Fish in Climate-Friendly and Healthy Diets

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ABSTRACT

While the adverse climate and health impacts of the Western diet have been demonstrated, the place of fish/seafood in climate-friendly and healthy diets is unclear. We tackle that question with a model simulating how a rational consumer urged to consume more fish would modify his diet. Those adjustments are translated into health outcomes by an epidemiological model and climate outcomes using life-cycle analysis coefficients. The application to France and Finland compares the impacts of promoting fish consumption to those of urging consumers to decrease their consumption of meat. For the same relative change, raising fish consumption generates more health benefits than decreasing meat consumption, and produces climate benefits as well. Promoting fish consumption is also highly cost-effective and should be prioritized over measures targeting meat consumption. Rather than stigmatizing meat consumers, climate-friendly and healthy diet recommendations may more effectively send a positive message urging citizens to consume more fish.

Key words: Diet, greenhouse gas emissions, consumption, sustainability, cost-effectiveness, cost-benefit, food choices, healthy eating, demand system.
JEL Codes: Q22, Q54, D12, I12.

INTRODUCTION

Due to their negative impacts on public health and the environment, food consumption patterns currently observed in developed countries are considered fundamentally unsustainable. As a result, various bodies, including international organizations such as the Food and Agriculture Organization of the United Nations (FAO), have called for the development of policies promoting sustainable diets, defined as nutritionally adequate diets with limited environmental impacts, in particular in relation to the climate, and which are culturally acceptable and affordable to all, including low-income groups (FAO 2012). Knowledge about the composition of such sustainable diets has also made much progress in recent years.

Considering the environmental dimension first, it has been established in the context of the EU that food accounts for around 30% of the total impact of final consumption (Tukker et al. 2011). Animal products, particularly meat from ruminants that produce methane, are respon-

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sible for relatively more greenhouse gas emissions (GHGE) than plant-based products and also impact food security negatively due to the heavy land and water requirements that their production entails (Steinfeld et al. 2006; Gonzalez, Frostell, and Carlsson-Kanyama 2011; Nijdam, Rood, and Westhoek 2012). Several literature reviews addressing the link between diet and climate have also drawn similar conclusions. For instance, Joyce et al. (2014) singled out as a key finding that "diets containing a higher ratio of plant to animal products are generally associated with lower GHGE." Hallstrom, Carlsson-Kanyama and Borrjesson (2015) studied the impact of dietary changes on GHGE, as well as land use, and concluded that "the reduction potential seems mainly to depend on the amount and type of meat and animal products included in the diet [. . .] the amount of red meat, and especially ruminant meat, seems to be a decisive parameter." Consequently, the consensus in environmental science is that switching to diets that contain less animal products would help preserve the environment and reduce GHGE.

On the health side, current dietary patterns in developed countries are strongly associated with adverse outcomes. In addition to excess intakes of fatty, salty, and sugary foods and beverages, high consumption of animal-based products is considered a risk factor for diet-related chronic diseases, such as type-2 diabetes, some cancers, and cardiovascular diseases (CVD). As a result, nutritional guidelines promoted by the World Health Organization (WHO) include recommendations to limit the intake of foods high in fat, salt, and sugar, as well as to reduce consumption of fresh and processed meats (IARC 2015).

Another segment of the literature has investigated the compatibility between health and environmental goals in the pursuit of sustainable diets. Aleksandrowicz et al. (2016) summarized that literature by comparing the impacts of 210 scenarios of dietary change on public health and different environmental indicators (GHGE, land use, water use). From those, 197 scenarios were associated with environmental gains, while 13 scenarios generated environmental degradation or no change. They found a high degree of correlation between land use and climate impacts across scenarios, but the consideration of health impacts blurs the picture because "health and environmental priorities may not always converge: for example, sugar may have low environmental impacts per calorie relative to other foods, and some fruits or vegetables may have higher GHGE per calorie than dairy and non-ruminant meats." Nonetheless, they reach the overall conclusion that in high-income countries, the strategy "to reduce dietary-related environmental impacts should focus on reducing animal-based foods."

If the literature on sustainable diets strongly supports a move away from animal-based diets towards plant-based diets, it is much less explicit about the place that fish and seafood consumption should have in those diets, even if some studies suggest that increasing fish and seafood consumption may have positive effects on both health and the environment.

At the nutritional level, it has been established that fish is a good source of omega-3 (n-3) fatty acids that may protect against risks of CVD (Raatz et al. 2013). Further, diets rich in fish appear to be particularly healthy, as is the case of the Mediterranean diet, which includes at least two portions of fish per week. Such diets have been found to be associated with superior health outcomes, both in terms of mortality and morbidity. Hence, Sofi et al. (2013) showed that a two-point increase in the score of adherence to the Mediterranean diet resulted in an 8% reduction in overall mortality and 10% reduction in the risk of CVD.

From an environmental point of view, diets rich in fish also seem preferable to diets rich in meat. Recently, Scarborough et al. (2014) compared the climate impact of different self-selected dietary patterns in the UK, finding that daily age- and sex-adjusted mean GHGE were worth 7.19 kg of CO2 equivalent (CO2e) for high meat eaters, as compared to 5.63 kg for medium meat eaters, 4.67 kg for low meat eaters, 3.91 kg for fish eaters, 3.81 kg for vegetarians, and 2.89 kg for vegans. In Norway, Abadie et al. (2016) analyzed a similar issue from a different angle by deriving the optimal price policy that favored the adoption of sustainable diets (i.e., nutritionally adequate diets with lower GHGE). The results showed that nearly all food categories should be taxed except poultry, fish, milk, eggs, vegetables, and fruits, which instead should be subsidized in order to encourage consumption.

Despite those recent investigations, knowledge about the place of fish and seafood in sustainable diets remains very partial, with a paucity of studies considering different sustainability dimensions (e.g., health, environment) simultaneously in their analysis. This raises the possibility of generating inconsistent conclusions and recommendations, depending on which angle is taken as the primary focus. Further, studies seeking to identify diets with superior properties, and the place of fish in those diets, do not take account of consumers' preferences and the related notions of cultural acceptability and affordability that nevertheless appear explicitly in the FAO's definition of sustainable diets. This is problematic because diets will only be more sustainable if they are better from a health and environmental point of view, and also if they are compatible with consumers' preferences and therefore adopted—that is to say, if they are culturally acceptable to consumers and do not generate excessively high costs of adoption.

Against this background, the primary goal of this article is to assess the climate and health effects of raising consumption of fish and seafood, giving due consideration to consumers' preferences and associated costs of dietary adjustment. More specifically, we characterize the economic, climate, and health impacts of a recommendation to increase fish consumption and then we balance the health and climate benefits of the change against consumers' cost of compliance. This allows us to judge the social desirability of raising fish consumption, considering simultaneously its economic, climate, and health effects. Using a similar approach but to give us a broader perspective, we also compare the health and climate effects of promoting fish consumption to decreasing meat consumption. Our novel analytical approach relies on an economic behavioral model of adjustments to dietary constraints, which captures that foods in diets are intricately linked through complex relationships of substitutability and complementarity.

