + \varepsilon \cdot \ln\left(\frac{p}{p_0}\right)\right) \iff q = \exp\left(\ln(q_0) + \varepsilon \cdot \ln\left(\frac{p}{p_0}\right)\right) \tag{3}$$

The total change in the annual carbon footprint from food per person is calculated as the difference between climate impacts before and after the change:

[4] For a more throughout discussion see Edjabou (2011).

Table 2
Changes in prices due to a carbon footprint tax.

	Price change due to tax (scenario 1)				Price change due to tax (scenario 2)			
	Level (DKK)[a]		Percentage		Level (DKK)[a]		Percentage	
	1A	1B	1A (%)	1B (%)	2A	2B	2A (%)	2B (%)
Milk	0.31	0.91	5.3	15.4	0.16	0.49	2.6	8.2
Cheese	2.94	8.59	4.9	14.2	1.36	4.29	2.3	7.1
Curdled milk	0.31	0.91	2.3	6.7	−0.04	−0.06	−0.3	−0.5
Eggs	0.52	1.52	0.9	2.8	−0.92	−2.41	−1.7	−4.4
Other dairy	0.31	0.91	0.4	1.0	−2.00	−5.41	−2.3	−6.1
Butter	1.69	4.94	4.5	13.0	0.70	2.23	1.8	5.9
Margarine	0.94	2.76	5.3	15.5	0.48	1.49	2.7	8.3
Beef	7.10	20.75	11.1	32.4	5.43	16.18	8.5	25.3
Fish	1.17	3.42	1.4	4.0	−1.04	−2.62	−1.2	−3.1
Pork	0.94	2.74	2.0	5.8	−0.31	−0.65	−0.6	−1.4
Other meat	3.77	11.02	4.9	14.3	1.76	5.53	2.3	7.2
Poultry	0.88	2.58	2.5	7.2	−0.06	0.02	−0.2	0.0
Sliced meat	0.94	2.74	2.1	6.1	−0.24	−0.47	−0.5	−1.1
Canned fish	0.23	0.68	0.5	1.4	−1.07	−2.88	−2.1	−5.8
Flour and bread	0.21	0.61	1.2	3.6	−0.23	−0.59	−1.4	−3.5
Sugar	0.26	0.76	1.4	4.2	−0.21	−0.53	−1.2	−2.9
Biscuits and cakes	0.23	0.68	0.5	1.6	−0.88	−2.37	−2.1	−5.5
Other foods	0.47	1.37	2.5	7.4	−0.01	0.06	−0.1	0.3
Fresh vegetables	0.36	1.06	2.7	8.0	0.02	0.12	0.1	0.9
Frozen vegetables	0.36	1.06	2.1	6.0	−0.10	−0.20	−0.6	−1.1
Fruit	0.13	0.38	1.0	2.8	−0.22	−0.58	−1.6	−4.3
Potatoes	0.05	0.15	0.7	2.0	−0.14	−0.38	−1.9	−5.1
Rice and pasta	0.52	1.52	3.1	9.1	0.08	0.33	0.5	2.0

[a] In 2007: 1 DKK ≈ 0.11$.

$$\Delta K_{pr.person} = \sum_{i=1}^{n}(k_i \cdot q_{i1} - k_i \cdot q_{i0}) \quad (4)$$

where $\Delta K_{pr.person}$ is the change in the annual carbon footprint per person in kg CO_2 equivalents, k_i is the CO_2 equivalent for the ith food group, and q_{i0} and q_{i1} is the consumption of food i before and after the price change.

The change in consumer surplus is calculated as an approximation to the expression given by Diewert (1992):

$$\Delta CS_{pr.person} = \sum_{i=1}^{n} 0.5 \cdot (p_{i1} - p_{i0}) \cdot (q_{i1} + q_{i0}) \quad (5)$$

To calculate the change in daily energy consumption in kJ and the daily consumption of saturated fat and sugar in grams per person due to changed consumption, we have calculated the weighted energy content in kJ per kg of food and grams of sugar and saturated fat based on data from the Food Composition Databank from the National Food Institute (Food composition databank, 2011). The weights are created according to the composition of the food group in question according to volume shares.

$$E_i = \sum_{j=1}^{m}(w_j) \cdot (E_j) \quad SF_i = \sum_{j=1}^{m}(w_j) \cdot (SF_j) \quad SU_i = \sum_{j=1}^{m}(w_j) \cdot (SU_j) \quad (6)$$

where E_i is the energy content in kJ, SF_i is the content of saturated fat in grams and SU_i the content of sugar in grams of food group i, w_j is the volume share of food j in food group i and E_j is the energy content, SF_j the content of saturated fat and SU_j the content of sugar in food j. The daily totals for the consumption of energy, saturated fat and sugar per person are then aggregated across food groups.

Results

When assessing the attractiveness of the different scenarios, the focus is primarily on whether they entail a significant reduction in the climate footprint and the associated cost in terms of loss in consumer surplus. Secondly we consider the induced changes in dietary health indicators measured in terms of the change in the intake of total calories, saturated fat and sugar. While reductions in greenhouse gases are positive in the assessment and decreases in consumer surplus are negative, a decrease in the intake of calories can be both negative and positive. In the case of Denmark where the average consumer has an excess intake of calories, a decrease is considered to be positive. As the Danes consume excessive amounts of sugar and saturated fat, a decrease in the intake of these nutrients is also considered to be positive.

In Table 3, the projected changes in carbon footprint and consumer surplus per person are shown as well as efficiency (costs per 1 kg CO_2 equivalent reduction in terms of reduced consumer surplus), while in Table 4 the changes in daily intakes of calories, saturated fat and sugar are shown per person. In both tables results are shown for the three set of elasticities that are used in the calculations.[5]

As anticipated, the reductions in carbon footprints are consistently highest in B-scenarios compared with the respective A-scenarios. The largest effect is seen in scenario 1B, where the total estimated yearly reduction in carbon footprint is 149–277 kg CO_2 equivalents per person, which equates to a 10.4–19.4% reduction in the total climate impact from food consumption (12.0% in the sensitivity analysis based on cross price elasticities alone). The smallest effect of 0.7–3.4% (2.3% in the sensitivity analysis) is seen in scenario 2A, where the low price of CO_2 is used for the calculation of the imposed tax and the tax level is adjusted to be revenue neutral for the state budget. Due to the small effect in terms of carbon footprint, we rule out scenario 2A in the subsequent discussions. Scenarios 1A and 2B reveal to some extent an equal reduction in carbon footprint of 4.0–7.9% in scenario 1A and 2.3–8.8% in scenario 2B. However in terms of cost efficiency, scenario 2B is the most efficient with a price of 0.15–1.73 DKK per kg CO_2 equivalent. So, in terms of economic efficiency, 2B is the preferred

[5] In scenario 2A and 2B the tax revenue equals 0 in the calculations based on the elasticities from Smed et al. (2007). As the calculations based on the two other set of elasticities are made for comparison it is chosen to keep the tax levels and hence the tax revenue are not equal to 0 for the two other set of elasticities.

