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A Cross-Country Comparison of the Sustainability Effects of Dietary Recommendations

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Abstract

We analyse ex-ante the effects of diet recommendations in France, Finland and Denmark. The simulation approach combines a behavioural model of adjustment to dietary constraints, an epidemiological model and an LCA model. We conclude that for the three countries: 1- The promotion of several diet recommendations would improve social welfare; 2- Healthy-eating recommendations targeting consumption of saturated fat, fruits/vegetables and salt should be prioritized for promotion; 3- Although synergies dominate, trade-offs between environmental and health objectives may occur in Finland and Denmark; and 4- The taste/utility cost of dietary change imposed on consumers should be included in the welfare analysis of diet recommendations.

Keywords: **nutrition; healthy eating; diet; sustainability; food choices**

1 Introduction

The negative health and environmental effect of current diets in high-income countries is an issue that has moved up the policy agenda in recent years. The standard policy response has been to develop informational measures to urge consumers to modify their food choices towards healthier options, but the effects of such measures are poorly understood. Although a few rigorous ex-post economic analyses of such measures have been developed (Capacci and Mazzocchi, 2011; Shankar et al., 2013), ex-ante analyses of their potential economic, health, environmental and welfare effects are missing, with the few exceptions upon which this paper is based. Conversely, the impact of taxes has been much more thoroughly investigated even if policy makers are reluctant to introduce taxes.

This lack of understanding of the effects of recommendations raises a number of difficulties in the design and implementation of public measures aimed at promoting healthy eating and sustainable food consumption. For instance, given that consumers do not respond to complex messages, the first step in designing an informational campaign is to select a clear target, that is, a food or nutrient whose consumption should be encouraged or discouraged. However, the existing toolkit of researchers cannot deliver a clear ranking of diet recommendations, or an assessment of their relative cost-effectiveness. The practical implication of this state of affair is that, for a given country at a given time, it is unclear whether, say, promotion of fruits and vegetable consumption should be prioritised over measures targeting the consumption of meat or intake of salt. The social desirability of such policies also remains unclear. Many authors question their effectiveness, pointing to seemingly limited effects on behaviours (Traill, 2012), but complete welfare analyses are almost non-existent. Another weakness of the literature is that it does not provide any metrics to measure the difficulty of complying with different recommendations for selected groups of the population.

Against this background, this paper applies a model of consumer response to dietary recommendations that has recently been proposed by Irz et al. (2015) to investigate the health and economic effects of dietary recommendations in France. That model was subsequently extended to cover environmental effects (Irz et al., 2016a) and uncertainty in health outcomes (Irz et al., 2016b), also in a French context. In light of that work, our contribution is to apply the same model to Denmark and Finland, in pursuit of several objectives: 1- To establish whether that approach is robust; 2- To assess whether the main results found in France – for instance regarding the relative magnitude of health and environmental benefits of various recommendations, or the synergies between environmental and health goals - also apply in different national contexts and hence may have general validity; and 3- To deliver practical advice regarding the promotion of sustainable diets in the three countries. The paper is organised as follows. The next section summarizes briefly the methodology, section 3 presents the data and calibration procedure, section 4 discusses the results and their interpretation, while section 5 concludes.

2 The theoretical model

Overview - The schematic structure of the model is presented in Figure 1. At its core is a behavioural model using empirically estimated preferences to simulate how a representative consumer complying with one or several new dietary constraints would adjust his/her diet, as well as the short-term utility loss due to compliance, which we call the taste cost of the adjustment. Those adjustments are then linked to an epidemiological model to calculate health effects, and a life-cycle analysis (LCA) model to simulate environmental effects. Monetization of the health and environmental effects allows calculation of the benefit from compliance, which can be compared to the private taste cost and public cost of developing measures to ensure compliance in an integrated efficiency analysis. The analysis can be carried out for any number of sub-populations for which data and parameters are available, hence allowing for the analysis of the equity effects of recommendation (e.g., is compliance more difficult for low-income groups? Which groups derive the largest health benefit from compliance?). We now turn to each sub-components of the model. Although this model starts from an "as if" assumption in the sense that it assumes compliance with a given recommendation (or set of recommendations), the analysis delivers useful information to compare the sustainability effects of recommendations and their impacts on welfare.

The behavioural model – The starting point is a model of whole diet adjustment to nutritional and/or environmental constraints (i.e., "dietary constraints") presented in more details in Irz et al. (2015) and based on the generalised rationing theory of Jackson (1991). We assume that an individual chooses the consumption of H goods in quantities $\boldsymbol{x}=(x_1, \dots x_H)$ to maximize a strictly increasing, strictly quasi-concave, twice differentiable utility function $U(x_1, \dots x_H)$, subject to a linear budget constraint $\boldsymbol{p}.\boldsymbol{x} \leq M$, where $\boldsymbol{p}$ is a price vector and M denotes income. We further assume that the consumer operates under N additional linear dietary constraints, imposing, for instance, a maximum permissible consumption of salt, or total greenhouse gas (GHG) emissions from the diet, or a minimum consumption of fruits and vegetables (F&V). Denoting by a_i^n the constant nutritional or environmental coefficient for any food i and target n, the value of which is known from LCA databases or food composition tables, the dietary constraints are expressed by: $\sum_{i=1}^{H} a_i^n x_i \leq r_n \; \forall n = 1,..., N$. The utility maximization problem is solved first in a Hicksian framework. We denote the compensated (Hicksian) demand functions of the non-constrained problem by $h_i(p,U)$, and those of the constrained model by $\tilde{h}_i(p,U,A,r)$, where A is the (N x H) matrix of technical coefficients, and $\boldsymbol{r}$ the N-vector of levels of the constraints. The solution requires the derivation of shadow prices $\tilde{p}$, defined as the prices that would have to prevail for the unconstrained individual to choose the same bundle of goods as the constrained individual: $\tilde{h}_i(p,U,A,r) = h_i(\tilde{p},U)$. Our empirical application only considers the introduction of a single constraint at a time and, in that simplified framework, the marginal change in shadow prices derived by Irz et al. (2015) are:

$$\frac{\partial \tilde{p}_i}{\partial r_1} = a_i^1 / (\sum_{i=1}^{H} \sum_{j=1}^{H} s_{ij} a_i^1 a_j^1) \qquad i = 1, \dots .H \qquad (1).$$

where $s_{ij} = \partial h_i / \partial p_j$ denotes the Slutsky coefficient of good i relative to price j. The corresponding adjustments in Hicksian demand induced by compliance with the constraint follow:

$$\frac{\partial \tilde{h}_k}{\partial r_1} = (\sum_{i=1}^{H} s_{ki} a_i^1) / (\sum_{i=1}^{H} \sum_{j=1}^{H} s_{ij} a_i^1 a_j^1) \qquad k = 1, \dots .H \qquad (2)$$

Equation (2) expresses the changes in compensated demands as functions of two sets of parameters only: first, the Slutsky coefficients, which describe consumers' preferences and the relative difficulty of substituting foods for one another; and, second, matrix A, which gathers technical coefficients measuring the properties of each food in the nutritional or environmental domain. Given that the Slutsky matrix is typically estimated empirically from observations on actual purchase behaviours, we claim that the model is based on realistic food preferences, unlike most programming-based models of diet optimization that make arbitrary assumptions about food preferences, either explicitly by imposing “palatability constraints” (Henson, 1991) or implicitly, through the choice of an arbitrary objective function (Shankar et al., 2008 or Darmon et al., 2008).

Expressions (1) and (2) show that a change in the nutritional constraints has an impact on the entire diet. This is true even for the goods that do not enter the constraints directly, as long as they entertain some relationship of substitutability or complementarity with any of the goods entering the constraints (i.e., as long as at least one Slutsky term s_{ki} is different from zero). Further, the model indicates that the magnitude and sign of any change in demand for any given product is unknown *a-priori* but depends in a complex way on the product’s technical coefficients and its substitutability with other products entering the constraints.

Real world consumers operating under a budget rather than utility constraint, we infer the changes in uncompensated demands by first calculating the compensating variation, which measures the loss of utility due to the imposition of the new dietary constraints. For any change in any of the constraint levels r_j , we have: $CV = -\sum_{i=1}^{H} p_i \partial \tilde{h}_i / \partial r_j < 0$. An approximate solution to the change in Marshallian demand Δx is then calculated by adding to Δh the income effect associated with the removal of the compensation: $\Delta x = \Delta h + \tilde{h}.\varepsilon^R CV / p.\tilde{h}$, where ε^R denotes the vector of income (or expenditure) elasticities, which is empirically estimable.

The epidemiological and environmental models - Simulation of health effects requires that changes in food consumption at household level, as described by the behavioural model, be translated into changes in individual intakes. This is accomplished under the assumption that (i) the percentage changes in intakes are the same for all the members of a given household, and (ii) the percentage changes are the same for at-home and out-of-home consumption. Changes in food intakes are then converted into changes in nutrients using food composition tables. Variations in nutrient intakes are finally translated into changes in mortality due to diet-related chronic diseases using the DIETRON epidemiological model of Scarborough et al. (2012). Based on relative risk ratios derived from world-wide meta-analyses, the model converts variations in ten nutritional inputs (fruits, vegetables, fibres, total fat, mono-unsaturated fatty acids (MUFA), poly-unsaturated fatty acids (PUFA), saturated fatty acids (SFA), trans-fatty acids (TFA), cholesterol, salt, energy) to estimate changes in diet-related chronic diseases (heart disease, strokes, and ten types of cancer) and related deaths. The environmental effects are limited to an analysis of climate impact, which is estimated by applying life-cycle analysis coefficients to each intake category.

Efficiency analysis – the behavioural model simply assumes compliance with dietary recommendations without considering the policy measures that would be necessary to implement to bring about compliance. Although that simplification precludes carrying out a full cost-benefit analysis, we nonetheless derive important insights regarding the relative efficiency of various recommendations through calculation of an efficiency threshold, defined as the maximum amount that could be invested by public authorities in order to ensure compliance with a given recommendation. Formally, promotion of a recommendation generates health benefits (denoted B_h) in the form of deaths avoided and reduced environmental externalities (denoted B_e), which can be calculated by valuing the health and environmental effects estimated by the model. In the sort-run, there are however costs imposed on consumers (i.e., the taste cost as measured by $-CV$ and capturing a loss of hedonic rewards), as well as (unknown) costs to the public sector (i.e., cost of interventions such as social marketing campaigns, denoted C_p). The cost effectiveness threshold of each recommendation is hence calculated as $Cp=Be+Bh+CV$, giving us a means of comparing the relative efficiency of all the selected recommendations.