Finally, because dietary patterns and preferences vary significantly across countries, we carry out a similar analysis in two countries, namely France and Finland, to investigate the generality or country specificity of our conclusions. The comparison of two countries, where fish represents an important part of the diet but with significant differences in eating habits, facilitates the interpretation of the results and the formulation of general conclusions—for instance that whole-diet substitutions are key to understanding the climate and health effects of promoting fish consumption. The main starting differences between the two countries can be summarized as follows. In both countries, fish consumption is high by European standards, with annual quantities available for consumption worth 36 kg/cap and 34 kg/cap in France and Finland, respectively, as compared to 22 kg/cap for the European average (FAO 2017). There are, however, qualitative differences in the types of fish consumed in the two countries. In Finland, salmonids (salmon and rainbow trout) account for more than half of consumption in quantity terms, and consumption of herring, while decreasing, remains significant (Setälä and Saarni 2015). In France, consumption of salmon is also high, but fish and seafood consumption is relatively more varied, with, for instance, relatively more consumption of cod, crustaceans, and cephalopods (FranceAgriMer 2017). Beyond fish and seafood, the French allocate relatively more of their food budget to meat, particularly beef and lamb, while budget shares for cereal products and dairy products are larger in Finland (Irz et al. 2017). The weight of land-based animal products in the

French diet explains that GHGE from food consumption is more than 10% higher in France than in Finland (Vieux et al. 2018).

This article is organized as follows. In the next section, we present the model used to simulate dietary adjustments and induced impacts on public health and the climate. The following section describes the data used to calibrate the model, as well scenarios analyzed in the two countries. The results are then presented, and the final section offers some conclusions and directions for future work.

THE MODEL

OVERVIEW

In order to evaluate the health and climate impacts of dietary change, we design a model comprised of three related components; namely, a behavioral model, an epidemiological model, and a life-cycle analysis (LCA) model, the main features of which are outlined below.

The behavioral model simulates how a representative consumer would adjust her diet from the observed level to comply with a dietary constraint, considering possible substitutions among food products. In the context of this work, the main dietary constraint analyzed is a 5% increase in fish consumption. The output of the behavioral model is then the food composition of the diet complying with the dietary constraint, as well as the associated change in short-term consumer utility. Because we simulate how consumers are most likely to react in order to comply with an exogenously given dietary constraint, the change in utility is negative and, in turn, attributable to the inferior properties of the complying diet. This is determined by the consumer in terms of taste, convenience, and any other attributes. For simplicity, we refer to this utility loss as a taste cost.[1]

The epidemiological model uses the changes in consumption of food products (the outputs of the behavioral model) as inputs. In the first stage, using food composition tables, we infer changes in nutrient intakes from changes in food consumption. In the second stage, variations in nutrient intakes are translated into changes in mortality due to diet-related chronic diseases using the DIETRON epidemiological model of Scarborough et al. (2012).

The LCA model also uses changes in food consumption (i.e., the outputs of the behavioral model) as inputs. Then, using the greenhouse gas content of each food product established by LCA in previous studies, it computes the associated change in GHGE.

Monetization of the health and environmental effects allows calculation of the benefit from adjustment to the dietary constraint, which can be compared to the private taste cost and public/industry cost of developing measures (e.g., generic advertising) to ensure compliance in an integrated efficiency analysis.

Although our model starts from an "as if" assumption in the sense that it assumes compliance with a given constraint (e.g., fish consumption +5%), the analysis delivers useful information to compare the climate and health effects of dietary changes and their impact on social welfare. With reference to an increase in fish consumption, the model provides a tool to answer some complex questions. What effect would it have on mortality due to chronic diseases and diet-related greenhouse gas emissions? Would that increase be socially desirable in the sense that

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[1] The behavioral model relies on the theory of the rational consumer, which assumes that a consumer behaves in order to maximize his/her utility subject to some constraints (e.g., budget). As a consequence, complying with an additional constraint cannot raise utility. If utility increased after imposition of a new constraint, this would contradict the key assumption that the observed behavior (which does not integrate this new constraint) maximizes utility in the first place.

its benefits would outweigh its costs? How does it compare to other changes (e.g., reduction in meat consumption) commonly proposed in order to raise the healthiness and climate friendliness of diets? We now describe each sub-component of the model in greater detail.

THE BEHAVIORAL MODEL

The starting point is a model of whole diet adjustment to nutritional and/or environmental constraints (i.e., "dietary constraints") presented in more detail in Irz et al. (2015) and based on the generalized rationing theory of Jackson (1991). We assume that an individual chooses the consumption of H goods in quantities $\boldsymbol{x} = (x_1, \ldots x_H)$ to maximize a strictly increasing, strictly quasiconcave, twice differentiable utility function $U(x_1, \ldots x_H)$, 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 minimum consumption of fish or a maximum consumption of meat. Denoting by a_i^n the constant technical coefficient for any food, i, and target, n, the value of which is known from food composition tables, the dietary constraints are expressed by:[2]

$$\sum_{i=1}^{H} a_i^n x_i \leq r_n \quad \forall\ n = 1, \ldots, N. \tag{1}$$

The utility maximization problem is solved first in a Hicksian framework (i.e., maintaining utility constant). 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 $(N \times H)$ 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: $\tilde{h}_i(p, U, A, r) = h(\tilde{p}, U)$. Our empirical application considers only 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:

$$\frac{\partial \tilde{p}_i}{\partial r_1} = a_i^1 \Big/ \left(\sum_{i=1}^{H} \sum_{j=1}^{H} s_{ij} a_i^1 a_j^1 \right) \quad i = 1, \ldots . H., \tag{2}$$

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:

$$\frac{\partial \tilde{h}_k}{\partial r_1} = \left(\sum_{i=1}^{H} s_{ki} a_i^1 \right) \Big/ \left(\sum_{i=1}^{H} \sum_{j=1}^{H} s_{ij} a_i^1 a_j^1 \right) \quad k = 1, \ldots . H. \tag{3}$$

Equation (3) expresses the changes in compensated demands as functions of two sets of parameters only: the Slutsky coefficients, which describe consumers' preferences and the relative difficulty of substituting foods for one another; and matrix A, which gathers technical coefficients measuring the content of each food aggregate in terms of target quantities (e.g., fish, meat). Given that the Slutsky matrix is typically estimated empirically from observations on actual purchase behaviors, we claim that the model is based on realistic food preferences, unlike virtually all

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[2] For instance, in the case of a constraint imposing a minimum level of fish consumption, those coefficients measure, for each food aggregate, the quantity of fish contained in one unit of the aggregate.

programming-based models of diet optimization that make arbitrary assumptions about food preferences, either explicitly (i.e., by imposing "palatability constraints," as for example, in Henson (1991) or implicitly (through the choice of an arbitrary objective function, as in Shankar, Srinivasan, and Irz, [2008] or Darmon, Ferguson, and Briend [2008]).