Table 3
Calculated changes in carbon footprint, consumer surplus and efficiency.

Scenario	Carbon footprint						Consumer surplus			Efficiency		
	kg CO_2-eq./pers./year.			% Change[a]			DKK/pers./year			DKK/kg CO_2 eq.		
	CD[b]	WCP[c]	NAD[d]	CD[b] (%)	WCP[c] (%)	NAD[d] (%)	CD[b]	WCP[c]	NAD[d]	CD[b]	WCP[c]	NAD[d]
1A	−112	−67	−56	−7.9	−4.7	−4.0	−356	−362	−363	3.17	5.41	6.43
1B	−277	−172	−149	−19.4	−12.0	−10.4	−977	−1017	−1026	3.53	5.93	6.90
2A	−48	−32	−9	−3.4	−2.3	−0.7	7	4	2	−0.15	−0.13	−0.20
2B	−126	−88	−33	−8.8	−6.2	−2.3	−18	−38	−56	0.15	0.43	1.73

[a] Percentage of initial emission from food consumption.
[b] CD = Consumer Data (Smed et al., 2007; Jensen, 2007).
[c] WCP = Without cross price.
[d] NAD = National Account Data (Jensen and Toftkær, 2002).

Table 4
Calculated changes in consumption of energy (kJ), saturated fat (g) and sugar (g).

Scenario	Energy (kJ)			Saturated fat (g)			Sugar (g)		
	% Change[a]			% Change[a]			% Change[a]		
	CD[b]	WCP[c]	NAD[d]	CD[b]	WCP[c]	NAD[d]	CD[b]	WCP[c]	NAD[d]
1A	−2.0	−2.0	−3.8	−4.0	−3.1	−3.3	0.3	−1.3	−1.3
1B	−5.3	−5.4	−10.1	−10.5	−8.4	−8.6	0.9	−3.6	−3.7
2A	2.2	0.5	1.3	−0.1	−0.4	−0.7	3.1	1.2	3.2
2B	6.1	1.2	3.1	0.0	−1.3	−2.3	8.9	3.2	8.7

[a] Percentage of pre-tax consumption which is 4181 kJ/pers./day, 46 gram saturated fat per pers./day and 33 g added sugar pers./day).
[b] CD = Consumer Data (Smed et al., 2007; Jensen (2007).
[c] WCP = Without cross price.
[d] NAD = National Account Data (Jensen and Toftkær, 2002).

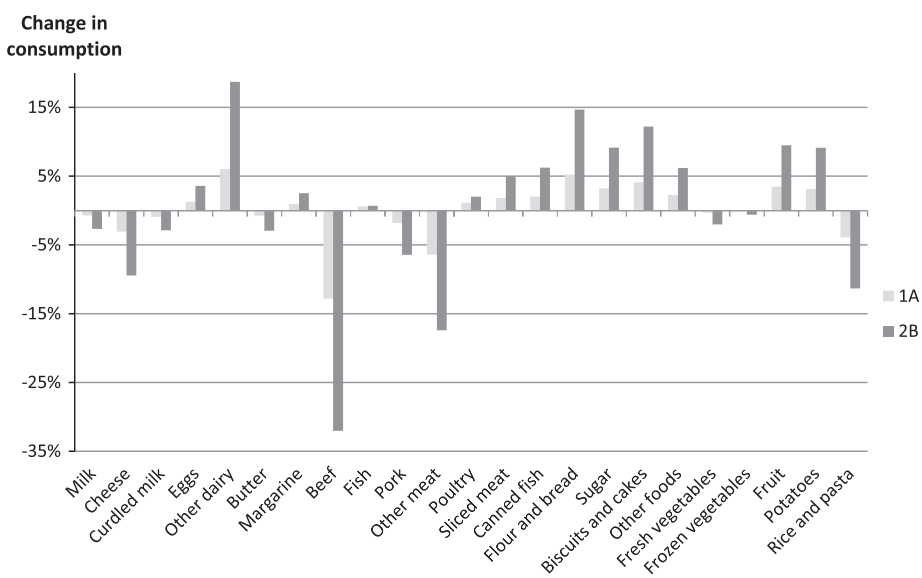

Fig. 1. Change in consumption of foods due to scenario 1A and 2B (% change from initial consumption).

scenario. The changed consumption following this scenario gives rise to an increase in calorie consumption of about 3.1–6.1%. Furthermore, we see a decrease in the consumption of saturated fat by 0.0–2.3% (1.3% in the sensitivity analysis) and an increase in the consumption of added sugar of 8.7–8.9%. If we compare this with the health consequences of scenarios 1A and 1B, it leads to a decrease in calorie consumption of 2.0–10.1%. Furthermore, we see a decrease in the consumption of saturated fat of 3.3–10.5% (3.1% in the sensitivity analysis) and an almost unchanged consumption of added sugar. Therefore, in terms of the derived health consequences of imposing a carbon tax, scenario 1A and 1B are favoured as they entail almost no adverse health effects. Of the two scenarios we do however prefer 1A to 1B, since the former is the most efficient.

In Figs. 1 and 2, we consider the changes in food consumption in more detail for the two preferred scenarios 1A and 2B.[6] Considering the changes in climate impacts, it appears that the most significant decreases in climate impacts are caused by a reduction in the climate impacts from beef, pork, other meat, cheese, milk and rice and pasta. The large reductions in beef and pork can be explained by the combined effects of price increases on meat, an income effect due to a

[6] For a comparison with the simulation based on national account elasticities see Appendix F.