3 Data and calibration

France – the model's calibration is explained in Irz et al. (2015) so that we only give a brief overview here. Food consumption data originates from a representative panel of French households (KANTAR Worldpanel), which was used previously to estimate a matrix of price and expenditure elasticities of demand for food by Allais et al. (2010). We have used those behavioural parameters and related product aggregation scheme as reported in the supplementary material of that article. The intake and food composition data comes from the French dietary intake survey INCA2.[1] The parameters of DIETRON are not country specific, so that adapting the DIETRON model to France only requires calibration of the initial mortality levels, by relevant causes. This is achieved by using the INSERM data on mortality in France attributable to major diet-related diseases.

Finland – The consumption data originates from the year 2012 Household Budget Survey (HBS), which used diary records of all food purchases destined for at-home consumption in a nationally representative sample of Finnish consumers (n=3495). This data supported the estimation of an approximate Exact Affine Stone Index (EASI) demand system (Lewbel and Pendakur, 2009), which presents several advantages over more common functional forms (e.g., AIDS). The product aggregation scheme was defined so as to allow both a nutritional assessment and an assessment in terms of climate change impact. The intake and food composition data came from the Finnish dietary intake survey FINDIET 2012, while the mortality data necessary to calibrate DIETRON are publicly available from the website of the Finnish Statistical Institute.

Denmark – The consumption data originates from the National Dietary Survey 2011-2013 (Pedersen et al., 2015), which is a representative sample based on 3,307 individuals' 7-day records of their intakes. The dietary intake data were disaggregated into more detailed commodity groups by means of household budget survey from Statistics Denmark and household purchase data from GfK Consumerscan Scandinavia panel (http://www2.gfkonline.dk/). An Exact Affine Stone Index (EASI) demand system was estimated on the basis of monthly data from the GfK panel dataset for the years 2006-2014, in order to obtain estimates of conditional price and budget elasticities for the same 20 commodity categories as for Finland.

For the three countries, the LCA coefficients derive from a systematic review of the grey and academic literature, as explained in detail in Pulkkinen and Hartikainen (2016). We also limit the study to individuals between the age of 25 and 74 and therefore focus on the effects of dietary changes on premature deaths (i.e., occurring before the age of 75).

Valuation of costs and benefits –The starting point of the valuation of the health benefit is the threshold value of a Quality Adjusted Life Year (QALY) that is applied in the UK to investigate the cost-effectiveness of medical care. That threshold, discussed in McCabe et al. (2008) and still recommended by the UK National Institute for Clinical Excellence, lies within the £20-30k range, which translates roughly into €24-36k at the current exchange rate. Given that epidemiological data show that the average number of Life Years Saved per DA is larger than 10 for most causes of mortality covered by DIETRON, we make the conservative assumption of 10 QALYs per DA, which implies a value of a DA in the €240-360k range. Leaning on the side of caution, we select the lowest value in this range, and the monetized health benefits should therefore be treated as lower bounds. In fact, that valuation of DA is much lower than the values of a statistical life (VSL) typically used in the cost-benefit analysis of public projects, as reviewed by Treich (2015). On the environmental side, there is much debate regarding the social cost of greenhouse gas emissions (Stratham, 2013). To address this uncertainty, we rely on the meta-analysis of the social cost of carbon developed by Tol

[1] Available at https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudesalimentaires-de-letude-inca-2-3/

(2012). That author, after fitting a distribution of 232 published estimates, derived a median of €32/ton, a value which we adopt due to its rigour and objectivity.

Choice of constraints – We choose to analyse the sustainability effects of a number of dietary constraints, based on previously available results for France (i.e., constraints generating the largest benefits or level of efficiency) as well as issues currently hotly debated with regard to food consumption. Irz et al. (2016a) found that the recommendations most commonly promoted on health grounds and targeting consumption of salt, F&V and saturated fat ranked highest in terms of overall efficiency in France. Those three constraints are therefore included in the comparison. In addition, the debate over the climate impact of current diets in high-income countries has intensified, based on solid evidence that that effect is significant, typically ranging from 15% to 30% of total GHG emissions (Esnouf et al., 2013). Further, it has been shown consistently that per unit impacts vary enormously across foods, so that dietary adjustments with existing foods could generate large climate benefits. Thus, many authors have recommended a reduction in meat consumption (particularly meat from ruminants) and substitutions with plant-based foods (Stehfest et al., 2009; Berners-Lee et al., 2012). We therefore test the impact of two recommendations to reduce meat consumption, one for all meat, and the other one for red meat only. An alternative policy approach would rely on the development of carbon labels for foods, as piloted in many countries (Cohen and Vandenbergh, 2012) together with informational measures to persuade consumers to reduce their climate impact. Therefore, a constraint on the total greenhouse gas emissions from foods, measured in terms of CO_2 equivalent (CO_{2e}) is introduced in the analysis.

4 Results

Table 1 describes the behavioural adjustments that take place when the six constraints are imposed on consumers separately. We simulate a 5% decrease for all targets except for F&V for which we simulate a 5% increase as F&V consumption should be encouraged. For each country and each constraint, the table presents two columns: the left one reports the contribution of each food group to the constrained quantity, hence giving a depiction of current diets in relation to the targeted characteristic. For example, the consumption aggregate “All meat” accounts for 47%, 30% and 52% of the total CO2e in France, Finland, and Denmark respectively. Meanwhile, for each constraint, the right column reports the change in consumption resulting from the imposition of the constraint.[2]