Expression (3) shows that a change in constraint level r_1 has an impact on the entire diet. This is true even for foods that do not enter the constraint directly, as long as they entertain some relationship of substitutability or complementarity with any of the foods entering the constraint (i.e., as long as at least one Slutsky term, s_{ki}, is different from zero). Thus, when imposing an exogenous increase in fish consumption, consumption of other foods, either substitutes or complements of fish, will be affected. Further, the model indicates that the magnitude and sign of any change in demand for any given food is unknown a priori but depends, in a complex way, on its technical coefficients (i.e., its composition) and substitutability with other foods.

Because real-world consumers operate under a budget constraint rather than a utility constraint, we infer the changes in uncompensated demand by first calculating the compensating variation (CV), which measures the loss of utility due to the imposition of the new dietary constraint. For a change in the constraint level r_1, we have: $CV = \Sigma_{i=1}^{H} p_i \, \partial\tilde{h}_i \, / \, \partial r_1 < 0$. Note that in that expression, the vector $\partial\tilde{h}_i \, / \, \partial r_1$ is computed using equation (3) and thus depends on the Slutsky coefficients. Those are, in turn, estimated empirically from observations on actual purchase behaviors and, as a consequence, the empirical basis for the estimate of the taste cost lies in consumers' preferences as revealed by their choices.

Finally, 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 MODEL

Simulation of health effects first requires that changes in food consumption at household level, as described by the behavioral model, be translated into changes in individual intake.[3] This is accomplished under the assumption that (1) the percentage change in intake is the same for all the members of a given household, and (2) the percentage change is the same for at-home and out-of-home consumption. Changes in food intake are then converted into changes in nutrients using food composition tables. Variations in nutrient intake 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 worldwide meta-analyses, the model converts variations in 10 nutritional inputs (fruits, vegetables, fiber, total fat, monounsaturated fatty acids, polyunsaturated fatty acids, saturated fatty acids (SFA), transfatty acids, cholesterol, salt, and energy) to estimate changes in diet-related chronic diseases (heart disease, stroke, and 10 types of cancer) and related deaths. The exact disease pathways may be direct, as in the case of the intake of fruits and vegetables (F&V) that lowers the risk of coronary heart disease, or indirect through an intermediate risk factor, as with the intake of saturated fat, which impacts the risk of stroke via its influence on blood cholesterol. An important indirect pathway operates through the reduction in food calories resulting from a dietary change, as it impacts body mass index,

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[3] The behavioral model is estimated using data from household purchases for at-home consumption.

which, when above the healthy range, is a significant risk factor for many diet-related chronic diseases.

We must acknowledge limitations of the DIETRON model to analyze the health effects of a dietary change centered on fish consumption. In particular, there are concerns over potential harm to human health from mercury, dioxins, and polychlorinated biphenyls (PCBs) present in some fish species (Mozaffarian and Rimm 2006 and references therein), but this is not taken into account by DIETRON.

ENVIRONMENTAL ASSESSMENT

Environmental effects are limited to an analysis of climate impact, which is estimated by applying LCA coefficients to each intake category. For both countries, the LCA coefficients measuring the greenhouse gas emissions resulting from consumption of each type of food derive from a systematic review of the grey and academic literature, as explained in detail in Hartikainen and Pulkkinen (2016). Appendix table A1 presents those coefficients for the meat and fish groups. Our empirical analysis used, in the first step, the average values of GHGE reported in the 4th column of table A1. However, to account for uncertainty in those coefficients, we also performed a sensitivity analysis using the upper-bound estimates of those coefficients, which are reported in the last column of table A1.

EFFICIENCY ANALYSIS

The behavioral model simply assumes compliance with an exogenously given dietary constraint without considering the collective measures that would be necessary 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 or industry in order to ensure compliance with a given constraint. Formally, promotion of a recommendation generates health benefits (denoted B_h) in the form of deaths avoided (DA) and reduced climate externalities (denoted B_e), which can be calculated by valuing the health and climate effects estimated by the model. In the short 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 or industry (i.e., cost of interventions, such as social marketing campaigns or generic advertising, denoted C_p). The cost effectiveness threshold of each constraint is hence calculated as $C_p = B_e + B_h + CV$, giving us a means of comparing the relative efficiency of all the selected constraints.

CALIBRATION OF THE BEHAVIORAL AND EPIDEMIOLOGICAL MODELS

The French model's calibration is explained in Irz et al. (2015), so we provide only 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, Bertail, and Nichèle (2010). We have used the behavioral parameters and related product aggregation scheme as reported in the supplementary material of that article.[4] The intake and food composition data are derived from the French dietary intake

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[4] Allais, Bertail, and Nichèle (2010) estimated demand elasticities for four representative households based on quartiles of household income. In the case of France, the behavioral model is calibrated separately for each income quartile.

survey INCA2 and are freely available from the open data platform of the French government at: https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudesalimentaires-de-letude-inca-2-3/.

For Finland, consumption data originate from the 2012 Household Budget Survey, 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 demand system (Lewbel and Pendakur 2009), which presents several advantages over more common functional forms (e.g., AIDS). The product aggregation scheme was defined to allow both a nutritional assessment and an assessment in terms of climate change impact. Elasticities, average intakes, and other technical coefficients for those aggregates are presented in more detail in Irz (2017).

The parameters of DIETRON are not country specific, so adapting the epidemiological model to France and Finland requires only calibration of the initial mortality levels, by relevant causes, in those two countries. This was achieved by using the INSERM data on mortality attributable to major diet-related diseases for the French model. The corresponding mortality data to calibrate the Finnish model was downloaded directly from the website of the Finnish Statistical Institute. In the two countries, the study focuses on individuals between the age of 25 and 74 and, therefore, investigates the effects of dietary changes on premature death (i.e., occurring before the age of 75).[5]

VALUATION OF COSTS AND BENEFITS

The starting point of the valuation of health benefits 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 (e.g., drugs, procedures). That threshold, discussed in McCabe, Claxton, and Culyer (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 (LYS) 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 (e.g., road improvement), as reviewed in Treich (2015).

On the environmental side, there is much debate regarding the social cost of GHGE. To address this uncertainty, we rely on the meta-analysis of the social cost of carbon developed by Tol (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 rigor and objectivity.

CHOICE OF CONSTRAINTS

Our analysis is primarily concerned with the effects of raising fish consumption on public health and GHGE in the two selected countries. Given that the parameters of the model (e.g., elasticities) are only valid at the margin (i.e., for small changes from observed consumption levels), we

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[5] We acknowledge significant differences in the data used to calibrate the model to the two countries, which creates difficulties when comparing results. Those difficulties should be kept in mind when reading the empirical section of this article.

consider the effect of an arbitrarily chosen 5% increase in fish consumption. Interpretation of the model results, however, is easier by comparison, and we thus also investigate the effects of other exogenously dietary constraints, which are unrelated to fish but hotly debated in relation to the sustainability of diets.