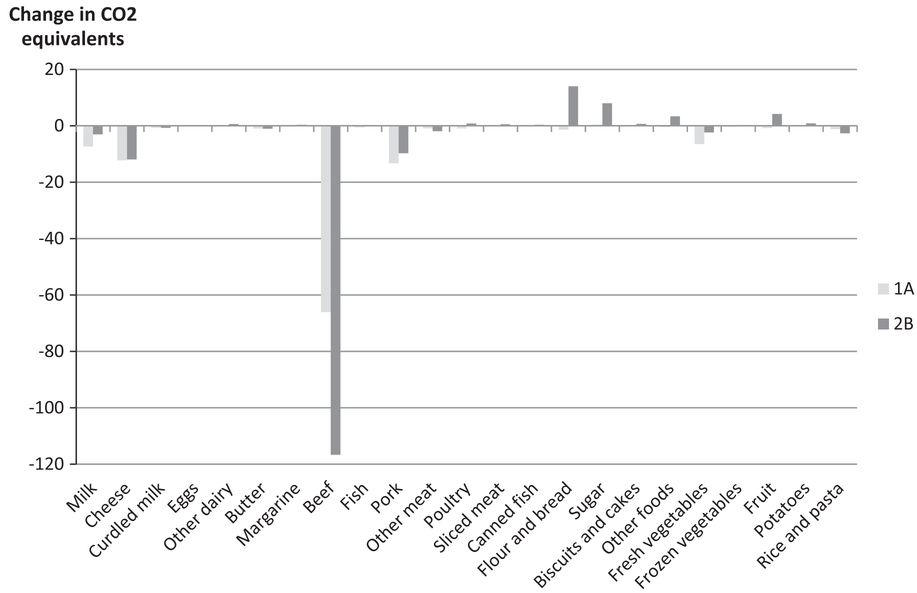

Fig. 2. Change in annual emission from scenario 1A and 2B (kg CO_2 equivalents per person/year).

general increase in the price levels and a negative cross price effect between meat and dairy products. The decline in the climate impact of both cheese and milk is mainly due to own price increases. The declines in the climate impact from rice and pasta are more surprising. The explanation for the observed changes is a combination of several factors. The tax leads to relatively small price increases in absolute values, but due to a low initial price per kg, the percentage price changes are rather high (see Table 2). This, combined with moderate own price elasticities, a high cross price elasticity between rice and pasta and fresh vegetables and a high initial consumption, leads to rather large overall decreases in the consumption. It is surprising that the climate impact of the consumption of pork decreases in scenario 2, even though the price of pork actually decreases. This can be explained by some relatively high price increases for milk, cheese and other meat, and moderately negative cross price elasticities between these groups and pork.

Considering the importance of using CO_2 equivalents that are based mainly on Danish produced foods, even though not only Danish food is consumed, the size of the import for the four major contributors to the decrease in CO_2 equivalents have to be considered, as well as the deviation between CO_2 equivalents for foreign and Danish produced foods. Approximately 75% of the consumed cheese is imported (80% of this originate from Germany, The Netherlands, Sweden, France or Belgium), 56% of beef is imported (81% of this originates from Germany, The Netherlands or Ireland), 30% of pork is imported (82% of this originates from Germany, The Netherlands or Spain) and 10% of milk is imported (91% of this originates from Germany or Sweden) (Statistics Denmark, 2012). If we weight the CO_2 equivalents for the particular type of food according to the size of the import[7] we get weighted equivalents of 23.03 for beef, 3.88 for pork, 9.67 for cheese and 1.22 for milk. If these equivalents are used instead of the equivalents for Danish produced food in scenario 2B on the dataset from Smed et al. (2007) we get a decrease in CO_2 equivalents at 6.6% compared to the 8.8% before, at a cost of 0.48 DKK/CO_2 equivalent (0.15 before). The total calories consumed increase by 4.4% (6.1% before), the consumption of added sugar increases by 7.17%, (8.9% before) and finally the decrease in the consumption of saturated fat is 0.9% (0.0% before). To enlarge the sensitivity analyses we repeat this analysis with all CO_2 equivalents changed to the minimum value from Appendix A and again all CO_2 eqvivalents changed to their maximum values. The resulting reduction in the CO_2 equivalents varies from 3.3 to 12.8% while the consumption of calories increases with 4.6–4.7%. Consumption of sugar increases by 6.2% and 10.4% in the two scenarios respectively and finally consumption of saturated fat increases by 0.5% in the minimum scenario and decrease by 2.9% in the maximum scenario. Based on this we think that the use of CO_2 equivalents for Danish produced foods only to a minor degree alters the main results.

Another important factor is the non-linearity of the CO_2 equivalent for beef. Based on the number of dairy cows in the EU-27 (Weidema et al., 2008), it has been estimated that almost half of EU beef comes from culled dairy cows and the remaining is produced in specialized beef production systems. In Denmark approximately 40% of all slaughtered animals are cows and one sixth of these are assumed to be from the suckler cow-calf system.[8] The rest of the slaughtered animals (approximately 60%) are calves, heifers or bulls and due to the inherent nature of the production system it is not unreasonable to assume that one fifth of this is likewise from the suckler cow-calf system. The used CO_2 equivalent of 27.3 CO_2 equivalents/kg Nguyen et al. (2010) are based on that we only observe a minor decrease in the consumption of milk due to the climate tax (6% in scenario 1A and 2.5% in scenario 2B) the amount of beef from the dairy cow system will be almost unaltered. Hence it is assumed that the decrease in the consumption of beef is mainly due to a decrease in consumption from the suckler cow-calf system.

The large increase in total calorie intake observed in Scenario 2B in both datasets is mainly due to an increase in the intake of flour and bread products and biscuits and cakes, which is also the main cause of the large increase in the intake of added sugar. The decrease in the intake of saturated fat is mainly due to the decrease in the consumption of animal-based products. Considering scenario 1A there is a much smaller increase in the consumption of sugar products, than in scenario 2B. In the simulation based on elasticities from the national account data the consumption of added sugar falls in this scenario, mainly due to decrease in the

[7] For CO_2 equivalents for the imported foods see Appendix A.

