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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 contents of foods. A calibration exercise simulates, for different income groups, how the French diet would respond to various nutrition recommendations, and those behavioural adjustments are translated into health outcomes through the DIETRON epidemiological model. This allows for the ex-ante comparison of the efficiency, equity and health effects of ten nutritional recommendations. Although most recommendations impose significant taste costs on consumers, they are highly cost-effective, with the recommendations targeting salt, saturated fat, and fruits and vegetables (F&V) ranking highest in terms of efficiency. A five percent change in consumption of any of those nutrients or food would reduce premature mortality in excess of 2100 lives annually. By contrast, urging consumers to modify their consumption of fibers, sugar-fat products and dietary cholesterol is unlikely to be socially desirable, often due to large unintended adjustments in some dimensions of dietary quality. Most recommendations are economically progressive, with the exception of that targeting F&V.

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

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Economic assessment of nutritional recommendations

1. 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 World Health Organization (WHO)/ Food and Agriculture Organization (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).

Nutritional recommendations can take different forms depending on whether the message involves nutrient intake goals or food-based guidelines. Some messages are usually formulated in terms of nutrients that can be found in a large number of foods across product groups. For instance the UK Food Standards Agency ran a campaign to encourage consumers to reduce salt intakes (Marshall et al., 2007). Given that three quarters of that salt is already present in the foods that consumers buy rather than added at home, and that a large number of foods contains significant quantities of salt, the campaign has implications for virtually all product groups. Other messages are also formulated in many countries to favour, for instance, a decrease in saturated fatty acids (Mason et al., 2009) and free sugar intakes.

National and international health promoting agencies have also developed food-based nutritional guidelines because diets are made of foods which are more than mere collections of nutrients, and consumers may have difficulties to put in practice nutrient-based recommendations. The WHO also justified food-based guidelines with the robust evidence from clinical and epidemiological studies that some dietary patterns are associated with reduced risks of specific diseases (WHO, 1996). One of the most frequent messages promoted by health agencies aims at encouraging individuals to consume more fruit and vegetables (F&V), as illustrated by the ‘5-a-day’ campaigns to promote the consumption of at least five portions of fruits and vegetables per day (Cappacci and Mazzocchi, 2011). Starchy foods and milky products are other food groups whose consumption is often promoted by public health experts (Mancino et al., 2008), whereas some of them have recommended a decrease in consumption of soft drinks (Jou and Techakehakij, 2012) or some types of meat.

General information campaigns, nutrition education and other interventions targeting at-risk categories of the populations aim at promoting knowledge of these guidelines thereby inducing dietary changes. Consumers are then supposed to make food choices and adapt their diets while complying with a whole range of nutritional norms. 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. This gap probably depends on the characteristics of the consumer with which food preferences vary systematically. Moreover, the benefits from complying might also differ among consumers. According to Etilé (2013, p. 56) the benefits increase with the level of education as future benefits and longevity increase with the level of education.

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, which are relatively more constrained by economic circumstances but also relatively more at risk of obesity and other chronic diseases? 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. But, 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. For instance, the 'healthy' diets (i.e., ones complying with a set of norms) hence calculated by Henson (1991) for the UK only involved four food items, and had a total cost equal to barely 20% of the observed average cost of the UK diet. The comparable results for Italy as calculated by Conforti and d'Amicis (2000) are of a diet composed of eight food items with a cost worth only 30% of that of the average diet. Those results are not surprising given that the enjoyment derived from food consumption transcends the satisfaction of purely nutritional needs, so that nutrition-led models produce diets that are not compatible with the nature of consumer preferences. This has been recognized and LP models have been modified accordingly through the addition of palatability constraints. However, in order for such models to produce realistic diets, a considerable number of constraints needs to be included - 52 in the case of Henson (1991). Given that those additions seem rather arbitrary, LP models tend to produce results that are highly subjective and largely driven by assumptions[1]. More recently, LP models have been used by nutritionists to determine optimal diets complying with nutritional or environmental recommendations (Darmon et al., 2006; Maillot et al., 2010; Macdiarmid et al., 2012). 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, 2003; Srinivasan et al., 2006; Shankar et al., 2008; 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, nutrient and energy intakes (see Thow et al. 2010, Etilé, 2011, and Eyles et al. 2012 for recent reviews). These studies typically estimate price elasticities from demand curves, which are conceptually