Our specific choice is to compare the climate and health effects of an increase in fish consumption to those generated by a decrease in meat consumption, distinguishing between all meat and meat from ruminants (henceforth referred to as "red meat"). This choice is justified first by the recognition that foods vary widely in terms of their environmental and climate impacts, with GHGE per unit of consumption of animal products far exceeding those of plant-based products. In particular, meat from ruminants imposes a very large climate burden due to methane production from enteric fermentation (Abadie et al. 2016; Nijdam, Rood, and Westhoek, 2012).

On the health side, recent meta-analyses have documented a probable link between consumption of different types of meat and negative health outcomes, although much discussion over the issue is ongoing. For instance, Larsson and Orsini (2014) reviewed prospective studies to conclude that high consumption of red meat, especially processed meat, may increase all-cause mortality. Another study by Abete et al. (2014) found that processed meat consumption could increase the risk of mortality from any cause and CVD, while red meat consumption was positively, but weakly, associated with CVD mortality. In 2015, the evidence was deemed sufficiently strong for the WHO to classify the consumption of red meat *as probably carcinogenic to humans* and the consumption of processed meat as *carcinogenic to humans*. The Associated Press release (IARC 2015) also stated that the review of the evidence gave overall support for current public health recommendations to limit the intake of meat.

Thus, our analysis also presents the assessment of the effects of reducing consumption of all meat and consumption of red meat by the same arbitrarily chosen level of 5%.

RESULTS

CHANGES IN FOOD CONSUMPTION

Table 1 describes simulated behavioral adjustments corresponding to the imposition of the three constraints on French and Finnish consumers, in each case considering a 5% variation from current levels. For each country and each constraint, the table presents two columns: the left reports the contribution of each food group to the constrained quantity (e.g., total consumption of fish); hence giving a depiction of current diets in relation to the targeted foods. Thus, in the case of France, the consumption aggregate "fish" unsurprisingly accounts for 96% of total fish consumption, but the table also shows that 4% of fish consumption originates from other consumption aggregates (ready meals). Meanwhile, for each constraint, the right column reports the change in consumption resulting from the imposition of the constraint. Thus, in the French case, requiring a 5% increase in consumption of fish results in a slightly more than proportional increase (+5.3%) in consumption of the aggregate fish because, at the same time, product categories containing some fish decrease (e.g., ready meals –2.9%).

The simulations reported in table 1 allow us to highlight several characteristics of the dietary adjustments that would take place if consumers were encouraged to increase their consumption of fish in France and Finland. Starting with France, we note that consumption of most of the non-fish categories respond to the imposition of the fish constraint. Conforming to intuition, some substitutions occur with other animal products, such as meat (–0.3%)—particularly from ruminants (–0.9%)—and eggs (–1.0%), while consumption of dairy products is not affected. The

Table 1. Simulated Impacts of an Increase in Fish Consumption and Decrease in Consumption of Meat and Red Meat on Total Food Consumption in France and Finland

Recommendation	France							Finland					
	Fish +5%		All Meat –5%		Red Meat –5%			Fish +5%		All Meat –5%		Red Meat –5%	
	Cont.	Var.	Cont.	Var.	Cont.	Var.		Cont.	Var.	Cont.	Var.	Cont.	Var.
Products													
All Meat	0.0	–0.3	93.7	–5.2	89.7	–0.7	All Meat	0.0	0.0	94.3	–4.9	76.1	–0.9
Red meat	0.0	–0.9	22.7	–8.2	89.7	–5.5	Red meat	0.0	0.1	4.9	–4.0	51.2	–8.5
Other meats	0.0	–0.1	38.8	–6.4	0.0	0.7	Pork	0.0	–0.2	21.5	–6.2	0.0	1.2
		0.0					Poultry/other	0.0	0.1	37.8	–2.8	0.0	–0.7
Cooked meats	0.0	–0.2	32.2	–1.3	0.0	0.8	Cooked meats	0.0	–0.2	30.0	–7.7	24.9	–1.6
Dairy	0.0	0.0	0.0	3.4	0.0	0.6	Dairy	0.0	–0.3	0.0	1.2	0.0	0.4
Milk products	0.0	0.0	0.0	3.3	0.0	0.7	Milk products	0.0	–0.3	0.0	0.7	0.0	0.4
Cheese/fats	0.0	0.1	0.0	4.2	0.0	0.1	Cheese	0.0	–0.2	0.0	3.0	0.0	0.5
							Fats	0.0	0.0	0.0	4.9	0.0	0.9
Other Animal Products	0.0	3.2	0.0	3.5	0.0	0.7	Other Animal Products	97.6	5.1	0.0	0.5	0.0	–0.2
Fish	96.1	5.3	0.0	7.5	0.0	1.7	Fish	97.6	5.1	0.0	0.5	0.0	–0.2
Eggs	0.0	–1.0	0.0	–3.3	0.0	–0.8							
Starchy Foods	0.0	–1.2	0.0	–2.2	0.0	–0.9	Starchy Foods	0.0	–0.5	0.0	0.7	0.0	0.4
Grains	0.0	–1.4	0.0	–0.3	0.0	–1.0	Grains	0.0	–0.4	0.0	1.8	0.0	0.9
Potatoes	0.0	–1.0	0.0	–4.5	0.0	–0.8	Potatoes	0.0	–0.6	0.0	–1.8	0.0	–0.8
F&V	0.0	0.4	0.0	0.6	0.0	0.6	F&V	0.0	0.1	0.0	0.9	0.0	0.4
F – Fresh	0.0	1.0	0.0	2.7	0.0	1.5	Fruits	0.0	0.2	0.0	0.7	0.0	0.4
F – Processed	0.0	–0.5	0.0	–3.2	0.0	0.2							
F&V juices	0.0	0.4	0.0	–0.3	0.0	0.8							
F – Dry	0.0	1.5	0.0	11.7	0.0	1.4							
V – Fresh	0.0	–0.4	0.0	–2.7	0.0	0.0	Vegetables	0.0	–0.2	0.0	1.2	0.0	0.2
V – Processed	0.0	0.0	0.0	–0.3	0.0	–0.5							
Ready meal	3.8	–2.9	6.3	–3.6	10.1	–1.1	Ready meal	2.4	–1.0	5.7	–1.5	23.9	–1.1
Plant-based fats	0.0	0.1	0.0	–1.2	0.0	0.1	Plant-based fats	0.0	–0.3	0.0	4.6	0.0	1.1
Salt-fat products	0.0	–0.3	0.1	10.3	0.1	1.2	Snacks	0.0	–0.1	0.0	–0.6	0.0	0.7
Sugar-fat products	0.0	–0.2	0.0	0.3	0.0	0.1	Sugar	0.0	–0.3	0.0	0.5	0.0	0.0
Soft drinks	0.0	–0.1	0.0	5.3	0.0	0.7	Soft drinks	0.0	–0.4	0.0	0.9	0.0	–0.8
Water	0.0	0.1	0.0	10.0	0.0	1.8	Water/tea/coffee	0.0	0.0	0.0	1.5	0.0	–0.1
Alcohol	0.0	–0.5	0.0	–0.4	0.0	0.3	Residual category	0.0	–0.2	0.0	0.5	0.0	–0.1