[8] This number is based on the number of living cows in Denmark from Statistics Denmark (http://www.statistikbanken.dk/statbank5a/default.asp?w=1280, accessed on 11 April 2012).

consumption of sugar and biscuits and cakes (this group is aggregated in these data). In Mohlin (2008), a tax of comparable size to the tax level in scenario 1B in this paper, was imposed on beef, pork, poultry, eggs and milk in the EU. In terms of kJ consumed, Mohlin found a decrease in the consumption of ruminant meat of 13%, pork of 8%, poultry of 7%, milk products of 1% and eggs of 7%. The resulting decrease in the total amount of kJ consumed was 1.3%. The present analysis imposes a tax on all products which implies considerably larger decreases in consumption of total calories in the uncompensated scenarios (1A and 1B) due to a larger income effect.

Discussion and conclusion

The overall result of the present partial analysis is that significant reductions in GHGs originating from food consumption in Denmark can be achieved through the use of differentiated taxes on food. This can be achieved without increasing the tax burden for Danish consumers if the whole tax system is revised. When comparing the reductions in GHG emissions using prices of 0.26 DKK and 0.76 DKK per kg of CO_2 equivalent, respectively, three parameters are taken into account; the total reduction in carbon footprints, cost efficiency and dietary health effects. The most GHG emission reducing scenario is 1B with a total reduction in the carbon footprint from foods of 10.4–19.4%. However, in terms of cost efficiency, scenario 2B is the most efficient with a price of 0.15–1.73 DKK per kg CO_2 equivalent. This scenario results in a total reduction in the carbon footprint from foods of 2.3–8.8%. However total consumption of calories and sugar are increasing even though we see either no change or a decrease in the consumption of saturated fat. If we look at the health consequences of scenario 1A and 1B, it leads to a decrease in the consumption of calories of 2.0–10.1% and a decrease in the consumption of saturated fat of 3.3–10.5%. Therefore, in terms of the derived health consequences of imposing a carbon tax, scenario 1A and 1B are favoured. However in terms of efficiency 1A is favoured among these two scenarios.

The idea that a change in dietary patterns can be an effective means to decrease GHG emissions as an addition to more conventional strategies is supported by, e.g. Stehfest et al. (2009) who consider the climatic benefits of a low meat diet. They find that a global transition to a low meat diet, as recommended for health reasons, would imply a decrease in GHG emissions equal to the formulated stabilisation target for emissions in 2050 being equal to about 50% of the 2005 emission level. In contrast Vieux et al., 2012 find that if meat is substituted with fruits and vegetables so that the total calories consumed are kept constant this will lead to a rise in GHG emissions. However, in order to assess the full welfare economic benefits of imposing climate taxes, the long term consequences, in terms of permanent changes in land use as a result of changed demand for ruminant meat and dairy products, have to be considered. Carbon emissions from land use change, especially deforestation in relation to meat production, are believed to be a significant contributor to climate change, accounting for 20–25% of total anthropogenic emissions during the 1990s (IPCC, 2000). Nguyen et al. (2010) argue that over a 20 year depreciation period, GHG emissions with the consideration of land use aspects were about 3.1–3.9 times as high as those without the consideration, hence if land use changes were included the effect of a carbon tax would be larger as the main changes in food consumption patterns are observed within the animal food group. Production of animal based foods use more land than the production of vegetable based foods. Furthermore, to access the full costs and benefits the associated changes in health care costs resulting from changed dietary patterns are to be considered as well.

Despite the anticipated positive outcome of imposing a climate related tax on foods in Denmark the tax has to be imposed on a larger scale in order to have any significant climatic impact since anthropogenic greenhouse gas emissions is a global public bad that are independent of borders. Denmark is one of the major meat consuming countries in the world per capita (World Resources Institute, 2010) and according to the law of diminishing marginal utility of consumption this implies that the anticipated effects of a tax are greater in Denmark than elsewhere. Comparing the results of this analysis with those from a similar analysis by Wirsenius et al. (2010) of the climate-related benefit of the introduction of greenhouse gas taxes on animal food, shows a surprising similarity between the calculated reductions. The results of their analysis suggest that a reduction of 7% of emission in CO_2 equivalents from animal foods in the EU-27 can be achieved by introducing a tax on food products of animal origin of € 60 per ton CO_2 equivalents (approximately 0.42 DKK per kg of CO_2 equivalent). If this result is compared with the 4.0–7.9% reduction in scenario 1A and taking into account that Wirsenius et al. (2010) only tax animal foods in their study and not all foods as is the case in the present study, but on the other hand takes land use changes into account the results in this paper seem reasonable. The relatively high consumption of meat in Denmark also implies that there is relatively greater potential for climate-related savings associated with the substitution of meat to less climate damaging foods by the average Dane than by the average European. Taking these differences into account, we can say that there is agreement between the results of this analysis for Denmark and the results of the analysis of the EU-27 by Wirsenius et al. (2010).

Whether a climate related tax on foods is political feasible is uncertain. Taxation of foods is still an issue which is discussed worldwide. Stimulants like soft drinks, tobacco and alcohol have been taxed for decades, whereas the recent imposed (but removed 1st of January 2013) Danish fat tax, to date still is the only case where real foods has been taxed due to health reasons (Smed, 2012). The problematic issue here, compared to taxation of stimulants, is that consumption of saturated fat in smaller amounts has no or even positive health impacts, whereas excess consumption has negative impact on health. The same issue prevails in relation to a climate tax. Furthermore, despite the advantages of introducing differentiated climate taxes on food products, there is also an associated disadvantage in that tax levels are static in the sense that they are not automatically adjusted if technological improvements are developed and implemented, resulting in a reduced environmental impact from production. Such a static environmental tax on food would not provide an incentive to invest and conduct research into improved technologies, since producers would not be rewarded for improving production technologies through a reduction in the climate tax. In contrast, an increased incentive to develop eco-efficient technologies could be created if a political decision was made to use tax revenues from a climate tax to subsidise technological improvements.

Appendix A

To find CO_2 equivalents of the 23 commodity groups used in the model the starting point was data by the Faculty of Agricultural Sciences, Aarhus University, provided in the publication "Climate on the Table" by the Danish Ministry of Food, Agriculture and Fisheries. However, we had to supplement with additional data and calculate weighted CO_2 equivalents for certain food groups. The CO_2 equivalents used in the model are highlighted in bold. The used data sources and extensive notes to CO_2 equivalents are shown. The applied data is for Danish produced food, when nothing else is stated (see Table A1).

Table A1
CO_2 equivalents for the 23 commodity groups.