The imposition of dietary constraints results in relatively large variations in consumption across the entire diet. Hence, in the French case, the imposition of the F&V constraint induces rational consumers to reduce their consumption of dairy products by 4%, which is quantitatively large and could be related to the French habit of eating either a fruit or a yoghurt as a dessert (hence, the two product categories are substitutes). In many cases, however, the adjustments would have been difficult to anticipate *a priori*, as illustrated by the relatively large increase in consumption of plant-based fats, animal fats and cheese resulting from the imposition of the “all meat” constraint in the Finnish model, or the large responses of demands for sugar-rich products and root vegetables to the imposition of the salt constraint in the Danish model. Further, one notices that within food groups, different product categories respond very differently to the imposition of a given constraint, so that substitutions occur both across large food groups and within those. For instance, the French results indicate that for four of the six simulated constraints, consumption of red meat and other fresh meat adjust in opposite directions. Similarly, in relation to the Finnish results, imposition of a reduction in

[2] In the case of Finland and Denmark the model represents the average consumer while in the case of France the model is composed of four representative households based on income quartiles. The adjustments are fairly similar across income quartiles, and Table 1 only reports the results for the second quartile, referred to as the “lower average” quartile.

CO_{2e} from the diet results in a decrease in consumption of beef/lamb and poultry, but also a less expected increase in consumption of pork and processed meat. A similar result emerges in the Danish case as the same constraint induces a decrease in consumption of beef/lamb and pork, but also an increase in consumption of poultry and processed meat.

Altogether, the simulations depict complex behavioural responses involving large substitutions among product groups, implying that simulating compliance with a given recommendation (e.g., F&V +5% or 5 portions) under a *ceteris paribus* assumption (i.e., holding constant all other components of the diet) would be inappropriate. The results also cast doubts over the ability of researchers to develop "reasonable" substitutions ex-ante or to impose ad-hoc palatability constraints in diet modelling.

Table 1 further reveals that the patterns of adjustment are specific to each country both qualitatively and quantitatively, although we find some similarities for some constraints. Thus the adjustments to the imposition of the salt constraint differ greatly across the three countries – for instance, compliance with that constraint induces consumption of meat and dairy to rise in France but shrink in Finland, while in Denmark the model predicts an increase in dairy consumption coupled with a decrease in meat consumption. Moreover, the size of adjustment also differs as the constraint on salt induces an increase in consumption of F&V which is quantitatively much larger in Finland (12%) than in France (3%) or Denmark (2%). A few regularities also emerge from the results. In all three countries, raising exogenously consumption of F&V induces a reduction in meat consumption and, symmetrically, imposing an exogenous decrease in meat consumption results in a rise in consumption of F&V, thus indicating strong substitutions between the two food categories. However, the simulations reveal, overall, country-specific patterns of adjustments to the imposition of dietary constraints. This level of heterogeneity in response is, of course, not unexpected as it is known that current diets vary across EU countries (Slimani et al., 2002) and that there are strong cultural influences on food preferences (Tiu Wright et al., 2001).

Table 2 presents the economic, health and climate effects resulting from the imposition of the constraints. The taste cost measuring the short-term loss in hedonic rewards represents in each case less than 1% of the food budget and thus appears relatively small[3]. However, the ranking of those taste costs captures the relative difficulty of adjusting diets to comply with recommendations and, on that basis, Table 2 indicates that, in France, the F&V constraint is hardest to comply with, followed by the SFA and CO_{2e} constraints. In Finland and Denmark, the largest taste costs relate to the salt constraint and the CO_{2e} constraint. The model therefore delivers some practical insights, for instance that it should be much easier to encourage F&V consumption in Finland and Denmark than in France. In all three countries the cost of targeting the climate impact of food directly through dietary change may be more challenging than reducing consumption of all meats. Reducing red meat consumption generates much lower taste costs than reducing all meat consumption, which comes from the fact that cross-category substitutions are more challenging for consumers to achieve than within-category substitutions. Further, although the taste cost is small as a share of the food budget, it still accounts for millions of euros when expressed annually for the whole population.[4] Those costs are typically

[3] We note that the Finnish model produces a small but negative taste cost in the case of the red meat constraint, which is anomalous and inconsistent with the theory. This problem relates to the approximation that is made when switching from the Hicksian constrained model to the Marhsallian solution, as explained in the methodology section.

[4] When comparing those results, it is important to keep in mind that the population of France is roughly 12 times larger than those of Finland and of Denmark.

ignored when assessing the social desirability of measures aimed at promoting healthy eating (e.g., Rajgopal et al., 2002).

The health effects are calculated as the annual number of deaths avoided due to the dietary change induced by each constraint and vary from a few hundreds to almost 3000 for France and from none to over 500 for Finland and Denmark.[5] Those health effects are deemed quantitatively significant as they account for up to 7% of the diet-related deaths captured by the epidemiological model DIETRON in the case of Finland, 4% in the case of France, and 3% in the case of Denmark (keeping in mind the relatively small 5% exogenous change in constraint levels). We also observe some consistency among the three countries in the relative magnitudes of the health effects: in all cases, a reduction in consumption of all meat and red meat delivers little health benefit if any (in the case of Denmark, it has a small but detrimental impact), while the salt and SFA constraints generate relatively large health improvements. The effects of rising F&V consumption are quantitatively significant in all three countries, especially in France. Finally, targeting directly a reduction in GHG impact of the diet results in substantial health gains in France and Finland but not in Denmark.

