ECONOMIC ASSESSMENT OF NUTRITIONAL RECOMMENDATIONS

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Abstract: *The effect of consumers' compliance with nutritional recommendations is uncertain because of potentially complex substitutions. To lift this uncertainty, we adapt a model of consumer behaviour under rationing to the case of linear nutritional constraints. Dietary adjustments are thus derived from information on consumer preferences, consumption levels, and nutritional coefficients for each food. The model is then used to simulate, for different income groups, how the French diet would respond to various food-based and nutrient-based recommendations, and calculate the related welfare and health effects. This allows for the ex-ante comparison of the efficiency, equity and health effects of nutritional recommendations.*

Keywords: food choice; nutrition; rationing; healthy diet; norms

Introduction

Although some controversy remains, a consensus now exists within the public health and medical communities that links nutritional factors to various chronic diseases, including obesity, strokes, diabetes, and some types of cancers. Hence, the Joint WHO/FAO Expert Consultation on Diet, Nutrition, and Prevention of Chronic Diseases concluded that the epidemiological evidence was sufficiently strong to set a list of 15 population nutrient intake goals, covering various nutrients and food product groups (World Health Organization, 2003). Those goals have in turn been adopted, sometimes with minor changes, by high-income countries where concerns about the increasing incidence of diet-related chronic diseases, and most notably obesity, are rising. They form the basis of the healthy-eating messages and informational campaigns that currently represent the policy option of choice to induce consumers to adopt healthier diets (Mazzocchi and Traill, 2011).

However, a lot of research shows that the adoption of nutritional recommendations and dietary change by consumers are difficult for many, with campaigns raising awareness of nutritional issues without having a large impact on behaviours (Pérez-Cueto et al., 2013). If several reasons can be proposed to explain the difficulties in changing behaviours, one is related to the "taste cost" of change, that is, the utility loss induced by a dietary change that brings a new balance between long-term health goals and short-term pleasure and hedonistic rewards. In other words, the difficulties in complying with nutrient and food-based guidelines are likely due to the lack of compatibility of consumers' preferences with the diets that they would have to adopt in order to comply with these guidelines.

How can we determine healthy diets complying with recommendations and compatible, as much as possible, with consumer preferences? How can we identify nutritional recommendations with the potential to improve health but generating minimal "taste costs", especially for low-income households? We argue that experts in both public health and economics are currently ill-equipped to answer those questions and, more generally, to assess how nutritional norms might influence real-world consumers, as available methods suffer from important shortcomings.

A first group of methods to address this issue builds on linear programming (LP) models to estimate least-cost diets complying with a list of nutritional requirements. However, as has long been recognized (Stigler, 1945), those models produce unrealistic diets which are extremely cheap and composed of only a handful of food items (see Henson (1991) for the UK, or Conforti and d'Amicis (2000) for Italy). Alternative programming approaches based on the minimization of the departure from current dietary patterns, rather than cost minimization, has also been proposed (Darmon et al., 2002; Srinivasan et al., 2006; Arnoult et al., 2010), but the objective functions remain arbitrary and implicitly restrict the substitution possibilities among goods. A second type of approach with a stronger theoretical basis uses empirically-estimated demand systems in order to simulate the effects of fiscal measures on food consumption as well as nutrient and energy intakes (see Etilé, 2011, and Eyles et al. 2012 for recent reviews). However, it is not clear how this framework can be extended to analyse the way whole diets may adjust to dietary recommendations.

Because of those limitations, this article develops a new analytical framework which builds on the microeconomic theory of the consumer under rationing, with the goal of identifying diets compatible with both nutritional norms and consumer preferences. In other words, we build a framework to estimate the substitutions, and overall changes in diet, that would take place if consumers complied with these norms. Unlike programming approaches, our framework is grounded in the microeconomic theory of the consumer, and is therefore able to capture complex but empirically estimable relationships of substitutability and complementarity among goods. Compared to the demand system analyses used to assess the effect of price variations on consumption and diet quality, we consider the dual problem which consists of determining the price system and the compensation value (i.e. the taste cost) such that a nutritional recommendation can be adopted without loss of utility.

The paper presents the theoretical model, followed by the data and empirical methods used to simulate the effects of compliance with ten different nutritional constraints. After discussing the results, we offer some concluding remarks.

A consumer model of dietary adjustment to nutritional recommendations

This section adapts the work of Jackson (1991) on generalized rationing theory to the case of linear nutritional constraints, and extends it by deriving the comparative statics results necessary to empirically estimate healthy diets compatible with consumer preferences. We adopt the conventional framework of neoclassical consumer theory by assuming that an individual chooses the consumption of H goods in quantities $x=(x_1,\ldots x_H)$ to maximize a strictly increasing, strictly quasi-concave, twice differentiable utility function $U(x_1,\ldots x_H)$, subject to a linear budget constraint $p.x \le M$, where p is a price vector and M denotes income. However, departing from the standard model, we now assume that the consumer operates under N additional linear constraints corresponding to N maximum nutrient intakes.[1] Those constraints could, for instance, correspond to maximum dietary intakes of salt, total fat, saturated fat, or free sugars, and their linearity implies an assumption of constant nutritional coefficients a_i^n for any food i and nutrient n, the value of which is known from food composition tables.[2] The constraints could also correspond to food-based constraints (such as recommendations on consumption of fruit and vegetables or starchy products).[3] The nutritional constraints are expressed by:

$$\sum_{i=1}^{H} a_i^n x_i \le r_n \ \forall n = 1,\ldots, N \qquad (1)$$

The method to solve this modified utility maximization problem parallels that used to analyse single good rationing by relying on the notion of shadow prices, i.e. prices that would have to prevail for the nutritionally unconstrained individual to choose the same bundle of goods as the nutritionally constrained household. Duality theory is used to relate constrained and unconstrained problems in order to identify the properties of demand functions under nutritional constraints. We denote the compensated (Hicksian) demand functions of the standard problem by $h_i(p,U)$, and those of the constrained model by $\tilde{h}_i(p,U,A,r)$, where A is the $(N \text{ x } H)$ matrix of nutritional coefficients, and r the N-vector of maximum