Commodity groups	Weighting scheme	Weights (%)	Applied CO_2 equivalents	kg CO_2/kg food	Other CO_2 equivalent data sources (for comparison)
Milk			Skimmed or minimilk	1.2[f]	1.06[j] (UK) 1.2[j] (N) 1.2[l] (S) 1.05[m] (S) 1.2[l] (GER) 1.0–1.3[m] (GER)
Cheese			Cheese	11.3[f]	8.79[n] (S) 8.0[o] (S) 8.5[k] (NL)
Curdled milk products			Skimmed or minimilk	1.2[f]	
Eggs			Eggs	2.0[f]	5.54[j] (UK) 2.48[j] (S)
Other dairy			Skimmed or minimilk	1.2[f]	
Butter			Butter (foreign data)	6.5[e]	
Margarine			Rapeseed oil	3.6[f,1]	
Beef			Beef	27.3[i,2]	16.0–27.3[i] (EU) 24[l] (GER) 28[l] (IRE) 18.2–23.2[m] (IRE) 25.3[j] (UK) 15.8[j] (UK) 32.2[j] (Brazil)
Fish	Shrimps[a]	20.0	Frozen shrimps	10.5[f]	
	Other fish	80.0	Fresh wild cod	1.2[f]	
			Cod, fliet, frozen	3.2[f]	
			Flat fish, wild, fresh	3.3[f]	
			Flat fish filet frozen	7.8[f]	
			Herring, wild, fresh	0.6[f]	
			Herring, filet, frozen	1.8[f]	
			Trout, fresh, farmed	1.8[f]	
			Trout, frozen, farmed	4.5[f]	
			Weighted CO_2 eq.	4.5[3]	
Pork			Pork	3.6[h]	6.35[j] (UK) 6.1[j] (S) 5.0[j] (S) 4.6[l] (GER) 5.7[l] (NL) 4.4[j] (Belg.) 3.3[l] (Spain)
Other meat			Lamb (foreign data)	11.6–17.4 [e]	
			Estimated CO_2 eq.	14.5[4]	
Poultry			Fresh chicken	3.1[f]	4.58[j] (UK)
			Frozen chicken	3.7[f]	
			Estimated CO_2 eq. for poultry	3.4[5]	
Processed meat			Pork	3.6[h,6]	
Processed fish			Estimated CO_2 eq.	0.9[7]	
Flour and bread			White bread	0.8[f]	0.98[j] (S)
			Brown bread	0.8[f]	
			White bread or brown bread	0.8	
Sugar			Sugar	1.0[f]	0.8[j] (Aust.)
Biscuits and cakes			Estimated CO_2 eq.	0.9[8]	
Other foods			Average CO_2 eq.	1.8[9]	
Fresh vegetables	Salad, Chinese cabbage, etc.[a]	1.1	Salad (foreign data)	0.3–3.3[e]	
	Cabbage	7.2	Cabbage (foreign data)	0.50[e]	
	Cucumber, tomatoes, etc.	33.2	Cucumber, tomatoes	3.9[g,10]	
	Roots, onions, champignons, etc.	58.5	Carrots and onions	0.1–0.4[g]	
			Weighted CO_2 eq.	1.4[11]	
Frozen vegetables			Fresh vegetables	1.4[12]	
Fruit	Citrus fruits[c]	22.9	Oranges (foreign data)	0.7[e]	0.24[j]
	Bananas[c]	27.1	Bananas (foreign data)	0.5[e]	0.45[j]
	Apples[c] and pear[c]	42.9	Apples imported (foreign data)	0.4[e]	
	Berries[c]	7.1	Strawberries (foreign data)	1.0[e]	1.0[j] (UK) 0.9[j] (Spain)
			Weighted CO_2 eq.	0.5[13]	
Potatoes			Potatoes	0.2[e]	
Rice and pasta	Pasta and durum-wheat[d]	47.7	Pasta (foreign data)	0.8[e]	6.4[j]
	Rice and rice flour	52.30	Rice (foreign data)	3.3[e]	0.81[j]
			Weighted CO_2 eq.	2.0[14]	

Sources for the weight shares and the CO_2 equivalents:
(a) Own calculations based on data from GfK Consumer Tracking, 2002.
(b) Own calculations based on data from GfK Consumer Tracking, 2007.
These types of food cover a total of 95% of the market. The distribution is calculated as if they cover the whole market.
(c) GfK Consumer Tracking, 2007.
These types of food cover a total of 70% of the market. The distribution is calculated as if they cover the whole market.
(d) Statistics Denmark, 2010.
(e) Danish Ministry of Food, Agriculture and Fisheries (2009)/Faculty of Agricultural Sciences, Aarhus University (2010).
(f) LCA Food (www.lcafood.dk).
(g) Environmental Protection Agency (2006).
(h) Dalgaard et al. (2007).

(i) Nguyen et al. (2010).
(j) Mogensen et al. (2009).
(k) van Middelaar et al. (2011).
(l) Lesschen et al. (2011).
(m) Crosson et al. (2011).
(n) Berlin (2002).
(o) Wallén et al. (2004).
Notes regarding the CO_2 equivalents:
(1) For margarine are used CO_2 eq. for rapeseed and soy oil, since no data for margarine could be found and the principal ingredient of margarine is rapeseed oil.
(2) The used CO_2 eq. is for Danish beef, based on Nguyen et al. (2010). According to Nguyen the global warming potential for beef produced in the EU ranged from 16.0 to 19.9 CO^2 eq. for diary calves and was 27.3 kg CO_2 eq. for suckler herds. As there is only to a small degree a decrease in the consumption of milk due to the tax it is reasonable to assume that the decrease in the consumption of beef is mainly from suckler herds.
(3) For fish the CO_2 eq. are weighted on the basis of weight shares. For shrimp the $CO_{2\text{-}}$ eq. for frozen shrimp are used, because they are deemed to constitute the largest part of consumption. As CO_2 eq. for "other fish types" are used the mean value of CO_2 eq. of other fish types.
(4) For other meat is the mean of the lamb used, because the food category "other meats" of sub-categories "lamb" and some undefined "other".
(5) For poultry the mean value of CO_2 eq. for fresh and frozen chicken respectively are used.
(6) For sliced processed meat the value for pork is used since the main part of the processed meat is pork.
(7) For canned and marinated fish is used the mean value for cod and herring.
(8) For biscuits are used the mean value between sugar and bread.
(9) For the main category "other food" is used an average CO_2 eq. for all other food groups. This average is calculated on the basis of consumption in 2007 and CO_2 eq. calculated for the remaining of the 23 food groups. The average CO_2 eq. is calculated as the total carbon footprint per. person for all food groups except "other foods" divided by the total annual food consumption.
(10) For tomatoes and cucumbers are applied mean value of CO_2 eq. for tomato and cucumber, as the Environmental Protection Agency (2006) is estimated to 3.45 per kg tomatoes and 4.3 kg per. kg cucumbers.
(11) For the fresh vegetables are CO_2 eq. weighted on the basis of weight shares.
(12) For frozen vegetables is used CO_2 eq. for fresh vegetables.
(13) For fruit is CO_2 eq. weighted on the basis of weight shares.
(14) For rice and pasta the CO_2 eq. are weighted on basis of weight shares.