The climate impact of the dietary adjustments simulated by the model is presented in the lower part of each country section in Table 2. As expected, the three constraints introduced primarily with the objective of reducing that impact generate lower emissions of greenhouse gas emissions in the three countries, but the reductions are relatively small for the two meat constraints, especially in the case of Finland (i.e., less than 1%). The environmental effects driven by the imposition of the other constraints with primarily public health objectives vary among the three countries. In particular, for France, the results suggest that there are always synergies between health and environmental objectives, with adoption of healthier diets in terms of F&V, salt and FSA also delivering reductions in GHG emissions. In the case of Finland, there are trade-offs between health and environmental objectives, since reductions in consumption of SFA and salt, which are desirable from a health point of view, unfortunately generate higher levels of diet-related GHG emissions. This results from the complex substitutions reported in Table 1: the decrease in salt intake leads Finnish consumers to reduce their consumption of processed meat but increase that of red meat and cheese. Similarly, a decrease in SFA intake leads to an increase in consumption of red meat and processed meat. In the case of Denmark, it is worth noting that the simulated environmental effect of imposing a reduction in SFA is also negative (although small).

Table 3 pieces together the economic, health and environmental effects to calculate the efficiency thresholds for the three countries and six constraints. As explained in the methodology section, that threshold represents the maximum amount that could be used by public authorities to promote a recommendation while ensuring that total benefits exceed total costs, assuming that the 5% target for the constrained quantity is attained.

In the case of France, the efficiency thresholds C_p are positive and large for all six constraints, but reductions in consumption of salt and SFA, as well as an increase in consumption of F&V, should be prioritised over reductions in meat consumption and measures targeting the carbon impact of diets directly. We note, however, that the thresholds are in all cases large, amounting to up to half a billion euros for the F&V constraint, and still worth €30 million annually for the "all meat" constraint. Those sums typically exceed the cost of public information campaigns aimed at inducing consumers to

[5] To compare the absolute number of DA in France, Finland, and Denmark, the figures for Finland and Denmark have to be multiplied by a factor 12.21 and 11.75 respectively to account for the difference in population size between those countries and France.

change their diets. For instance, Capacci and Mazzocchi (2011) report that the ambitious "5-a-day" UK campaign to encourage consumption of F&V, which was partially successful since it raised consumption by 8%, had a total budget of less than £3 million (roughly €4 million). On that basis, our results support the idea that more resources should be allocated to the promotion of sustainable diets in France by informational measures.

In the case of the two Nordic countries, the efficiency thresholds are much more modest. The differences in magnitude of the thresholds reflect in part the relative sizes of the populations in the three countries, but there are also important qualitative discrepancies. In particular, for Finland and Denmark, the thresholds calculated for the "all meat" and CO_{2e} constraints are negative, indicating that public measures aimed at inducing consumers to comply with those constraints would not be socially desirable. The threshold for the red meat constraint is also very small in Finland and negative in Denmark. Thus, the results do not support the targeting of meat consumption and greenhouse gas emissions by policies aiming at improving the sustainability of the Finnish and Danish diets. In the case of Finland, that result is explained, in the case of the two meat constraints, by small health effects, but in the case of the CO_{2e} constraint, the large taste cost of adjustment is the key factor. In the case of Denmark, that result is explained by a negative impact on health of the dietary changes. The efficiency thresholds for the three constraints aimed primarily at improving public health remain, however, considerable, lending credit to the proposition that more resources should be allocated to the promotion of healthy-eating via informational measures in Finland. This is also the case in Denmark for recommendations on F&V consumption and SFA consumption, although the recommendation on salt brings benefits that are lower than the taste cost. That last Danish result depends, however, on the parameters used to monetize the health and environmental impacts. More importantly, we acknowledge that our conclusions regarding the ranking of recommendations only hold if one accepts the commensurability of benefits in the health and environmental domains, as for Finland (Denmark) two (one) of the three public health measures actually result in an increase in GHG emissions. Much debate remains, however, regarding the appropriateness of that idea (Munda, 2016).

5 Conclusion

This paper applied a novel approach to the ex-ante analysis of the sustainability effects of diet recommendations in French, Finnish, and Danish contexts. The cross-country comparison of results demonstrates that consumers in different countries adjust differently to similar recommendations. This was largely expected from the theory, which implies that changes in consumption and related effects depend on several factors, including the initial diet, food preferences as measured by elasticities, the nutritional composition of foods, as well as the initial burden of diet-related chronic diseases. The simulations also indicate that there exist clear synergies in the pursuit of healthy and climate friendly diets in France, but that in Finnish and Danish contexts trade-offs may exist, with some healthy-eating recommendations resulting in larger greenhouse gas emissions due to the whole diet substitutions that they induce. Moreover, in the Nordic countries, and especially in Denmark, the health effects of more environmentally motivated measures, such as reductions in meat consumption or GHG from the diet, may be negative. Thus, the analysis points to the need to carefully tailor the design of diet recommendations to each country's context, and the necessity to factor in the food preferences of consumers in the analysis of those recommendations. However, for all three countries, we reach the same overarching conclusion that: 1- The promotion of some diet recommendations is clearly welfare improving, so that it would be desirable to allocate more resources to it; 2- The recommendations with the traditional public health goals of encouraging consumption of F&V, and reducing consumption of SFA and salt (to a lower extent in Denmark), should be prioritized for promotion if one accepts the commensurability of environmental and health benefits. In that case, this also means that there is no obvious need to reformulate current recommendations to take account of the climate effect of diets; 3- Measures with a stronger climate focus, such as reductions in meat consumption or the direct targeting of CO_2 emissions, should not be prioritized for promotion, particularly in the context of Nordic countries ; and 4- Taking account of the taste/utility cost of dietary change imposed on consumers is important in the welfare analysis of diet recommendations, although that cost has been ignored in most of the existing literature on the subject. In further analysis, we will test the robustness of those conclusions by developing a sensitivity analysis with respect to key parameters of the model (e.g., valuation parameters, relative risk ratios of the epidemiological model).