Notes: For each recommendation, we provide the contribution of each food group to the constrained quantity (column entitled ‘Cont.’) and the change in consumption resulting from the imposition of the constraint (column entitled ‘Var.’). Hence, for France, 96.1% of fish consumption originates from the “Fish” aggregate, but ready meals are also a source of fish (3.8%). Imposing a 5% increase in fish consumption generates the adjustments in consumption described in the Var. column. For France, results are given for the second income quartile of the population, as the behavioral model was calibrated for four classes of consumers (a representative consumer for each income quartile) due to the availability of demand elasticities. For Finland, results are given for the entire population, as the behavioral model was calibrated for a single representative consumer. The classifications of products for France and Finland differ slightly. Hence, for France, the ‘other animal products’ category includes two main products, fish and eggs, while for Finland it only includes fish (whereas eggs are included in the ‘Poultry/other’ aggregate). Other differences in the aggregation scheme need to be acknowledged. For example, for France the ‘other meats’ category aggregates the ‘Pork’ and ‘Poultry/other’ categories that are distinguished in the Finnish aggregation scheme. Conversely, for fruits and vegetables, the classification for France is more detailed.

adjustments with plant-based products reflect substitutions with starchy foods but complementarity with fruits and vegetables (+0.4%), although the disaggregated results for the F&V categories reveal that the adjustments are not uniform across types of fruits and vegetables. For instance, consumption of fresh fruit increases with the 5% increase in fish consumption, while that of processed fruit actually declines (by 0.5%). Among the remaining food products (i.e., "Other" aggregate), we note a particularly large decrease in consumption of ready meals (–2.9%).

This first set of French results demonstrates complex behavioral responses involving significant substitutions among product groups, implying that simulating the effect of an increase in fish consumption under a ceteris paribus assumption (i.e., holding constant all other components of the diet) would be inappropriate. The results also cast doubt over the ability of researchers to devise "reasonable" substitutions ex ante; by imposing ad-hoc palatability constraints (for instance), as is often done in diet modelling.

The French simulations of the effects of decreases in meat consumption confirm the substitutability of meat and fish, but the relationship appears quantitatively stronger in that direction. Thus, according to the simulations, French consumers would compensate a 5% reduction in all meat consumption by raising their consumption of fish more than proportionally (7.5%). In the case of a 5% reduction in red meat, the response of fish consumption is still positive, but quantitatively much smaller (+1.7%), as consumers would also offset the decrease in red meat consumption by raising their consumption of other meats (+0.7%).

Table 1 further reveals that the patterns of adjustment are specific to each country both qualitatively and quantitatively. Hence, in the case of Finland, the simulations confirm the substitutability of fish and other animal products, in line with the French results, but the main effect now occurs through dairy products (–0.3%) rather than meat (no aggregate change). In particular, we note a marginal increase in consumption of red meat as a result of the imposition of the fish constraint in Finland, a result to which we will return when discussing the climate impact of those dietary adjustments. The other consumption changes related to the rise in fish consumption in Finland are broadly consistent with those depicted for France: there is evidence of substitutability between fish and starchy foods (–0.5%) as well as composite dishes (–1%), but complementarity between fish and F&V (+0.1%). However, the overall adjustment in the entire food consumption basket appears relatively more limited in the case of Finland as compared to France.

The adjustments to consumption variations of all meat and red meat in Finland confirm the limited substitutability between those two food categories and fish. In fact, the results suggest that fish consumption would actually decrease, albeit only marginally (–.2%), if red meat consumption was curtailed by 5% in Finland.

Overall, the simulations reveal country-specific patterns of adjustments to the imposition of dietary constraints. This level of heterogeneity in response is, of course, expected, as it is known that current diets vary across EU countries (Slimani et al. 2002), and there are strong cultural influences on food preferences (Tiu Wright, Nancarrow, and Kwok, 2001).

In order to better understand the functioning of the model, table 2 reports the shadow prices calculated from application of formula (2). The first column from the left presenting numbers shows that inducing French consumers to raise their purchases of fish by 5% would require a fairly small decrease in price (–3.3%). The shadow prices of the products that do not contain fish are equal to their market prices, which is a result that follows from theory (i.e., for a product category *i* that does not contain any fish, the technical coefficient, a_i^1, in equation (2) is simply equal to zero). For ready meals containing a small amount of fish, shadow prices differ from market

Table 2. Percentage Difference between Shadow and Market Prices

	France				Finland		
Recommendation	Fish +5%	All Meat –5%	Red Meat –5%		Fish +5%	All Meat –5%	Red Meat –5%
Products							
All Meat				All Meat			
Red meat	0.0	9.8	3.8	Red meat	0.0	5.5	10.3
Other meats	0.0	13.3	0.0	Pork	0.0	7.4	0.0
				Poultry/other	0.0	7.8	0.0
Cooked meats	0.0	10.6	0.0	Cooked meats	0.0	9.4	1.4
Dairy				Dairy			
Milk products	0.0	0.0	0.0	Milk products	0.0	0.0	0.0
Cheese/fats	0.0	0.0	0.0	Cheese	0.0	0.0	0.0
				Fats	0.0	0.0	0.0
Other Animal Products				Other Animal Products			
Fish	–3.3	0.0	0.0	Fish	–6.0	0.0	0.0
Eggs	0.0	0.0	0.0				
Starchy Foods	0.0	0.0	0.0	Starchy Foods	0.0	0.0	0.0
Grains	0.0	0.0	0.0	Grains	0.0	0.0	0.0
Potatoes				Potatoes			
F&V	0.0	0.0	0.0	F&V	0.0	0.0	0.0
F – Fresh	0.0	0.0	0.0	Fruits			
F – Processed	0.0	0.0	0.0				
F&V juices	0.0	0.0	0.0				
F – Dry	0.0	0.0	0.0				
V – Fresh	0.0	0.0	0.0	Vegetables	0.0	0.0	0.0
V – Processed							
Ready meal	–0.1	3.3	0.5	Ready meal	–0.2	2.2	1.6
Plant-based fats	0.0	0.0	0.0	Plant-based fats	0.0	0.0	0.0
Salt-fat products	0.0	0.2	0.0	Snacks	0.0	0.0	0.0
Sugar-fat products	0.0	0.0	0.0	Sugar	0.0	0.0	0.0
Soft drinks	0.0	0.0	0.0	Soft drinks	0.0	0.0	0.0
Water	0.0	0.0	0.0	Water/tea/coffee	0.0	0.0	0.0
Alcohol	0.0	0.0	0.0	Residual category	0.0	0.0	0.0

Notes: For France, results are given for the second income quartile of the population, as the behavioral model was calibrated for four classes of consumers (a representative consumer for each income quartile) due to the availability of demand elasticities. For Finland, results are given for the entire population, as the behavioral model was calibrated for a single representative consumer. The classifications of products for France and Finland differ slightly. Hence, for France, the 'other animal products' category includes two main products, fish and eggs, while for Finland it only includes fish (whereas eggs are included in the 'Poultry/other' aggregate). Other differences in the aggregation scheme need to be acknowledged. For example, for France the 'other meats' category aggregates the 'Pork' and 'Poultry/other' categories that are distinguished in the Finnish aggregation scheme. Conversely, for fruits and vegetables, the classification for France is more detailed.

prices, but only by a small margin (–0.1%). The corresponding results for Finland indicate a wider gap between shadow and market prices for the fish constraint.