Appendix B

The prices we use for the 23 food commodity groups are calculated based on data from GfK Consumer Scan Scandinavia. The price of fish and canned fish are extrapolated from the year 2002, since fish and canned fish were missing in the dataset for 2007 (see Table B1).

Appendix C. Calculation of changed consumption

The elasticity expression:

$$\varepsilon = \frac{dq}{dp} \cdot \frac{p}{q} \tag{C1}$$

If the elasticity is assumed to be constant it can be considered as a differential equation with the following solution:

$$q = k \cdot p^{\varepsilon}, \tag{C2}$$

where k is a constant.

That $q = k \cdot p^{\varepsilon}$ is the solution to this differential equation can be proved by differentiating the expression:

$$\frac{dq}{dp} = \frac{d(k \cdot p^{\varepsilon})}{dp} = k \cdot \varepsilon \cdot p^{(\varepsilon-1)} \tag{C3}$$

and inserting q and $\frac{dq}{dp}$ in the original Eq. (C1):

$$\frac{dq}{dp} \cdot \frac{p}{q} = k \cdot \varepsilon \cdot p^{(\varepsilon-1)} \cdot \frac{p}{k \cdot p^{\varepsilon}} = \varepsilon \cdot \frac{k \cdot p^{\varepsilon}}{k \cdot p^{\varepsilon}} = \varepsilon \tag{C4}$$

For a known pair of correlated values (p_0, q_0) the constant k is determined by inserting p_0 and q_0 in Eq. (C2):

$$q_0 = k \cdot p_0^{\varepsilon} \iff k = \frac{q_0}{p_0^{\varepsilon}} \tag{C5}$$

The solution to the differential Eq. (C2) can then be expressed as:

$$q = k \cdot p^{\varepsilon} = \frac{q_0}{p_0^{\varepsilon}} \cdot p^{\varepsilon} = q_0 \cdot \left(\frac{p}{p_0}\right)^{\varepsilon}, \quad \text{which can be rewritten as :}$$

$$\ln(q) = \ln(q_0) + \varepsilon \cdot \ln\left(\frac{p}{p_0}\right) \iff q = \exp\left(\ln(q_0) + \varepsilon \cdot \ln\left(\frac{p}{p_0}\right)\right) \tag{C6}$$

Which is then used to calculate the new quantities after imposing the tax.

Appendix D

See Table D1.

Appendix E

See Table E1.

Table B1
Prices for the 23 commodity groups. *Source*: GfK Consumer Tracking Scandinavia.

Food groups	Extrapolated prices, 2007 (DKK/kg) (baseret på priser fra 2002)	Calculated prices, 2007 (DKK/kg)
Milk	6.54	5.93
Cheese	57.37	60.32
Curdled milk	13.31	13.66
Eggs	53.97	55.13
Other dairy	92.66	88.63
Butter	27.30	37.95
Margarine	15.29	17.83
Beef	55.62	64.01
Fish	84.69	
Pork	39.90	47.55
Other meat	60.16	77.04
Poultry	30.22	36.00
Sliced meat	41.29	45.00
Canned fish	49.99	
Flour and bread	18.33	16.79
Sugar	11.32	18.15
Biscuits and cakes	34.67	42.76
Other foods	21.87	18.40
Fresh vegetables	13.60	13.25
Frozen vegetables	15.82	17.72
Fruit	14.13	13.45
Potatoes	21.61	7.43
Rice and pasta	15.64	16.71

Table D1
Own and cross price elasticities (ε_{ij}).