[1] The results can be generalised to minimum constraints without difficulty.
[2] Nutritionists (e.g., Darmon et al., 2002) also base their analysis on this linearity assumption (which also implies that there are no interactions between food items).
[3] Those product-based recommendations are formally similar to nutrient-based recommendations because in many cases consumers eat prepared dishes that include different products (e.g., a pizza contains vegetables as well as dairy products).

nutrient amounts. By definition of the vector of shadow prices $\tilde{p}$, the following equality holds: $\tilde{h}_i(p,U,A,r) = h_i(\tilde{p},U)$. The minimum-expenditure function of the nutritionally-constrained problem $\tilde{C}(p,U,A,r)$ can be related to the ordinary expenditure function $C(p,U)$ as follows:

$$\tilde{\boldsymbol{C}}(\boldsymbol{p},\boldsymbol{U},\boldsymbol{A},\boldsymbol{r}) = \sum_{\boldsymbol{j}=1}^{\boldsymbol{H}} \boldsymbol{p}_{\boldsymbol{j}} \tilde{\boldsymbol{h}}_{\boldsymbol{j}}(\boldsymbol{p},\boldsymbol{U},\boldsymbol{A},\boldsymbol{r}) = \boldsymbol{C}(\tilde{\boldsymbol{p}},\boldsymbol{U}) + \sum_{\boldsymbol{j}=1}^{\boldsymbol{H}} (\boldsymbol{p}_{\boldsymbol{j}} - \tilde{\boldsymbol{p}}_{\boldsymbol{j}}) \boldsymbol{h}_{\boldsymbol{j}}(\tilde{\boldsymbol{p}},\boldsymbol{U}). \tag{2}$$

It is evident that the constrained regime is fully characterized by the combination of unconstrained demand functions, unconstrained expenditure function, and shadow prices. In turn, shadow prices are calculated by exploiting the idea that they minimize $\tilde{C}$ subject to the nutritional constraints (1) - or what Jackson (1991) calls the virtual price problem. Using equation (2), the Lagrangian of the virtual price problem is: $L = C(\tilde{p},U) + \sum_{j=1}^{H} (p_j - \tilde{p}_j) h_j + \sum_{n=1}^{N} \mu_n (r_n - \sum_{j=1}^{H} a_j^n h_j)$. Assuming non-satiation so that all virtual prices are strictly positive, the Kuhn-Tucker conditions are:

$$\begin{aligned}
&\frac{\partial C}{\partial \tilde{p}_i} - h_i + \sum_{j=1}^{H} (p_j - \tilde{p}_j) \frac{\partial h_j}{\partial \tilde{p}_i} - \sum_{n=1}^{N} \mu_n \sum_{j=1}^{H} a_j^n \frac{\partial h_j}{\partial \tilde{p}_i} = 0 \qquad i = 1,\ldots,H \\
&\mu_n (r^n - \sum_{j=1}^{H} a_j^n h_j) = 0 \qquad n = 1,\ldots,N \\
&\mu_n \geq 0, \qquad n = 1,\ldots,N
\end{aligned} \tag{3}$$

Using Shephard's lemma, and denoting by s_{ij} the Slutsky term $\partial h_i / \partial p_j$, the first equation in (3) becomes: $\sum_{j=1}^{H} \left[(p_j - \tilde{p}_j) - \sum_{n=1}^{N} \mu_n a_j^n \right] s_{ji} = 0 \qquad i = 1,\ldots,H$. For this set of equations to hold generally, it is necessary for the term in bracket to be equal to zero. Assuming that all *N* constraints are binding, the virtual price problem therefore reduces to:

$$\begin{aligned}
&\tilde{p}_i = p_i - \sum_{n=1}^{N} \mu_n a_i^n \qquad i = 1,\ldots,H \\
&\sum_{i=1}^{H} a_i^n h_i(\tilde{p},U) = r_n \qquad n = 1,\ldots,N
\end{aligned} \tag{4}$$

The first set of equations is easily interpreted: each shadow price is the sum of the actual price and a sum of terms depending on the composition of the good in each constrained nutrient, as well as the influence of each constraint on minimum expenditure as measured by the Lagrange multipliers.[4] In general, system (4) is highly non-linear and cannot be solved analytically, but we circumvent that problem to analyse the relationship between food demand and nutrient constraint by deriving relevant static comparative results. In the following, we only consider the case in which there is only one constraint. The first set of equations in (4) can then be used to express all prices in terms of p_H:

$$\tilde{p}_i = p_i - (p_H - \tilde{p}_H) \frac{a_i^1}{a_H^1} \qquad i = 1,\ldots.,H-1 \tag{5}$$

The response of the H-1 shadow prices to a change in the level of the nutritional constraint can therefore be expressed solely as a function of the response of the Hth shadow price to the same change:

[4] Note that if a product does not enter any constraint, then its shadow price is equal to its actual price.

$$\frac{\partial \tilde{p}_i}{\partial r_1} = \frac{a_i^1}{a_H^1}\frac{\partial \tilde{p}_H}{\partial r_1} \qquad i = 1,....,H-1 \tag{6}$$

Totally differentiating the nutritional constraint expressed as in (4) and using (6), one obtains:

$$\sum_{i=1}^{H} a_i^1 \sum_{j=1}^{H} s_{ij} \frac{a_j^1}{a_H^1}\frac{\partial \tilde{p}_H}{\partial r_1} = 1 \Rightarrow \frac{\partial \tilde{p}_H}{\partial r_1} = \frac{a_H^1}{\sum_{i=1}^{H}\sum_{j=1}^{H} s_{ij} a_i^1 a_j^1} \tag{7}$$