CLIMATE AND HEALTH EFFECTS

Table 3 presents the simulated economic, health, and climate effects resulting from the imposition of the three constraints in each country. The taste cost measuring the short-term loss of hedonic rewards represents less than 0.1% of the food budget in each case and, thus, appears

Table 3. Economic, Health, and Climate Effects of the Simulated Dietary Adjustments

	France			Finland		
	Fish +5%	All Meat –5%	Red Meat –5%	Fish +5%	All Meat –5%	Red Meat –5%
Taste Cost						
Total (€M)	10	76	10	0.3	9	–2
% Food budget	0.01	0.10	0.01	0.002	0.07	–0.01
DA for DIETRON Diseases						
Total	394	245	229	29	–4	10
% DIETRON Diseases	0.6	0.4	0.3	0.4	–0.1	0.1
% CHD	35	21	28	53	41	66
% Stroke	20	22	19	28	75	13
% Cancers	45	57	53	19	–15	21
CO2 Equivalent						
Total (Kt)	–400	–1,487	–892	–14	–36	–44
% Change	–0.6	–2.1	–1.3	–0.2	–0.6	–0.8

Notes: DA indicates deaths avoided. The row labelled ‘Total’ provides the total number of DA. The row labelled ‘% DIETRON disease’ expresses those DA as a proportion of the total number of deaths attributable to the diseases taken into account by DIETRON. The rows ‘% CHD,’ ‘% Stroke,’ and ‘% Cancers’ provide the proportions of DA attributable to the change in the incidence of CHD, strokes, and cancers (summing to 100%, as only those three disease groups are considered in the model). In the CO2 equivalent section, ‘% change’ indicates the changes in GHGE relative to total emissions from food consumption.

small, although it is worth keeping in mind that we only test small/marginal changes in the constraint levels. More informative, the ranking of those taste costs captures the relative difficulty of adjusting diets to comply with the exogenous constraints. On that basis, table 3 indicates that, in both countries, the difficulty of raising fish consumption by 5% is comparable to that of diminishing consumption of red meat by 5%. Both changes are much less difficult for consumers than a 5% decrease in consumption of all meat. The fact that, in both countries, the taste cost of reducing consumption of all meat is significantly larger than the taste cost of only reducing consumption of red meat was expected, as it is intuitive that cross-category substitutions are more difficult for consumers to achieve than within-category substitutions (i.e., among relatively close substitutes).

Although the taste costs are small relative to the food budget, they still account for millions of euros when expressed annually for entire populations (e.g., €10 million for France and the fish constraint). Those costs are typically ignored when assessing the social desirability of measures aimed at promoting consumption changes (e.g., Rajgopal et al. 2002), but are included in the efficiency analysis of the three recommendations below. However, the main insight from the calculation of the taste costs is that the barriers imposed by habits, tastes, and preferences to increasing fish consumption appear relatively limited in both countries, which hints at the potential effectiveness of generic advertising and other informational measures to boost fish consumption.

Health effects are calculated as the annual number of DA due to dietary changes induced by each constraint and vary from 200 to 400 for France and from 0 to 29 for Finland. Those health effects are deemed small, but significant, as they account for up to 0.6% of the diet-related deaths captured by the epidemiological model DIETRON (keeping in mind the marginal 5% exogenous change in constraint levels). More importantly, when comparing results for the different constraints, analysis reveals that, in both countries, raising fish consumption by 5% would generate significantly more health benefits than a 5% decrease in meat consumption. In Finland, the surprising finding that a decrease in meat consumption would actually *raise* mortality from diet-related chronic diseases (i.e., negative DA in table 3) illustrates that inclusion of whole-diet substitutions is paramount for the calculation of health effects, and that well-intended recommendations ("eat less meat") may generate undesirable effects.[6] Closer analysis reveals that many seemingly paradoxical results are explained by whole-diet substitutions and their impact on energy intake. For instance, in the case of France, although the 5% decrease in meat consumption is accompanied by a more than proportional increase in fish consumption (+7.5%, table 1), the effect on health (table 3) is less than the exogenous 5% increase in fish consumption. This happens because fish and meat account for a small share of the total diet and there are many changes outside of those two groups that explain the difference in outcomes between the two simulations. Most importantly, we find that the fish recommendation results in a larger decrease in calories than the meat recommendation (table 4). In turn, table 1 establishes that the 5% reduction in meat consumption is largely offset by a significant increase in consumption of dairy products (milk products +4.2%, cheese +3.3%). In the case of the 5% reduction in fish consumption, consumption of most other food categories is either impacted negatively or not at all (e.g., dairy), with the exception of the desirable increase in F&V consumption.

Table 3 further documents the pathways to better dietary health, and we observe differences both across countries and constraints. In France, the fish constraint as compared to the meat constraints, reduces mortality relatively more due to its effect on the incidence of cancers, although a similar result is not observed in the case of Finland.

Table 4 provides additional elements quantifying the relative contribution of the variation in energy intake (i.e., calories) to the reduction in mortality.[7] It turns out that for France, the reduction in energy intake induced by the adoption of the three recommendations is the main driver of the health benefit. That statement is also true in Finland for the fish recommendation, but not for the case of meat recommendations. Altogether, the simulations indicate that fish is typically included in less caloric meals than alternatives, and that this reduction in calories represents a key mechanism by which fish consumption improves dietary health.

The climate impacts of the dietary adjustments simulated by the model are presented in the lower part of table 3. In both countries, we find that increasing fish consumption induces a reduction in GHGE, although the effect is quantitatively small (–0.6% in France and –0.2% in Finland). The larger reduction simulated for France is in line with the greater substitutability of fish for red meat in France than in Finland, as mentioned above in relation to table 1. In both countries, we also find that curtailing consumption of all meat and red meat would have a significantly larger climate impact than raising fish consumption.

Finally, table 3 brings to light the more general point that while healthier diets tend to be more climate friendly, the ranking of the three recommendations depends on both country and type of impact. Hence, for health (i.e., number of DA):

- 'Fish' > 'All meat' > 'Red meat' in France
- 'Fish' > 'Red meat' > 'All meat' in Finland

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[6] The result is explained by the increase in total calories resulting from the substitutions associated with reduced meat consumption. For instance, table 1 reports substantial increases in the consumption of energy-rich dairy products (cheese, butter) and plant-based fats. The additional calories drive an increase in body mass index, increase the risk of diet-related diseases, and ultimately increase mortality. The negative health effect of the additional calories (–24 DA) is larger than the positive health effect of the improvement in diet quality (+20 DA), as described in table 4.