	Milk	Cheese	Curdled milk	Eggs	Other dairy	Butter	Margarine	Beef	Fish	Pork	Other meat	Poultry	Sliced meat	Canned fish	Flour and bread	Sugar	Biscuits and cakes	Other foods	Fresh vegetables	Frozen vegetables	Fruit	Potatoes	Rice and pasta
Milk	−0.477	−0.260	−0.080	−0.313	−1.167	−0.095	−0.045	−0.131	−0.062	−0.232	−0.051	−0.072	0.633	0.202	0.282	0.091	0.064	0.109	−0.266	−0.060	−0.251	−0.080	−0.052
Cheese	−0.181	−1.213	−0.364	−0.328	−0.658	−0.095	−0.045	−0.131	−0.062	−0.232	−0.051	−0.072	0.633	0.202	0.282	0.091	0.064	0.109	−0.266	−0.060	−0.251	−0.080	−0.052
Curdled milk	0.497	−0.326	−0.983	0.540	−0.520	−0.095	−0.045	−0.131	−0.062	−0.232	−0.051	−0.072	0.633	0.202	0.282	0.091	0.064	0.109	−0.266	−0.060	−0.251	−0.080	−0.052
Eggs	0.043	0.220	0.613	−1.422	−0.241	−0.095	−0.045	−0.131	−0.062	−0.232	−0.051	−0.072	0.633	0.202	0.282	0.091	0.064	0.109	−0.266	−0.060	−0.251	−0.080	−0.052
Other dairy	−5.528	8.149	−1.492	0.048	−1.664	−0.095	−0.045	−0.131	−0.062	−0.232	−0.051	−0.072	0.633	0.202	0.282	0.091	0.064	0.109	−0.266	−0.060	−0.251	−0.080	−0.052
Butter	−0.110	−0.129	−0.034	−0.032	−0.006	−1.083	−0.441	0.380	0.181	0.673	0.148	0.210	0.863	0.275	0.099	0.032	0.022	0.038	−0.705	−0.158	−0.665	−0.212	−0.138
Margarine	−0.110	−0.129	−0.034	−0.032	−0.006	0.701	−1.032	0.380	0.181	0.673	0.148	0.210	0.863	0.275	0.099	0.032	0.022	0.038	−0.705	−0.158	−0.665	−0.212	−0.138
Beef	−0.494	−0.578	−0.154	−0.144	−0.026	0.004	0.002	−1.184	0.048	0.521	−0.508	0.086	−0.599	−0.191	0.016	0.005	0.004	0.006	0.477	0.107	0.450	0.143	0.093
Fish	−0.494	−0.578	−0.154	−0.144	−0.026	0.004	0.002	0.447	−0.794	0.428	−0.543	0.122	−0.599	−0.191	0.016	0.005	0.004	0.006	0.477	0.107	0.450	0.143	0.093
Pork	−0.494	−0.578	−0.154	−0.144	−0.026	0.004	0.002	0.078	−0.222	−1.178	−0.462	−0.219	−0.599	−0.191	0.016	0.005	0.004	0.006	0.477	0.107	0.450	0.143	0.093
Other meat	−0.494	−0.578	−0.154	−0.144	−0.026	0.004	0.002	−0.179	−0.455	1.456	−1.007	0.267	−0.599	−0.191	0.016	0.005	0.004	0.006	0.477	0.107	0.450	0.143	0.093
Poultry	−0.494	−0.578	−0.154	−0.144	−0.026	0.004	0.002	0.473	0.088	0.484	−0.017	−1.438	−0.599	−0.191	0.016	0.005	0.004	0.006	0.477	0.107	0.450	0.143	0.093
Sliced meat	0.048	0.056	0.015	0.014	0.003	0.163	0.077	−0.030	−0.014	−0.054	−0.012	−0.017	−1.030	−0.499	0.085	0.027	0.019	0.033	0.067	0.015	0.063	0.020	0.013
Canned fish	0.048	0.056	0.015	0.014	0.003	0.163	0.077	−0.030	−0.014	−0.054	−0.012	−0.017	0.605	−0.993	0.085	0.027	0.019	0.033	0.067	0.015	0.063	0.020	0.013
Flour and bread	0.686	0.803	0.214	0.200	0.036	−0.319	−0.150	−0.108	−0.051	−0.191	−0.042	−0.060	−0.688	−0.219	−0.954	−0.349	−0.393	−0.482	−0.154	−0.035	−0.145	−0.046	−0.030
Sugar	0.686	0.803	0.214	0.200	0.036	−0.319	−0.150	−0.108	−0.051	−0.191	−0.042	−0.060	−0.688	−0.219	0.433	−0.926	−0.074	−0.139	−0.154	−0.035	−0.145	−0.046	−0.030
Biscuits and cakes	0.686	0.803	0.214	0.200	0.036	−0.319	−0.150	−0.108	−0.051	−0.191	−0.042	−0.060	−0.688	−0.219	0.418	0.009	−1.029	0.107	−0.154	−0.035	−0.145	−0.046	−0.030
Other foods	0.686	0.803	0.214	0.200	0.036	−0.319	−0.150	−0.108	−0.051	−0.191	−0.042	−0.060	−0.688	−0.219	0.407	−0.133	−0.041	−1.078	−0.154	−0.035	−0.145	−0.046	−0.030
Fresh vegetables	−0.048	−0.056	−0.015	−0.014	−0.003	−0.121	−0.057	0.066	0.032	0.117	0.026	0.037	0.342	0.109	−0.277	−0.090	−0.063	−0.107	−0.852	−0.366	0.078	−0.018	−0.821
Frozen vegetables	−0.048	−0.056	−0.015	−0.014	−0.003	−0.121	−0.057	0.066	0.032	0.117	0.026	0.037	0.342	0.109	−0.277	−0.090	−0.063	−0.107	0.285	−1.150	0.321	0.164	−0.031
Fruit	−0.048	−0.056	−0.015	−0.014	−0.003	−0.121	−0.057	0.066	0.032	0.117	0.026	0.037	0.342	0.109	−0.277	−0.090	−0.063	−0.107	0.201	−0.323	−1.087	−0.675	0.026
Potatoes	−0.048	−0.056	−0.015	−0.014	−0.003	−0.121	−0.057	0.066	0 ε .032	0.117	0.026	0.037	0.342	0.109	−0.277	−0.090	−0.063	−0.107	1.134	0.052	−1.090	−0.575	−0.091
Rice and pasta	−0.048	−0.056	−0.015	−0.014	−0.003	−0.121	−0.057	0.066	0.032	0.117	0.026	0.037	0.342	0.109	−0.277	−0.090	−0.063	−0.107	−1.920	−0.005	2.135	−0.003	−0.559

Table E1
Own and cross price elasticities, based on national accounting data (ε_{ij}).