That is, the response of the shadow price of product *H* to a change in the level of the nutritional constraint is proportional to the nutritional content of product *H*. Plugging this expression back into (6) gives the remaining *H-1* shadow price changes, from which follows the change in demand for any of the *H* goods:

$$\frac{\partial \tilde{h}_k}{\partial r_1} = \frac{\sum_{i=1}^{H} s_{ki} a_i^1}{\sum_{i=1}^{H}\sum_{j=1}^{H} s_{ij} a_i^1 a_j^1} \qquad k = 1,....H \tag{8}$$

It is evident from this expression that a change in the nutritional constraint has an impact on the entire diet. This is true even for the goods that do not enter the constraint directly, as long as they entertain some relationship of substitutability or complementarity with any of the goods entering the constraint (i.e., as long as at least one Slutsky term s_{ki} is different from zero). Further, the numerator of expression (8) indicates that the magnitude and sign of any change in demand is unknown *a-priori* but depends on the product's composition relative to and substitutability with other products entering the constraint. From an empirical perspective, what is important is that expressions (8) can easily be calculated by combining a matrix of Hicksian demand parameters to a set of easily available nutritional coefficients. Hence, assuming that we have a matrix of price elasticities describing the behaviour of an unconstrained individual, equation (8) provides a means of inferring how that individual would modify his diet in order to comply with the nutritional norm.

The welfare (or taste) cost of satisfying nutritional constraints can be evaluated by the compensating variation CV. We have $CV = C(p,U) - \tilde{C}(p,U,A,r)$. Using (2), the CV associated with a (marginal) variation of the constraint is written as: $CV = -\sum_{i=1}^{H} p_i \frac{\partial \tilde{h}_i}{\partial r_1}$. Besides welfare assessment, the CV is used to evaluate the change in Marshallian demand Δx (i.e., maintaining the budget but not utility constant): $\Delta x = \Delta h + \tilde{h}.\varepsilon^R \frac{CV}{p.\tilde{h}}$, with ε^R denoting the income (or expenditure) elasticity. This economic model, which supports the simulation of the adjustment of the whole diet to the nutritional recommendation, is then linked to the epidemiological model DIETRON in order to assess health outcomes (Scarborough et al. (2011), Scarborough et al. (2012a,b)).

Data and empirical procedure

KANTAR WorldPanel data on food purchases of a representative sample of 19,000 French households were used to obtain information on food purchases (expenditure, quantity) and prices. The characteristics of the data set are presented in detail in Allais et al. (2010) [5] and we also used the price

[5] http://ajae.oxfordjournals.org/content/suppl/2010/01/23/aap004.DC1/aap004supp.pdf

and expenditure elasticities published in that article. Food items were aggregated into 22 categories, and the empirical analysis considers four representative consumer types based on income quartiles and henceforth referred to as "modest", "lower average", "upper average", and "well-off".

The nutritional contents of the 22 food aggregates were calculated using the food composition database associated with the INCA2 survey, a cross-sectional national survey carried out in 2006-2007 by the ANSES.[6] The nutritional content of each of the 22 food categories was determined on the basis of the average consumption of a French adult as estimated in the INCA2 survey.[7] Recipes and edible parts for each food category were defined on that basis and used to formalize the nutritional constraints.[8]

Calibrating the DIETRON model to France requires first data on mortality and causes of deaths[9], which we obtained from INSERM (French Research Institute on Health and Medicine), for persons between the age of 24 and 75 years. We then used an inequality index to allocate deaths to the different income quartiles.

Linking the economic and epidemiological models is challenging because of the different units of observations (individuals versus households). The relative changes in Marshallian demand calculated from the economic model were applied to representative individuals, divided according to income quartile and gender (i.e., eight types in total). Baseline intakes of the 22 food aggregates for those representative households came from the INCA2 database.

Results

The methodology is applied to simulate the effect on food consumption, nutrient consumption, health and welfare of ten different nutritional constraints. In each case, the relative variation in the level of the constraint is five percent of its initial level, and the direction is chosen so as to increase dietary quality. We consider a total of 10 nutritional constraints, including six nutrient-based constraints related to the consumption of added sugar, salt, fibers, total fat, saturated fatty acids (SFA) and cholesterol. The remaining four food-based recommendations cover consumption of fruits and vegetables (F&V), salt-fat products, sugar-fat products and soft drinks.

We start with the impact of the different recommendations on food consumption, focusing on the "lower average" income group of households (Table 1).[10] Each column of Table 1 corresponds to a different constraint and presents two sets of percentages: the initial contribution of each food group to the constrained food/nutrient on the left, and the change in consumption resulting from the imposition of the constraint on the right. Focusing on the first constraint, let us note at the outset that a five percent increase in F&V consumption corresponds to a daily consumption increase of 19 g/day (i.e., a quarter of a portion). Imposition of this relatively small variation in the constraint level results in important changes in consumption of several food aggregates: the increase in F&V consumption is associated with a particularly large decrease in consumption of starchy foods (-16%) but consumption of dairy products is also impacted substantially (-4%).[11] Hence, the relations of complementarity and substitutability

[6] The INCA 2 survey is based on a nationally representative random sample of adults aged 18-79 years (n=2624) who completed 7-day diet records, aided by a photographic manual of portion sizes. See: www.anses.fr

[7] We thus implicitly consider that the nutrient content of the 22 food categories is identical for the four representative consumers.

[8] The matrix of nutritional content of the 22 food groups is available from the authors upon request.

[9] The relative risks used in the model to translate a change in diet to a change in the risk of mortality from any disease are taken from international meta-analysis and are not country specific.

[10] The corresponding results for the other three household types are available from the authors upon request.