[1] To illustrate this arbitrariness with reference to the same examples, Henson (1991) introduces a constraint to impose the complementarity of flour and fats, but one could equally argue that meats and starches are complements. Meanwhile, Conforti and D'Amicis (2000) introduce even more stringent constraints that impose, for instance, 'that the total amount of pork meat that enters the solution must be a given proportion of the total amount of meat'. The arbitrariness underlying the models is also apparent in the fact that the constraints vary widely across studies. The suspicion therefore lingers that particular constraints are introduced in response to unsatisfactory model results (i.e. results judged unrealistic by the researcher), which leads to the idea that the final results are indeed assumption driven. Stigler (1945) makes a similar point with reference to the minimum cost diets calculated by dieticians, as illustrated by the following quote (p. 314): '…the particular judgments of the dieticians as to minimum palatability, variety, and prestige are at present highly personal and non-scientific, and should not be presented in the guise of being parts of a scientifically-determined budget'.

derived from constrained utility maximization, given prices and a budget constraint. Then using nutrient and energy conversion matrices, it is easy to evaluate the impact of price policies on nutrient and energy intakes of consumers.[2]

This kind of research has been based on incomplete food demand systems (e.g., LaFrance and Hanemann, 1989, Chouinard et al., 2007, Bertail and Caillavet, 2008, Nordström and Thunström, 2009) thus restricting the analysis of substitutions and complementarities to a subset of products. However, some contributions have estimated complete food demand systems (Smed et al., 2007, Allais et al. 2010), which allows consideration of a large set of interdependent demand relationships. Such methods can support the simulation of impacts of price policies, taxes or subsidies, on food consumption and nutrient intakes. However, compliance with food-based or nutrient-based recommendations can only be assessed ex-post rather than introduced as constraints in order to determine the price modifications needed to comply with these constraints. Hence, it is not clear how this framework can be extended to analyse how 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.

The solution to that seemingly simple problem has far-ranging and policy-relevant implications. It can allow us to assess the difficulty of achieving a given norm by identifying the magnitude and nature of the required substitutions in consumption. It also provides the basis for

[2] In some cases, an health impact is estimated from the change in food, nutrient or energy intake. This allows estimation of the cost effectiveness of the policy (e.g. Cash et al., 2005, Mouzon (de) et al. 2012).

measuring the "taste cost" of complying with a particular nutritional norm, which can then be used in conventional cost-benefit analysis. This is important because, as shown clearly by Votruba (2010) for the case of a ban on trans fats, the social desirability of a nutritional policy often hinges on the magnitude of those (typically unknown) taste costs. Further, by anticipating the full change in diet implied by a norm, it permits an assessment of the effectiveness of the policy in improving diet quality and health outcomes. Finally, the model identifies the optimal set of taxes that should be applied to foods, together with appropriate income transfers, in order to achieve a given nutritional objective.

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 nutrient intakes (and then finally, on compliance with nutritional recommendations), we consider in this paper 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.

Section 2 presents the theoretical model. In section 3, we present the data and empirical methods used to simulate the impact of various nutritional recommendations on diets, welfare and health. Section 4 summarises the empirical results for ten recommendations. Section 5 concludes the paper.

2. A rational 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.[3] 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.[4] The constraints could also correspond to food-based constraints (such as recommendations on consumption of fruit and vegetables or starchy products).[5] The nutritional constraints are expressed by:

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

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

[3] The results can be generalised to minimum constraints without difficulty.
[4] Nutritionists (e.g., Drewnowski and Darmon, 2005) also base their analysis on this linearity assumption (which also implies that there are no interactions between food items).
[5] 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).