	Whole milk	Semi skimmed	Curdled	Other dairy	Butter	Margarine	Eggs	Cheese	Beef	Pork	Poultry	Other meat	Fish	Bread, flour, cereals etc.	Sugar products	Fruit, vegetables and potatoes
Whole milk	−1.143	0.188	0.206	−0.166	0.289	−0.395	0.236	−0.199	0.012	0.030	0.006	0.000	0.008	0.025	0.022	0.023
Semiskimmed	0.133	−0.371	−0.395	−0.226	0.160	0.009	0.083	−0.489	0.012	0.030	0.006	0.000	0.008	0.025	0.022	0.023
Curdled	0.301	−0.722	−0.730	−0.203	−0.483	0.158	−0.381	1.065	0.012	0.030	0.006	0.000	0.008	0.025	0.022	0.023
Other dairy	−0.187	−0.315	−0.193	−0.394	−0.186	−0.190	−0.190	−0.176	0.012	0.030	0.006	0.000	0.008	0.025	0.022	0.023
Butter	0.238	0.194	−0.243	0.143	−0.724	−0.215	0.168	−0.411	0.012	0.030	0.006	0.000	0.008	0.025	0.022	0.023
Margarine	−0.531	−0.064	0.085	−0.048	−0.426	0.123	−0.177	−0.527	0.012	0.030	0.006	0.000	0.008	0.025	0.022	0.023
Eggs	0.243	0.116	−0.281	−0.351	0.205	−0.115	−0.621	−0.249	0.012	0.030	0.006	0.000	0.008	0.025	0.022	0.023
Cheese	−0.087	−0.257	0.319	0.105	−0.253	−0.142	−0.096	−0.575	0.012	0.030	0.006	0.000	0.008	0.025	0.022	0.023
Beef	0.003	0.004	0.002	0.002	0.004	0.002	0.003	0.006	−0.398	0.607	−0.084	0.213	−0.877	−0.012	−0.010	−0.011
Pork	0.003	0.004	0.002	0.002	0.004	0.002	0.003	0.006	0.067	−1.204	−0.014	0.136	0.040	−0.012	−0.010	−0.011
Poultry	0.003	0.004	0.002	0.002	0.004	0.002	0.003	0.006	−0.189	−0.129	−0.519	−0.499	0.250	−0.012	−0.010	−0.011
Other meat	0.003	0.004	0.002	0.002	0.004	0.002	0.003	0.006	0.000	0.000	0.000	−16.891	0.000	−0.012	−0.010	−0.011
Fish	0.003	0.004	0.002	0.002	0.004	0.002	0.003	0.006	0.000	0.094	0.180	0.000	−0.301	−0.012	−0.010	−0.011
Bread, flour, cereals etc.	0.009	0.011	0.005	0.006	0.010	0.007	0.007	0.017	0.012	0.030	0.006	0.000	0.008	−0.927	0.073	−0.140
Sugarproducts	0.009	0.011	0.005	0.006	0.010	0.007	0.007	0.017	0.012	0.030	0.006	0.000	0.008	0.091	−1.009	−0.019
Fruit, vegetables and potatoes	0.009	0.011	0.005	0.006	0.010	0.007	0.007	0.017	0.012	0.030	0.006	0.000	0.008	−0.148	−0.036	−0.807

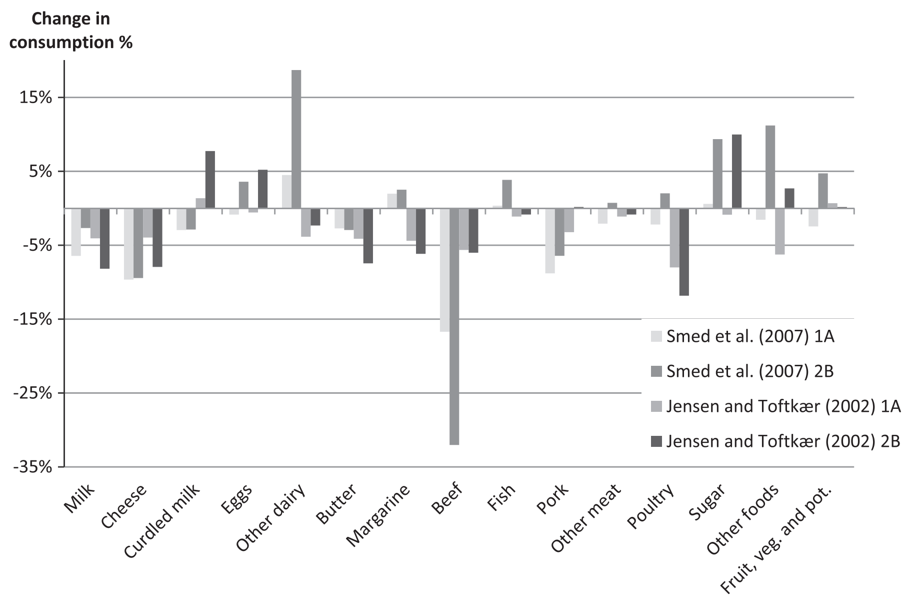

Fig. F1. Change in consumption of foods due to scenario 1A and 2B (% change from initial consumption).

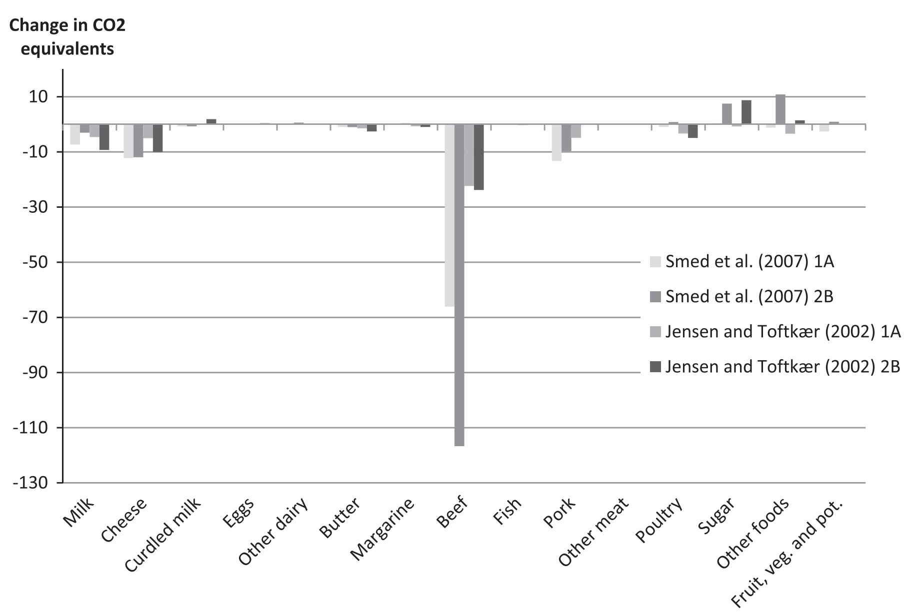

Fig. F2. Change in annual emission from scenario 1A and 2B (kg CO_2 equivalents per person/year).

Appendix F. Change in consumption

Compared between simulations using national account based elasticities and the Smed and Jensen elasticities (see Figs. F1 and F2).

The elasticities from Smed et al. (2007) are more detailed than the national account elasticities. Therefore the results based on the Smed et al. (2007) elasticities are weighted together to match the results from the national account elasticities in the following way based on volume shares. Fish and canned fish are weighted together to one group; Fish. Other meat and sliced meat are weighted together to one group; Other meat. Sugar products and cakes and biscuits are weighted together to one group; Sugar products. Flour and bread, rice and pasta and other food is weighted together to one group; Other food. Fresh vegetables, frozen vegetables, fruit and potatoes are weighted together to one group; Fruits, vegetables and potatoes.

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