[11] Note that the increase in F&V food category is different from 5% (the target for an increase in the total consumption of F&V). This is because some other food categories (ready meals, sugar-fat products) also include some F&V. Then, the

among food products captured by the model appear quantitatively important, which already suggests that simulating the health effects of nutritional recommendation under a "ceteris paribus" assumption (i.e., assuming here constancy of the diet except for the increased consumption of F&V) would be inappropriate.

Considering the simulation results at a higher level of product disaggregation in Table 1, we note that some complex substitutions also occur within product groups. For instance, within the animal products group,[12] the F&V constraint induces a relatively large decrease in consumption of red meat (-9%), cooked meats (-3%) and eggs (-8%), but a relatively large increase in consumption of fish (+10%) and other meats (+6%). Even within the F&V category, changes in consumption are not uniform, with much larger increases for the processed fruit and vegetable categories than for the corresponding fresh categories. More surprisingly, the simulations show that imposing the F&V constraint results in a decrease, albeit small, in consumption of some types of fruits (namely, fresh and dry ones).

Lower Average	F & V +5%		Salt-Fat Prod. -5%		Sugar-Fat Prod. -5%		Soft Beverage -5%		Fibers +5%		Na -5%		Total Fat -5%		SFA -5%		Cholesterol -5%		Added Sugar -5%	
Red meat	0%	-9,1%	0%	0,3%	0%	1,1%	0%	0,3%	0%	-1,1%	1%	1,9%	3%	0,1%	3%	-0,3%	7%	-2,2%	0%	5,4%
Other meats	0%	6,2%	0%	0,4%	0%	1,9%	0%	0,4%	0%	1,8%	3%	4,6%	6%	5,1%	4%	14,1%	14%	0,5%	0%	4,4%
Cooked meats	0%	-3,3%	0%	0,0%	0%	-2,1%	0%	-0,1%	0%	-2,7%	19%	-2,5%	10%	-3,4%	9%	-3,7%	14%	-2,1%	0%	-2,5%
Fish	0%	9,7%	0%	0,1%	0%	2,0%	0%	0,1%	0%	-5,6%	4%	7,6%	2%	4,6%	1%	8,7%	4%	2,7%	0%	3,6%
Eggs	0%	-7,6%	0%	1,4%	0%	-3,2%	0%	0,5%	0%	-6,6%	1%	4,9%	3%	1,4%	2%	-16,0%	19%	-21,7%	0%	-1,3%
Animal pdts	0%	0,6%	0%	0,3%	0%	0,3%	0%	0,2%	1%	-1,8%	29%	3,0%	23%	1,8%	19%	3,7%	58%	-2,4%	1%	2,2%
Grains	0%	-6,2%	0%	-0,5%	0%	-1,3%	0%	-0,2%	16%	22,4%	13%	-16,5%	1%	1,1%	1%	-2,2%	0%	0,5%	1%	-0,4%
Potatoes	0%	-27,6%	0%	-0,6%	0%	6,1%	0%	-1,5%	7%	6,5%	1%	-2,8%	2%	-5,1%	1%	2,8%	1%	3,3%	0%	-1,7%
Starchy food	0%	-16,1%	0%	-0,5%	0%	2,1%	0%	-0,8%	24%	15,0%	15%	-10,2%	3%	-1,8%	2%	0,1%	1%	1,8%	1%	-1,0%
Fruits - Fresh	41%	-1,1%	0%	0,0%	0%	-1,6%	0%	0,3%	22%	-0,9%	0%	0,0%	0%	-2,8%	0%	-5,0%	0%	-0,7%	0%	0,7%
Fruits - Processed	3%	27,0%	0%	1,1%	0%	-0,2%	0%	1,0%	1%	-1,3%	0%	2,2%	0%	-35,7%	0%	-31,0%	0%	-4,7%	4%	-4,7%
F & V juices	6%	4,0%	0%	0,1%	0%	6,8%	0%	0,8%	1%	-4,3%	0%	3,8%	0%	3,6%	0%	4,6%	0%	-0,2%	2%	11,2%
Vegetables - Fresh	33%	9,5%	0%	0,5%	0%	-1,4%	0%	0,1%	16%	-4,1%	3%	6,7%	1%	6,4%	0%	15,8%	0%	3,7%	0%	-1,4%
Vegetables - Processed	10%	18,4%	0%	0,2%	0%	0,7%	0%	0,5%	10%	13,3%	5%	-2,9%	0%	3,2%	0%	10,8%	0%	1,9%	0%	4,5%
Fruits - Dry	0%	-6,0%	0%	0,4%	0%	1,1%	0%	-1,7%	1%	7,4%	0%	12,0%	1%	-8,2%	0%	-5,1%	0%	7,4%	0%	-15,9%
F & V	93%	5,5%	0%	0,2%	0%	0,4%	0%	0,4%	52%	-1,2%	8%	2,6%	2%	0,9%	1%	3,9%	0%	0,9%	7%	2,2%
Milk products	0%	-4,3%	0%	0,2%	0%	0,4%	0%	0,5%	2%	-4,2%	7%	3,0%	6%	-2,5%	8%	-5,5%	5%	0,5%	16%	0,2%
Cheeses, butters, fresh creams	0%	-2,9%	0%	-0,8%	0%	-2,1%	0%	-0,1%	0%	-0,2%	15%	-4,0%	27%	-0,4%	44%	-7,4%	21%	-2,3%	0%	-4,3%
Dairy pdts	0%	-4,0%	0%	0,0%	0%	-0,1%	0%	0,3%	3%	-3,4%	21%	1,6%	33%	-2,1%	52%	-5,9%	26%	0,0%	16%	-0,7%
Ready meals	4%	-11,7%	0%	-0,3%	0%	-0,6%	0%	-0,6%	7%	3,0%	9%	-7,5%	4%	-4,1%	4%	-5,7%	4%	0,6%	1%	-4,3%
Oil, margarine, condiments	0%	12,0%	0%	1,4%	0%	5,5%	0%	0,4%	0%	0,1%	4%	5,3%	23%	-20,4%	9%	-2,6%	0%	8,8%	0%	3,5%
Salt-fat products	0%	-20,7%	100%	-5,0%	0%	8,5%	0%	-1,4%	2%	7,1%	7%	-27,6%	1%	6,0%	1%	-28,4%	0%	7,4%	0%	5,8%
Sugar-fat products	3%	2,1%	0%	0,2%	100%	-5,0%	0%	0,2%	12%	0,9%	6%	-0,7%	10%	-0,4%	12%	-5,9%	10%	-2,0%	57%	-4,0%
Soft drinks	0%	-18,4%	0%	-0,9%	0%	5,5%	100%	-5,0%	0%	2,1%	0%	-5,9%	0%	4,2%	0%	2,8%	0%	4,1%	15%	-19,2%
Water	0%	-20,0%	0%	-0,6%	0%	1,3%	0%	-0,2%	0%	-9,0%	1%	1,6%	0%	3,7%	0%	9,7%	0%	8,4%	0%	6,3%
Alcoholic beverages	0%	12,9%	0%	0,1%	0%	2,9%	0%	-0,2%	0%	2,2%	0%	1,3%	0%	2,2%	0%	4,8%	0%	0,8%	2%	1,9%