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7 Figures and Tables

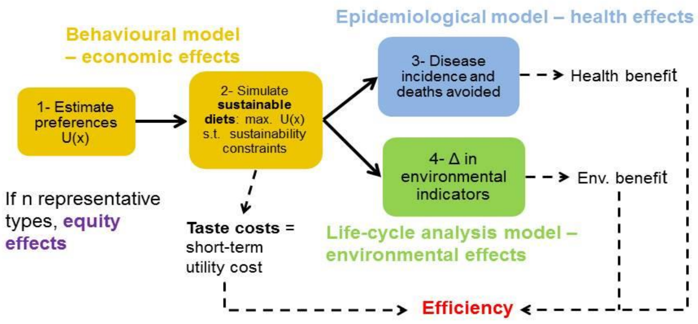

Figure 1 – Overall structure of the model

France (lower-average income quartile) — Constraints

	F&V +5%		Salt -5%		SFA -5%		All meat -5%		Red meat -5%		CO_2e -5%	
All meat	**0.0**	**-0.3**	**23.4**	**1.7**	**16.6**	**5.2**	**93.7**	**-5.2**	**89.7**	**-0.7**	**46.9**	**-3.0**
Red meat	0.0	-9.1	1.4	1.9	3.4	-0.3	22.7	-8.2	89.7	-5.5	28.0	-19.9
Other meats	0.0	6.2	2.7	4.6	4.4	14.1	38.8	-6.4	0.0	0.7	12.1	0.4
Cooked meats	0.0	-3.3	19.3	-2.5	8.8	-3.7	32.2	-1.3	0.0	0.8	6.8	4.1
Dairy	**0.0**	**-4.0**	**21.5**	**1.6**	**52.1**	**-5.9**	**0.0**	**3.4**	**0.0**	**0.6**	**23.3**	**0.2**
Milk products	0.0	-4.3	6.6	3.0	8.3	-5.5	0.0	3.3	0.0	0.7	11.7	0.0
Cheese/butter	0.0	-2.9	14.9	-4.0	43.8	-7.4	0.0	4.2	0.0	0.1	11.7	0.9
Other animal prod.	**0.0**	**3.2**	**5.1**	**6.6**	**2.7**	**-0.5**	**0.0**	**3.5**	**0.0**	**0.7**	**3.0**	**3.6**
Fish	0.0	9.7	3.7	7.6	0.7	8.7	0.0	7.5	0.0	1.7	2.0	8.9
Eggs	0.0	-7.6	1.4	4.9	2.0	-16.0	0.0	-3.3	0.0	-0.8	1.0	-5.4
Starchy foods	**0.2**	**-16.1**	**14.5**	**-10.2**	**2.2**	**0.1**	**0.0**	**-2.2**	**0.0**	**-0.9**	**2.2**	**-3.6**
Grains	0.2	-6.2	13.4	-16.5	0.7	-2.2	0.0	-0.3	0.0	-1.0	1.5	-3.4
Potatoes	0.0	-27.6	1.1	-2.8	1.5	2.8	0.0	-4.5	0.0	-0.8	0.7	-3.7
F&V	**92.7**	**5.5**	**8.3**	**2.6**	**0.9**	**3.9**	**0.0**	**0.6**	**0.0**	**0.6**	**6.9**	**2.4**
F - Fresh	40.7	-1.1	0.1	0.0	0.1	-5.0	0.0	2.7	0.0	1.5	1.8	5.9
F - Processed	2.8	27.0	0.0	2.2	0.0	-31.0	0.0	-3.2	0.0	0.2	0.3	-0.3
F&V juices	6.3	4.0	0.1	3.8	0.1	4.6	0.0	-0.3	0.0	0.8	1.4	2.6
V - Fresh	32.6	9.5	3.2	6.7	0.4	15.8	0.0	-0.3	0.0	-0.5	2.0	-1.0
V - Processed	9.9	18.4	4.8	-2.9	0.2	10.8	0.0	-2.7	0.0	0.0	1.3	-0.8
F - Dry	0.5	-6.0	0.1	12.0	0.2	-5.1	0.0	11.7	0.0	1.4	0.1	7.6
Other												
Ready meals	4.2	-11.7	9.2	-7.5	3.6	-5.7	6.3	-3.6	10.1	-1.1	5.5	-4.3
Oil, margarine	0.0	12.0	4.2	5.3	8.8	-2.6	0.0	-1.2	0.0	0.1	1.8	-0.7
Salt-fat prod.	0.0	-20.7	7.1	-27.6	1.0	-28.4	0.1	10.3	0.1	1.2	0.4	6.4
Sugar-fat prod.	2.9	2.1	5.6	-0.7	12.1	-5.9	0.0	0.3	0.0	0.1	4.4	0.5
Soft drinks	0.0	-18.4	0.2	-5.9	0.1	2.8	0.0	5.3	0.0	0.7	0.5	7.5
Water	0.0	-20.0	0.7	1.6	0.0	9.7	0.0	10.0	0.0	1.8	1.4	8.3
Alcohol	0.0	12.9	0.2	1.3	0.0	4.8	0.0	-0.4	0.0	0.3	3.6	1.0