[7] The other contribution is that of diet quality.

Table 4. DA Attributable to the Change in Dietary Energy and Other Changes

	Red Meat –5%	All Meat –5%	Fish +5%
France			
DA – Total	229	245	394
DA – Energy	167	237	380
DA – Other	63	8	14
% Energy effect	73	97	97
Finland			
DA – Total	10	–4	29
DA – Energy	0	–24	33
DA – Other	11	20	–4
% Energy effect	–4	544	114

However, for GHGE:

- ‘All meat’ > ‘Red meat’ > ‘Fish’ in France
- ‘Red meat’ > ‘All meat’ > ‘Fish’ in Finland

This implies that a careful account of substitutions and preferences in each country is necessary when assessing the climate and health effects of dietary adjustments and that aggregation of impacts across sustainability dimensions to establish unambiguous ranking requires further analysis, which we present next.

EFFICIENCY ANALYSIS

To carry out the efficiency analysis, we monetize the health benefit (DA) and environmental benefit (reduction in GHGE) described in table 3, using appropriate valuation parameters described in the methodology section. The column labelled “Benefits” in table 5 then displays the sum of the monetized health and environmental benefits, expressed in millions of euros, while the column labelled “% health” quantifies the share of the health benefit in the total benefit from

Table 5. Efficiency Analysis

	Benefits (M€)	% Health Benefit	Cost (M€)	C_p Max Campaign (M€)	Ranking
France					
Fish +5%	107	88	10	98	1
All meat –5%	106	55	76	30	3
Red meat –5%	84	66	10	73	2
Finland					
Fish +5%	7	94	0	7 (77)	1
All meat –5%	0	–	9	–9 (–100)	3
Red meat –5%	4	63	–2*	4* (42)*	2

Notes: * Theoretically inconsistent negative cost not included in calculation. The column ‘% Health’ indicates the proportion of total benefit attributable to the health impact of a recommendation. In the column ‘Cp Max campaign,’ the numbers in parentheses for Finland simply scale up the figures directly to their left to take account of the difference in population size between Finland and France.

the dietary adjustment. Thus, in France, the simulations indicate that inducing consumers to raise their consumption of fish by 5% would generate a total benefit worth €107 million, 88% of which would be from better health, and the remaining 12% from a reduction in GHGE.

The column labelled "Cost" simply replicates the taste cost reported in table 3 and therefore estimates the loss of rewards, mainly in terms of convenience and taste, which consumers would experience in the short run due to dietary adjustment. In turn, the column before last presents the threshold values, C_p, measuring the maximum amount of resources that could be used by industry or government to bring about the assumed dietary change while ensuring that benefits exceed costs. Thus, still in the case of France, we estimate that it would be socially desirable to spend up to €98 million annually to boost fish consumption through generic advertising and/or social marketing, provided that it resulted in an increase in consumption worth 5% from currently observed levels. The last column simply provides the ranking of the different constraints based on the value of the threshold, C_p.

The results indicate that, in both countries, the value of the efficiency threshold is relatively large (€98 million and €7 million, respectively) and likely to exceed the cost of measures that could bring about the targeted dietary change (+5% in consumption of fish). Although it is difficult to anticipate the effectiveness of information provision in modifying dietary behaviors, some academic studies have been published on the subject, albeit not specifically about fish. For instance, Capacci and Mazzocchi (2011) reported that the ambitious "5-a-day" UK campaign to encourage consumption of fruits and vegetables, 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 the promotion of fish consumption in France and Finland through provision of information to consumers is likely to represent money well spent (i.e., to raise social welfare).

The difference in magnitude of the efficiency thresholds between the two countries is explained to a large extent by differences in population, as France has about 11 times more adults than Finland. To facilitate the comparison, the efficiency threshold is also calculated for Finland assuming an adult population of the same size as France, resulting in the adjusted figures presented in parentheses in table 5. This exercise reveals that, after accounting for population size, the values of the efficiency thresholds corresponding to the fish constraint in the two countries are of the same order of magnitude and large. In both cases, the bulk of the benefit derives from improvements in health rather than reductions in GHGE.

Comparison of the efficiency results for the fish and meat constraints also generates valuable insights. Most importantly, in both countries we find that raising consumption of fish by 5% results in higher efficiency thresholds than decreases in meat consumption, with the same ranking of the three constraints. The least attractive option would be to seek to reduce consumption of all meat by 5% and, for both countries, the result is explained by the significant taste costs that this reduction would impose on consumers in the short run. This provides additional confirmation of the importance of including a realistic representation of consumer preferences when assessing measures to raise the healthiness and climate-friendliness of diets.

SENSITIVITY ANALYSIS

We now examine the robustness of the results presented in the previous sections in relation to uncertainty surrounding the CO2 coefficients derived from LCA. Table 6 depicts variations in

Table 6. Variations in GHGE (CO2 Equivalent, CO2e) Induced by the Adoption of the Three Recommendations for Two Different Sets of LCA Coefficients for Fish

	ΔCO2e (Kt)		ΔCO2e (%)	
	LCA Coef. Best Estimates	LCA Coef. Upper Bounds	LCA Coef. Best Estimates (%)	LCA Coef. Upper Bounds (%)
France				
Red meat –5%	–892	–886	–1.3	–1.2
All meat –5%	–1,487	–1,460	–2.1	–2.0
Fish +5%	–400	–380	–0.6	–0.5
Finland				
Red meat –5%	–45	–44	–0.8	–0.8
All meat –5%	–36	–35	–0.6	–0.6
Fish +5%	–14	–13	–0.2	–0.2

GHGE induced by the adoption of the three recommendations for two different levels of CO2 coefficients for fish/seafood, corresponding to the average and upper-boundary values of those coefficients reported in appendix table A1. Overall, shifting from average to upper-boundary values results in 20 and 16% increases in the CO2 coefficients of the 'fish basket' in France and Finland, respectively. However, table 6 shows that such an increase in CO2 coefficients has a very low impact on the GHGE of the whole diet. This is explained first by the modest place that fish products occupy in French and Finnish diets overall. A second reason is that, even with a 20% increase in the average CO2 coefficient of the fish category, that category remains much less impactful than meat products. In fact, the CO2 coefficients of the fish group would have to be higher by several orders of magnitude to modify our conclusions, which are deemed robust in that dimension.

At another level, and as noted previously, health benefits are calculated by placing a value on DA that falls below most VSL estimates. It is clear, however, that using a more conventional VSL would only reinforce our conclusions: the health benefits and related efficiency thresholds would rise, hence confirming the social desirability of promoting fish consumption. Further, given that health benefits account for the highest share of total benefit for the fish recommendations (table 5), the change would not alter the ranking of recommendations.