Table 1: Changes in food consumption induced by the imposition of nutritional constraints (percentage on the right in each column) & initial contribution of each food group to the constrained nutrient/food (percentage on the left in each column) for the "Lower-average" consumer type.

The consumption changes associated with the imposition of the other nine constraints are rather varied and difficult to summarise. However, the results indicate that, compared to the simulated effect described above with regard to the F&V constraint, imposition of any of the other three food-based constraints results in relatively smaller adjustments in food consumption – for instance, for the constraints imposed on salt-fat products, none of the reported changes in consumption exceeds 2% (except for the targeted product group). Reducing consumption of soft drinks only has a small impact on the overall diet, while the adjustments are a bit larger in the case of the constraint imposed on sugar-fat products. Further, the simulations reveal that some recommendations can have surprisingly large unintended effects, as illustrated by the 8.5% increase in consumption of salt-fat products induced by the imposition of the constraint on sugar-fat products.

change in F&V consumption takes into account the changes in consumption of the F&V food category as well as the changes in the consumption of the other food categories which contain some F&V.

[12] This group does not include dairy products.

The results relative to the remaining six nutrient-based constraints are also heterogenous but, in some cases at least, the simulated consumption changes are substantial. Thus, the fiber constraint is associated with a 15% increase in consumption of starchy foods, while the sodium constraint would reduce consumption of this same food category by over 10%. Significant adjustments in consumption occur as a result of the imposition of the two fat constraints, which induce a reduction in consumption of dairy products while at the same time, and more surprisingly, raising aggregate consumption of other animal products. However, the exact profile of dietary adjustment is substantially different depending on the type of fat (i.e., total or saturated), which is the subject of the constraint. Most of the reduction in added sugar is achieved by a decrease in consumption of sugar-fat products and soft drinks, while the cholesterol constraint results in a large reduction in egg consumption – all results that conform to intuition.

Overall, the simulations reveal that compliance with diet recommendations by a rational consumer implies large changes in consumption patterns, whose economic and health effects can only be adequately assessed by considering adjustments in the whole diet. Those complex adjustments reflect the nature of consumers' preferences for foods and would not have been possible to anticipate at the outset. To further understand how the model works, the percentage differences between shadow prices associated with each constraint and actual prices are given in Table 2 for the same "lower average" household type.

Lower Average	F & V +5%	Salt-Fat Prod. -5%	Sugar-Fat Prod. -5%	Soft Beverage -5%	Fibers +5%	Na -5%	Total Fat -5%	SFA -5%	Choles terol -5%	Added Sugar -5%
Red meat	0,0%	0,0%	0,0%	0,0%	0,0%	0,8%	3,2%	5,5%	2,6%	0,0%
Other meats	0,0%	0,0%	0,0%	0,0%	0,0%	1,2%	4,7%	5,7%	4,3%	0,1%
Cooked meats	0,0%	0,0%	0,0%	0,0%	-0,1%	8,6%	7,1%	10,9%	4,0%	0,2%
Fish	0,0%	0,0%	0,0%	0,0%	-0,1%	2,6%	1,8%	1,4%	1,9%	0,0%
Eggs	0,0%	0,0%	0,0%	0,0%	-0,1%	5,0%	15,8%	20,4%	46,3%	0,5%
Grains	-0,4%	0,0%	0,0%	0,0%	-21,3%	23,1%	3,8%	3,4%	0,2%	2,3%
Potatoes	0,0%	0,0%	0,0%	0,0%	-27,2%	5,5%	12,9%	19,5%	2,0%	0,0%
Fruits - Fresh	-34,7%	0,0%	0,0%	0,0%	-12,9%	0,1%	0,4%	0,3%	0,0%	0,2%
Fruits - Processed	-24,4%	0,0%	0,0%	0,0%	-7,7%	0,1%	0,4%	0,1%	0,0%	33,8%
F & V juices	-16,5%	0,0%	0,0%	0,0%	-2,2%	0,3%	0,6%	0,4%	0,0%	5,9%
Vegetables - Fresh	-34,0%	0,0%	0,0%	0,0%	-11,5%	3,0%	1,4%	1,0%	0,0%	0,0%
Vegetables - Processed	-22,7%	0,0%	0,0%	0,0%	-16,5%	9,9%	1,3%	1,0%	0,0%	0,4%
Fruits - Dry	-6,5%	0,0%	0,0%	0,0%	-10,8%	0,9%	11,3%	6,1%	0,0%	0,2%
Milk products	0,0%	0,0%	0,0%	0,0%	-0,8%	3,1%	4,4%	10,8%	1,4%	7,6%
Cheeses, butters, fresh creams	0,0%	0,0%	0,0%	0,0%	-0,1%	6,6%	20,3%	54,4%	6,3%	0,0%
Ready meals	-3,3%	0,0%	0,0%	0,0%	-3,6%	6,6%	4,9%	7,1%	2,1%	0,4%
Oil, margarine, condiments	0,0%	0,0%	0,0%	0,0%	-0,1%	11,0%	99,5%	64,2%	0,3%	0,0%
Salt-fat products	0,0%	5,1%	0,0%	0,0%	-5,8%	28,7%	9,0%	10,8%	1,1%	1,1%
Sugar-fat products	-1,4%	0,0%	19,8%	0,0%	-3,7%	2,3%	7,1%	13,9%	2,9%	24,6%
Soft drinks	0,0%	0,0%	0,0%	5,4%	-0,7%	0,5%	0,4%	0,6%	0,0%	41,5%
Water	0,0%	0,0%	0,0%	0,0%	0,0%	1,4%	0,0%	0,0%	0,0%	0,0%
Alcoholic beverages	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%	0,0%	0,0%	0,0%	1,0%