Finland (whole population) and **Denmark (whole population)** — Constraints

	Finland F&V +5%		Finland Salt -5%		Finland SFA -5%		Finland All meat -5%		Finland Red meat -5%		Finland CO_2e -5%		Denmark F&V +5%		Denmark Salt -5%		Denmark SFA -5%		Denmark All meat -5%		Denmark Red meat -5%		Denmark CO_2e -5%	
All meat	**0.0**	**-1.1**	**23.4**	**-4.1**	**11.7**	**3.7**	**94.3**	**-4.9**	**76.1**	**-0.9**	**30.4**	**-5.7**	**0.0**	**-1.3**	**43.3**	**-3.9**	**26.0**	**0.3**	**100.0**	**-4.9**	**100.0**	**-0.5**	**52.3**	**-1.7**
Beef/lamb	0.0	-2.4	0.9	6.9	0.4	3.1	4.9	-4.0	51.2	-8.5	6.2	-31.8	0.0	-2.0	6.4	0.6	4.4	3.2	21.9	-5.6	87.4	-5.9	33.0	-16.7
Pork	0.0	-1.4	3.3	0.9	2.4	6.6	21.5	-6.2	0.0	1.2	5.7	5.1	0.0	-2.1	4.6	-4.3	1.9	1.1	18.2	-10.2	0.0	-0.8	5.5	-6.0
Poultry/other	0.0	-1.0	8.3	-1.0	3.7	-0.1	37.8	-2.8	0.0	-0.7	13.0	-11.1	0.0	-0.8	7.1	-3.8	0.8	1.6	19.6	-2.9	0.0	1.4	3.8	4.7
Processed	0.0	-0.9	10.9	-14.9	5.3	8.6	30.0	-7.7	24.9	-1.6	5.5	0.7	0.0	-0.9	25.2	-6.1	18.9	-2.6	40.2	-3.4	12.6	1.3	10.0	4.2
Dairy	**0.0**	**-1.2**	**17.7**	**-1.6**	**55.6**	**-0.1**	**0.0**	**1.2**	**0.0**	**0.4**	**30.5**	**-4.5**	**0.0**	**-0.8**	**10.6**	**1.0**	**47.4**	**-6.9**	**0.0**	**2.9**	**0.0**	**0.5**	**18.4**	**0.2**
Milk/other dairy	0.0	-1.0	5.9	-2.3	9.4	0.5	0.0	0.7	0.0	0.4	14.8	-5.7	0.0	-1.0	2.7	1.6	18.2	-7.5	0.0	3.0	0.0	0.5	8.2	0.2
Cheese	0.0	-3.1	5.7	6.2	9.7	0.1	0.0	3.0	0.0	0.5	8.2	-2.0	0.0	-0.7	6.5	-2.8	8.3	-1.0	0.0	2.1	0.0	0.4	6.5	0.6
Animal fats	0.0	-1.5	6.1	-3.1	36.5	-8.7	0.0	4.9	0.0	0.9	7.5	6.4	0.0	1.0	1.5	0.2	21.0	-11.0	0.0	2.6	0.0	0.5	3.7	-0.2
Other animal prod.	**0.0**	**-0.54**	**3.3**	**5.3**	**1.0**	**1.6**	**0.0**	**0.5**	**0.0**	**-0.2**	**2.0**	**2.4**	**0.0**	**-1.5**	**4.6**	**2.1**	**0.2**	**4.1**	**0.0**	**0.2**	**0.0**	**-0.5**	**2.3**	**-0.2**
Fish	0.0	-0.5	3.3	5.3	1.0	1.6	0.0	0.5	0.0	-0.2	2.0	2.4	0.0	-1.5	4.6	2.1	0.2	4.1	0.0	0.2	0.0	-0.5	2.3	-0.2
Starchy foods	**6.5**	**-0.3**	**27.2**	**-4.2**	**9.6**	**-3.1**	**0.0**	**0.7**	**0.0**	**0.4**	**9.2**	**0.3**	**6.8**	**0.4**	**26.2**	**-6.2**	**7.5**	**-0.4**	**0.0**	**1.8**	**0.0**	**0.3**	**6.9**	**0.5**
Grains	1.4	0.3	24.2	-3.4	7.0	-3.1	0.0	1.8	0.0	0.9	7.3	4.6	1.3	-0.6	19.6	-2.3	7.4	-1.6	0.0	1.8	0.0	0.3	5.5	0.7
Roots, tubers etc.	5.1	-1.5	3.0	-6.2	2.6	-3.2	0.0	-1.8	0.0	-0.8	2.0	-9.3	5.5	2.3	6.7	-14.1	0.1	2.0	0.0	1.8	0.0	0.3	1.4	0.0
F&V	**89.1**	**5.7**	**3.2**	**11.6**	**0.5**	**3.1**	**0.0**	**0.9**	**0.0**	**0.4**	**8.6**	**7.2**	**92.3**	**5.2**	**7.8**	**2.3**	**3.1**	**1.6**	**0.0**	**1.9**	**0.0**	**0.3**	**7.7**	**1.4**
Fruits	55.1	6.0	0.4	12.8	0.2	2.8	0.0	0.7	0.0	0.4	4.9	7.1	52.7	6.2	0.1	3.9	3.0	0.9	0.0	1.9	0.0	0.3	3.8	1.3
Vegetables	34.0	5.2	2.8	9.5	0.4	3.5	0.0	1.2	0.0	0.2	3.7	7.4	39.6	4.0	7.7	0.5	0.1	2.5	0.0	1.9	0.0	0.3	3.9	1.5
Other																								
Composite dishes	2.4	0.5	3.6	5.1	1.9	-0.6	5.7	-1.5	23.9	-1.1	3.6	-7.4	0.0	-2.2	0.0	8.1	0.0	7.0	0.0	0.4	0.0	0.5	0.0	5.7
Plant based fats	0.0	-3.6	2.4	-35.1	7.9	-23.4	0.0	4.6	0.0	1.1	0.7	16.7	0.0	0.9	1.5	-0.9	9.5	-6.8	0.0	2.2	0.0	0.4	1.0	1.3
Snacks	0.0	-2.7	0.8	5.3	0.4	-8.4	0.0	-0.6	0.0	0.7	0.1	3.2	0.0	-1.1	0.8	4.8	1.8	-16.4	0.0	0.5	0.0	0.1	0.2	3.7
Sugar	0.0	-0.7	2.1	-2.1	8.5	-4.2	0.0	0.5	0.0	0.0	5.7	-0.9	0.0	-1.1	0.4	17.0	3.2	1.1	0.0	1.0	0.0	0.2	1.8	0.9
Soft drinks	0.0	-0.2	0.2	-3.9	0.0	-1.8	0.0	0.9	0.0	-0.8	0.6	0.5	0.0	-1.0	0.2	3.0	0.0	2.8	0.0	1.1	0.0	0.2	1.4	0.3
Tea/coffee/water	0.0	-1.6	0.3	18.8	0.2	4.3	0.0	1.5	0.0	-0.1	6.0	-6.9	0.0	-0.8	0.0	2.5	0.9	0.7	0.0	0.8	0.0	0.2	3.7	-2.2
Residual category	2.0	-1.7	15.7	-14.7	2.7	0.2	0.0	0.5	0.0	-0.1	2.5	3.2	0.9	2.5	4.2	-41.8	0.3	8.1	0.0	1.1	0.0	0.2	0.5	-1.1