CONCLUSION

In order to contribute to the scientific debate on sustainable diets, this study quantified the climate and health impacts of several food-based dietary recommendations, including an increase in fish consumption, by combining a model of rational behavior under dietary constraints, an epidemiological model of diet-related mortality, and an LCA model of environmental impact. The strength of this approach is, first, that it permits the ex ante assessment of dietary recommendations related to fish and meat consumption in multiple dimensions: taste cost borne by consumers, mortality avoided through reduction in diet-related chronic diseases, and curtailment in GHGE. This contributes to improving the evaluation of the sustainability effects of those dietary recommendations by actually considering possible convergence, or tradeoffs, across sustainability dimensions. Second, the analytical approach takes into account consumers' preferences, as summarized by demand elasticities, and the complex relations of substitution and complementarity among foods in the whole diet. Third, theoretical foundations support an efficiency analysis of dietary recommendations, which can, therefore, be ranked on the basis of an objective, all-encompassing criterion. Finally, the analysis was conducted in a similar way for two countries, France and Finland. This is important to interpret results and derive robust conclusions, because consumption patterns vary widely across countries, as do tastes, preferences, and diet-related disease burdens.

The empirical results indicate that the patterns of adjustments to those exogenous changes differ between the two countries, although the broad substitutability of fish for other animal products is confirmed and, in both cases, consumers respond through complex modifications of their diets. The taste cost of increasing fish consumption, which measures the loss in hedonic rewards (taste, convenience) experienced by consumers in the short run, is small, suggesting that the barriers imposed by habits and taste/preferences to increasing fish consumption are limited. In both countries, we estimate that raising fish consumption by 5% would generate larger health benefits than either of the two meat constraints (i.e., reductions of 5% of all meat and red meat), and that most of the health improvement would result from a lower energy intake of the modified diet, suggesting that fish naturally contributes to less caloric meals. Increase in fish consumption also delivers climate benefits which, although only limited in magnitude, confirm that raising fish consumption enhances sustainability in both its health and climate dimensions.

Placing monetary value on environmental and health benefits, and taking into account the costs imposed on consumers, industry (for generic advertising), and the public sector (for implementing policies), we find that promoting fish consumption is cost efficient and socially desirable. Promotion of fish consumption should also be prioritized over measures aimed at reducing consumption of meat. Thus, rather than stigmatizing meat consumers, we suggest that healthy and climate-friendly diet recommendations may more effectively send a positive message urging consumers to raise their consumption of fish and seafood. Stakeholders of the fish supply chain may also want to insist collectively on the positive climate and health benefits associated with the promotion of fish consumption.

The analytical approach also presents some limitations, which must be acknowledged and should be kept in mind when interpreting the results. Most significantly, important health and environmental impacts of dietary changes were not taken into account in the analysis, mainly because of a lack of data. On the environmental side, it is very likely that increased demand for fish and seafood would have to rely primarily on aquaculture, given the observed stagnation of global catch of wild seafood (Tacon and Metian 2015). However, the environmental sustainability of aquaculture production is itself hotly debated (Bronnmann and Asche 2017). For instance, as fish farms rely increasingly on feed inputs from agricultural sources, growth in fish consumption raises legitimate concerns over land use, biodiversity, and the pressure exerted by farming on its natural resource base (Froehlich et al. 2018). Recent results have established that aquaculture requires less feed crop and land than terrestrial meat production, but given the complexity of substitutions that our analysis has put to light, it is unclear how integration of more environmental indicators would modify our conclusions. Increased seafood consumption may also reinforce concerns about overfishing (Farmery et al. 2016). On the health side, food safety issues related to potential contaminants in fish and seafood products were also ignored. Thus, the proposed assessment is only partial, and other sustainability dimensions will have to be integrated in the future as sustainability indicators become available.

APPENDIX

LCA COEFFICIENTS AND UNDERLYING ASSUMPTIONS

Table A1. GHGE Coefficients for Meat and Fish Products

			GHGE (kg CO2 eq./kg)		
	Food Category	Indicator Product	Best Estimate (average)	Lower Bound	Upper Bound
Meat	Beef	Beef	42.5	36.1	52.9
	Pork	Pork	10.2	7.7	11.2
	Lamb	Lamb	34.3	33.7	67.7
	Livestock meat, other	Avg. meat	22.2	18.5	27.5
	Poultry	Chicken	5.8	4.7	7.4
	Preserved meat	Ham, sausage	5.6	4.3	6.0
	Sausage	Ham, sausage	5.7	4.4	6.1
	Meat specialties	Ham, sausage	5.6	4.3	6.0
	Pastes, pâtés, and terrines	Ham, sausage	5.6	4.3	6.0
	Meat imitates	Tofu	1.5	1.2	2.9
	Meat and meat products (unspecified)	Avg. meat	22.2	18.5	27.5
	Game mammals	Avg. meat	22.2	18.5	27.5
	Game birds	Chicken	5.8	4.7	7.4
	Mixed meat	Avg. meat	22.2	18.5	27.5
	Edible offal, farmed animals	Avg. meat	22.2	18.5	27.5
Fish & Seafood	Fish and other seafood (unspecified)	Avg. fish	3.6	2.7	4.5
	Fish products	Avg. fish	3.6	2.7	4.5
	Fish offal	Avg. fish 5%	1.1	0.6	1.1
	Crustaceans	Shrimp	9.6	7.2	12.1
	Water mollusks	Mussels	6.7	5.0	8.4
	Amphibians, reptiles, snails, insects	Avg. fish	3.6	2.7	4.5
	Tuna, canned	Tuna, canned	4.0	2.9	5.0
	Tuna, not canned	Tuna, not canned	4.1	3	5.1
	Salmon	Salmon	5.5	4.8	6.1
	Cod	Cod	4.5	3.3	5.6
	Other fatty fish	Small pelagics (herring, sardine)	2.1	1.6	2.6
	Other non-fatty fish	Groundfish (cod, sole)	2.9	2.1	3.6

Source: Hartikainen and Pulkkinen (2016).

The LCA coefficients presented in table A1 are reproduced from Hartikainen and Pulkkinen (2016) where the underlying methodology is explained in detail. The functional unit is the quantity of CO2 equivalent, expressed in kilograms, per kilogram of ready-to-eat food. Weight changes during food preparation and cooking were taken into account in the analysis. The system boundaries were chosen to include primary production, processing, packaging, storing, and cooking at home in the analysis, but transport, consumers' travel to food shops, food waste, and other indirect effects were excluded.

For the fish and seafood category, and for those species produced both by aquaculture and wild fisheries, GHGE estimates were first estimated separately for the two subsectors, then aggregated using weights representing the relative importance of each sub-sector. The GHGE estimates for wild fish/seafood used figures on the fuel consumption of fishing boats reported in the literature. For aquaculture, some LCA estimates were used together with some expert evaluations, where needed. The exact references are listed in Hartikainen and Pulkkinen (2016). The analysis did not distinguish imports from domestic production.

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