Table 2 : Relative difference between shadow and actual price of each food aggregate ("Lower-average" consumer type).

Focusing on the F&V constraint, we note that the shadow prices of all the food products containing fruits or vegetables are lower than actual prices in order to encourage greater consumption, as expected. However, the table also reveals that the relative differences between shadow and actual prices are large for several product categories. Further, that difference varies greatly across the categories of products containing fruits and vegetables, from -1% for sugar-fat products (mainly containing some dry fruits) to -35% for fresh fruits. From the theory section, we know that, for a given consumer, the shadow price of a product is a function of: a) the cost of the constraint μ_1 in equation (3), which depends itself on substitution possibilities and other characteristics of food preferences; b) the F&V content of the product; and c) its actual price. The difference between shadow and actual prices is then greater for fresh produce, which account for more than 70% of F&V consumption (see Table 1), than for processed F&V whose price is higher. It is relatively smaller for ready meals as their content in F&V is low.

For the other three food-based recommendations, only the shadow price of the target food group deviates from actual prices, but the positive difference, which corresponds to an implicit tax, is much larger in the case of the constraint imposed on sugar-fat products than on either salt-fat products or soft drinks. This is mainly because the own-price elasticity of sugar-fat products is lower than the own-price elasticity of salt-fat products and soft drinks. For the remaining six nutrient-based recommendations, the shadow prices of a large number of product groups differ from actual prices, simply indicating that those nutrients originate from a wide range of foods. For all six constraints, we observe that some of the differences are large (i.e., at least 20%) for several product categories, which suggests that part of the substitutions required to satisfy the constraint are relatively difficult. The large differences between shadow and actual prices make intuitive sense: for instance, the constraints on saturated fat and total fat implies a large shadow price of the oil group, the cholesterol constraint is associated with a high shadow price of eggs, and that on added sugar with a high shadow price of soft drinks.

The welfare cost of satisfying the different constraints are measured by the compensating variations reported in Figure 1 as a share of the food budget for each of the four consumer types. In a first step, we ignore distributional aspects focusing only on the "lower average" type. It is apparent that the welfare costs are modest, varying from half a percent of the food budget in the case of the F&V constraint to a near negligible percentage for the constraints imposed on the consumption of soft drinks and salt-fat products. However, before concluding to the insignificance of taste costs, one should keep in mind that the 5% variations in the levels of the constraints are also small. Further, the relative magnitudes of the CVs match the levels of dietary adjustments described in Table 1 and the differences between shadow and actual prices described in Table 2. Hence, the relatively large CV for the F&V constraint is associated with large consumption changes and relatively large differences between actual and shadow prices, while the opposite is true for the constraint imposed on salt-fat products.

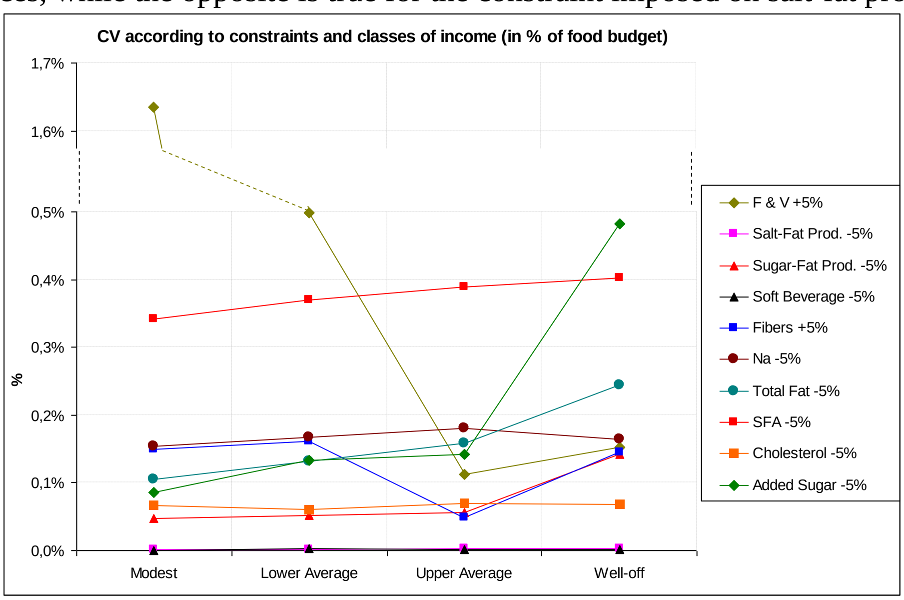

Figure 1: CVs of all ten nutritional constraints, for each type of consumer.