Table 1: Impact of constraint on consumption. The table presents the contributions to the constrained quantity (for each constraint, shaded column, in %) and the adjustments in consumption (for each constraint, non-shaded column, in %) induced by compliance with the constraint.

	F&V +5%	Salt -5%	SFA -5%	All meat -5%	Red meat -5%	CO2e -5%
FRANCE						
Taste Cost						
Total (€M)	466	128	288	76	10	207
% food budget	**0.64**	**0.17 %**	**0.37 %**	**0.10 %**	**0.01 %**	**0.27 %**
DA for DIETRON diseases						
Total	2 506	2 844	2 138	245	229	1 140
% Dietron disease	**3.8 %**	**4.3%**	**3.2%**	**0.4%**	**0.3%**	**1.7%**
CO2 equivalent						
Total (Kt)	-3167	-355	-47	-1487	-892	-4112
% change	**-4.5 %**	**-0.5 %**	**-0.1 %**	**-2.1 %**	**-1.3 %**	**-5.0 %**
FINLAND						
Taste Cost						
Total (€M)	4	78	18	9	-2	62
% food budget	**0.03 %**	**0.55 %**	**0.13 %**	**0.07 %**	**-0.01 %**	**0.43 %**
DA for DIETRON diseases						
Total	149	543	303	-4	10	123
% Dietron disease	**2.0 %**	**7.4 %**	**4.1 %**	**-0.1 %**	**0.1 %**	**1.7 %**
CO2 equivalent						
Total (Kt)	-16	167	36	-36	-44	-283
% change	**-0.3 %**	**2.9 %**	**0.6 %**	**-0.6 %**	**-0.8 %**	**-5.0 %**
DENMARK						
Taste Cost						
Total (€M)	8	61	12	16	6	36
% food budget	**0.05 %**	**0.42 %**	**0.08 %**	**0.11 %**	**0.04 %**	**0.24 %**
DA for DIETRON diseases						
Total	135	198	574	-54	-44	-69
% Dietron disease	**0.8 %**	**1.1 %**	**3.3 %**	**-0.3 %**	**-0.3 %**	**-0.4 %**
CO2 equivalent						
Total (Kt)	-45	-22	18	-113	-97	-347
% change	**-0.6 %**	**-0.3 %**	**0.3 %**	**-1.6 %**	**-1.4 %**	**-5.0 %**

Table 2: Effect of recommendations on short-term consumer welfare, health and greenhouse gas emissions

	F&V +5%	Salt -5%	SFA -5%	All meat -5%	Red meat -5%	CO2e -5%
FRANCE						
Benefits (M€)	703	694	515	106	84	405
Cost (M€)	466	128	288	76	10	207
Cp (M€)	237	566	226	30	73	198
Ranking	2	1	3	6	5	4
FINLAND						
Benefits (M€)	36	125	71	0.1	4	38
Cost (M€)	4	78	18	9	-2*	62
Cp (M€)	33	47	53	-9	4*	-23
	(398)	(571)	(652)	(-113)	(47)	(-285)
Ranking	3	2	1	5	4	6
DENMARK						
Benefits (M€)	34	48	137	-9	-7	-5
Cost (M€)	8	61	12	16	6	36
Cp (M€)	26	-13	126	-25	-14	-41
	(302)	(-156)	(1477)	(-298)	(-163)	(-485)
Ranking	2	3	1	5	4	6

Table 3: Efficiency analysis (Note: The Finnish and Danish figures in parentheses are scaled up by factors 12.21 and 11.75 respectively to account for the difference in population size between those countries and France. The adjusted figures are then comparable to the corresponding French figures).