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* x *H)* matrix of nutritional coefficients, and *r* the *N*-vector of maximum nutrient amounts. By definition of the vector of shadow prices $\tilde{p}$, the following equality holds:

$$\tilde{h}_i(p,U,A,r) = h_i(\tilde{p},U) \tag{2}$$

The minimum-expenditure function of the nutritionally-constrained problem $\tilde{C}(p,U,A,r)$ can be related to the ordinary expenditure function $C(p,U)$ through the following steps, using equation (2):

$$\begin{aligned}\tilde{C}(p,U,A,r) &= \sum_{j=1}^{H} p_j \tilde{h}_j(p,U,A,r) \\ &= \sum_{j=1}^{H} \tilde{p}_j h_j(\tilde{p},U) + \sum_{j=1}^{H}(p_j - \tilde{p}_j)h_j(\tilde{p},U) \\ &= C(\tilde{p},U) + \sum_{j=1}^{H}(p_j - \tilde{p}_j)h_j(\tilde{p},U)\end{aligned} \tag{3}$$

From equations (2) and (3), 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 nutritional constraints - or what Jackson (1991) calls the virtual price problem:

$$\underset{p}{Min}\ \tilde{C}(p,U,A,r)\ subject\ to\ (1) \tag{4}$$

Using the last equality in (3) relating constrained and unconstrained expenditure functions, the Lagrangian of the virtual price problem is:

$$L = C(\tilde{p},U) + \sum_{j=1}^{H}(p_j - \tilde{p}_j)h_j + \sum_{n=1}^{N}\mu_n(r_n - \sum_{j=1}^{H} a_j^n h_j) \tag{5}$$

with μ_n the Lagrange multiplier associated with the n^{th} nutritional constraint. Assuming non-satiation so that all virtual prices are strictly positive, the Kuhn-Tucker conditions are:

$$
\begin{aligned}
&\frac{\partial C}{\partial \tilde{p}_i} - h_i + \sum_{j=1}^{H}(p_j - \tilde{p}_j)\frac{\partial h_j}{\partial \tilde{p}_i} - \sum_{n=1}^{N}\mu_n \sum_{j=1}^{H} a_j^n \frac{\partial h_j}{\partial \tilde{p}_i} = 0 \qquad i = 1,\dots,H \\
&\mu_n (r^n - \sum_{j=1}^{H} a_j^n h_j) = 0 \qquad n = 1,\dots,N \\
&\mu_n \geq 0, \qquad n = 1,\dots,N
\end{aligned} \tag{6}
$$

Using Shephard's lemma, and denoting by s_{ij} the Slutsky term $\partial h_i / \partial p_j$, the first equation in (6) becomes:

$$
\sum_{j=1}^{H}\left[(p_j - \tilde{p}_j) - \sum_{n=1}^{N}\mu_n a_j^n\right] s_{ji} = 0 \qquad i = 1,\dots,H \tag{7}
$$

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:

$$
\begin{aligned}
&\tilde{p}_i = p_i - \sum_{n=1}^{N}\mu_n a_i^n \qquad i = 1,\dots,H \\
&\sum_{i=1}^{H} a_i^n h_i(\tilde{p}, U) = r_n \qquad n = 1,\dots,N
\end{aligned} \tag{8}
$$

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.[6] In general, system (8) 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. In this case (where N=1) the system simplifies to:

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

$$\tilde{p}_i = p_i - \mu_1 a_i^1 \qquad i = 1,...,H$$
$$\sum_{i=1}^{H} a_i^1 h_i(\tilde{p}, U) = r_1 \tag{9}$$

The first set of equations implies that deviations between shadow prices and market prices are proportional to the nutritional coefficients of the goods entering the single nutritional constraint. The second equation simply states that the nutritional constraint is binding. The first set of equations can be used to express all prices in terms of p_H:

$$\tilde{p}_i = p_i - (p_H - \tilde{p}_H)\frac{a_i^1}{a_H^1} \qquad i = 1,....,H-1 \tag{10}$$

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:

$$\frac{\partial \tilde{p}_i}{\partial r_1} = \frac{a_i^1}{a_H^1}\frac{\partial \tilde{p}_H}{\partial r_1} \qquad i = 1,....,H-1 \tag{11}$$