The equity effects of the nutritional recommendations are evaluated by comparing the CVs for each constraint across the four consumer types (Figure 1). Those effects can be significant, although no general pattern emerges. The constraint on F&V consumption is regressive, as it imposes a welfare loss exceeding 1.6% of their food budget on "modest" consumers, while the corresponding figure for the "well-off" is less than 0.2%. Other recommendations are progressive, most notably that relating to consumption of added sugar, and some recommendations (e.g., cholesterol) appear neutral from an equity point of view. Those CVs represent the economic component of the equity effect of the recommendations, which will have to be weighed against their health effects for a full assessment.

The analysis of health impacts starts by converting the consumption changes described in Table 1 into the 10 nutritionally-relevant inputs of the DIETRON model. The results, not reported for lack of space, indicate that imposition of the constraints induce substantial but complex adjustments in the nutritional profile of the diet, with an ambiguous overall effect on dietary quality. For instance, while imposition of the F&V constraint results in nutritionally-desirable decreases in consumption of salt, cholesterol, saturated fat, and energy, it also affects some dietary dimensions adversely (e.g., consumption of fibers shrinks and that of total fat rises). Further, in some cases the undesirable and unintended nutritional effects of the recommendations appear large, as with the fibers constraint which induces substantial increases in consumption of salt and calories (+3.3% and +1.8% respectively), as well as a reduction in consumption of F&V. For virtually all the constraints, some nutritional trade-offs are apparent, which justifies pursuing the assessment of health impacts by applying DIETRON to estimate the health outcomes of the simulated dietary changes.

	F & V	Salt-Fat Prod.	Sugar-Fat Prod.	Soft Beverage	Fibers	Na	Total Fat	SFA	Chole sterol	Added Sugar
DA for DIETRON diseases										
CHD	865	38	99	34	-1 045	952	532	994	56	411
Stroke	398	20	31	20	-562	504	96	231	-24	147
M/L/P cancer	323	14	-70	10	13	112	93	339	100	-28
Oesophagus cancer	398	16	13	21	-543	471	126	265	-6	145
Lung cancer	29	2	-31	9	0	11	-99	-134	-19	24
Stomach cancer	88	8	4	4	-102	114	3	51	-8	19
Pancreas cancer	118	4	22	5	-224	176	74	111	-10	60
Colorectum cancer	199	7	37	8	-377	296	125	187	-17	101
Breast cancer	-183	-4	-42	-5	337	-266	-160	-219	20	-101
Endometrial cancer	175	4	40	5	-321	253	154	210	-19	97
Kidney cancer	95	3	17	4	-180	142	57	86	-8	47
Gallbladder cancer	8	0	2	0	-15	11	6	8	-1	4
Total DA	2 513	112	123	117	-3 018	2 777	1 008	2 129	64	926
%	3,81%	0,17%	0,19%	0,18%	-4,58%	4,21%	1,53%	3,23%	0,10%	1,41%
% Net of Energy effect	1,20%	0,07%	-0,26%	0,05%	0,50%	0,32%	0,14%	1,02%	0,30%	0,13%
CV (€ 2006 / year)	12,56	0,05	1,47	0,03	2,60	3,45	3,23	7,78	1,37	4,10
Consumer Cost per DA (K€ 2006)	185	15	442	10		46	119	136	789	164
Δ Health Disparity Index*	-0,021	0,000	0,002	0,000		0,003	0,010	0,008	0,002	0,015

* Health Disparity Index = %death("Modest") / (100 - %death("Modest") over %death("Well-off") / (100 - %death("Well-off")

A decrease in this index means a reduction in the health disparities between the two populations.

Table 3: Population-level health, welfare, efficiency, and equity effects of the nutritional constraints.

Table 3 first presents the simulated health effect of the imposition of each constraint expressed as a number of deaths avoided (DA) due to the reduced incidence of coronary heart disease (CHD), strokes, and ten different types of cancer. Some of those effects are rather large: the salt constraint is estimated to save almost 2800 lives annually, while compliance with the F&V or saturated fat constraints would save more than 2000 lives annually. This represents in each case a three to four percent decrease in the total mortality attributable to the diseases included in the DIETRON model, which can be considered substantial given the relatively small changes that are imposed exogenously. However, the other seven constraints are also revealed to be much less effective in reducing mortality. The dietary recommendations targeting added sugar and total fat would save around 1000 lives each, while for the remaining constraints the gains would be of the order of 100 lives, with the exception of the fiber constraint, which is simulated to actually *increase* mortality considerably. This demonstrates the significance, from a health point of view, of the complex substitutions and associated changes in overall diet quality that the microeconomic model captures.

The row of Table 3 with the heading "% net of energy effect" gives the percentage of deaths avoided considering only the changes in dietary quality induced by each recommendation, while holding total calories constant. It is evident that changes in energy associated with the adoption of the constraints account for the bulk of the variation in mortality, except in the case of the cholesterol constraint. For instance, in the case of the recommendation on F&V, the change in dietary quality accounts for a 1.20% drop in mortality, while the reduction in calories accounts for the remaining 2.61% drop in mortality (i.e., 3.81%-1.20%). The effects of variations in calories are particularly large for the fat constraint, which is consistent with the view that the high fat content and energy density of foods are factors contributing positively to total calorific intake. In a similar vein, the results indicate that the main health benefit from a diet rich in F&V derives indirectly from a reduction in the size of the diet, as measured by calories, rather than a direct improvement in dietary quality.

We now bring together the economic assessment of welfare effects and epidemiological assessment of health effects in order to compare the dietary recommendations in terms of efficiency and equity. The number of deaths avoided is first expressed, for each recommendation, relative to the welfare cost imposed on consumers in Table 3.[13] Even after excluding the fibers constraint, which increases mortality, it is evident that this first measure of cost-effectiveness of the ten recommendations varies enormously, and that the most effective recommendations are not necessarily those that save the most lives. The most cost-effective recommendation pertains to soft drinks, with a welfare cost per avoided death of only €10k. This high level of cost-effectiveness is attributable to the particularly small taste cost of the recommendation, which is understandable given the minor dietary adjustments and associated changes in shadow prices that we already documented for that constraint. The recommendation to reduce consumption of salt-fat products also shows a high level of cost effectiveness (€15k/DA). The constraint on salt imposes a significantly larger welfare cost per death avoided (€46k/DA), but it is also the most cost-effective of all the recommendations with large health effects (i.e., saving thousands of lives annually).

Overall cost-effectiveness of health interventions is frequently assessed in term of the cost per Quality Adjusted Life Year (QALY) gained. For instance, the National Institute of Health and Care Excellence in the UK considers that the cost of a QALY should not exceed £20-30k (i.e., €24-36k).[14] On the conservative basis of 10 QALY per DA, the threshold per DA thus amounts to € 240-360k. Against this yard stick, our results indicate that the taste costs of nutritional recommendations can be substantial – for instance, in the case of the F&V constraint, those costs amount to €185k/DA. Yet, even using the lowest estimate of the value of a DA (€240k), the simulations suggest that a public intervention (e.g. information campaign) with an annual budget worth up to €137 million would be cost effective provided that it achieved the target 5% increase in consumption of fruits and vegetables.[15] Although we do not tackle the issue of campaign effectiveness here, this does not seem to be an unrealistic objective. Comparable calculations in Table 4 give threshold values of the annual cost of interventions to reduce consumption of salt, saturated fat, fat, added sugar, soft drinks and salt-fat products ranging from €538 million to €25 million. Those figures represent considerable annual amounts that point to the cost effectiveness of all those measures. On the other hand, application of a similar logic lead to the conclusion that the recommendations targeting sugar-fat products, cholesterol and, of course, fibers would not be cost effective.

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[13] This first assessment is only partial in the sense that we do not take into account the cost of promoting the recommendations through public health campaigns, nutritional education etc. We return to this issue in the next paragraph.

[14] http://www.nice.org.uk/newsroom/features/measuringeffectivenessandcosteffectivenesstheqaly.jsp

[15] The threshold cost of the intervention is calculated as (240-185)*2513 DA.

The threshold value of the annual cost of intervention is strongly correlated with the number of DA and much less with the cost/DA. Using this threshold value as the key criterion to rank the alternatives (lower part of Table 4), five recommendations seem particularly attractive: four are nutrient- based (salt, SFA, total fat, and added sugar) and one is food-based (F&V). The four nutrient-based recommendations reduce the health inequality index whereas the food-based recommendation increases it.

	F & V	Salt-Fat Prod.	Sugar-Fat Prod.	Soft Beverage	Fibers	Na	Total Fat	SFA	Chole sterol	Added Sugar
DA	2 513	112	123	117	-3 018	2 777	1 008	2 129	64	926
Consumer Cost per DA (K€)	185	15	442	10		46	119	136	789	164
Max Campaign (M€)	137	25	-25	27		538	122	222	-35	70
Δ Health Disparity Index	-0,021	0,000	0,002	0,000		0,003	0,010	0,008	0,002	0,015
Ranking										
DA	2	8	6	7	10	1	4	3	9	5
Consumer Cost per DA (K€)	7	2	8	1		3	4	5	9	6
Max Campaign (M€)	3	7	8	6		1	4	2	9	5
Δ Health Disparity Index	1	2	5	3		6	8	7	4	9

Table 4: Final comparison of the constraints based on their health, efficiency and equity effects.

Conclusion

Given the growing evidence that food choices have a profound impact on human health, consumers are increasingly urged to modify the foods and nutrients that they purchase and eat. However, designing nutritional policies is difficult because adjustments in one part of the diet have potential consequences for other parts of the diet, as foods are interrelated *via* complex relationships of substitutability and complementarity. We analyzed this problem by developing a whole-diet model that can be used to simulate how all food choices change when consumers are urged to comply with dietary norms. By extending the theory of the consumer under rationing, we show that adjustments in consumption can be estimated by combining data on food consumption, price and expenditure elasticities, as well as food composition data. We demonstrate the practicality of the approach by investigating how food consumption, economic welfare, and health outcomes would respond if French consumers adopted food-based or nutrient-based recommendations.

Despite some inevitable limitations of the approach, the results generate important insights. Most of the nutritional recommendations currently promoted by public health experts are likely to be highly cost-effective, but our analysis concludes that targeting reductions in salt and SFA intakes, as well as an increase in F&V consumption, represent particularly attractive options. On the other hand, inciting consumers to increase their intakes of fibers is unlikely to be socially desirable because of large unintended adjustments in other dimensions of the diet. Further, our analysis suggests that promoting a reduction in consumption of soft drinks is unlikely to generate large health benefits, although this is probably due to the specific structure of the French diet (i.e., relatively small share of soft drinks in total energy in the first place) and cannot be generalized to countries with very different dietary habits (e.g., UK).

There are many directions in which the analysis presented in the paper can be developed. Extending the theoretical and empirical models to include several simultaneous constraints would bring more realism to the approach and could also help design optimal taxes for the pursuit of multidimensional goals. At another level, the model could also be used to infer consumers' willingness to pay for food products with modified nutritional properties.

Finally, it is worth stressing that the approach has relevance beyond the scope of nutritional policy. For instance, assessing the consequences in terms of greenhouse gas emissions of urging individuals to reduce their consumption of animal products requires a clear understanding of how whole diets might respond to the policy. In a similar vein, development of an integrated food policy requires that the consequences of healthy-eating policies be known all the way down to the farm level, and the proposed methodology provides a solid starting point for that type of inquiry.

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