Totally differentiating the nutritional constraint expressed as in (9) and using (11), one obtains:

$$\sum_{i=1}^{H} a_i^1 \sum_{j=1}^{H} s_{ij} \frac{a_j^1}{a_H^1}\frac{\partial \tilde{p}_H}{\partial r_1} = 1 \Rightarrow \frac{\partial \tilde{p}_H}{\partial r_1} = \frac{a_H^1}{\sum_{i=1}^{H}\sum_{j=1}^{H} s_{ij} a_i^1 a_j^1} \tag{12}$$

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 (11) gives the corresponding *H-1* shadow price changes:

$$\frac{\partial \tilde{p}_i}{\partial r_1} = \frac{a_i^1}{\sum_{i=1}^{H}\sum_{j=1}^{H} s_{ij} a_i^1 a_j^1} \qquad i = 1,....H \tag{13}$$

As for product *H*, the response of the shadow price of a product *k* to a change in the level of the nutritional constraint is proportional to the nutritional content of product *k*. From which follows the change in demand for any of the *H* goods:

$$\frac{\partial \tilde{h}_k}{\partial r_1} = \frac{\sum_{i=1}^{H} s_{ki} a_i^1}{\sum_{i=1}^{H} \sum_{j=1}^{H} s_{ij} a_i^1 a_j^1} \qquad k = 1,....H \qquad (14)$$

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 (14) 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 (14) 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 price elasticity describing the behaviour of an unconstrained individual, equation (14) provides a means of inferring how that individual would modify his diet in order to comply with the nutritional norm (e.g., how his/her consumption of any food would respond to, for instance, a reduction in his/her intake of saturated fat). It should be understood that the changes in the diet are evaluated according to Hicksian demand functions which are constructed assuming that the utility of the consumer remains constant.

The welfare cost of satisfying nutritional constraints can be evaluated by the compensating variation CV. By definition, the compensating variation is the difference between the initial expenditure (more generally the initial wealth) and the expenditure that maintains the utility constant in the nutritionally-constrained problem. Note that in the nutritionally-constrained problem, final expenditure is evaluated at market prices (as prices do not change). The compensating variation is thus a measure of the taste cost of the nutritional constraint. We have $CV = C(p,U) - \tilde{C}(p,U,A,r)$. Using (3), the CV associated to a (marginal) variation of the constraint is written as:

$$CV = -\sum_{i=1}^{H} p_i \frac{\partial \tilde{h}_i}{\partial r_1} \qquad (15)$$

A change in the constraint Δr_1 induces a change in the (vector of) compensated demands Δh and, from (15), we have the associated compensating variation CV=-p. Δh. Those changes are estimated in the compensated framework, that is, assuming the utility of the consumer remains constant. To evaluate the change in consumption in a Marshallian context (denoted Δx), that is without maintaining a constant level of utility (but rather for a given budget constraint), we apply the following formula:

$$\Delta x = \Delta h + \tilde{h}.\varepsilon^R \frac{CV}{p.\tilde{h}} \qquad (16)$$

with ε^R denoting the income (or expenditure) elasticity.

Assessing the impact on health of changes in diet

We use (16) to evaluate the impact of a nutritional recommendation on food consumption and derive the impact on nutrient consumption by using the left hand side of (1). To go a step further we need to assess the impact on health of such changes. Rather than evaluating the impact on diet quality (through an indicator of quality such as the Healthy Eating Index (Guenther et al. 2012), we use an epidemiological model (DIETRON model) that links changes in intakes of foods and nutrients to changes in adverse health outcomes (Scarborough, Nnoaham et al. 2012, and Scarborough, Allender et al. (2012)).[7] A full description of the development, parameterisation and assumptions supporting the DIETRON model is available in Scarborough et al. 2011.

3. Data and empirical procedure

The model presented in the previous section is applied to estimate the variation in household consumption induced by the adoption of nutritional and dietary recommendation (e.g. increase consumption of F&V by 5%, decrease salt consumption by 5%, etc.) for different representative households. In a second step, this variation in household consumption is translated into changes in individual food and nutrient intakes. The health effects are then assessed by using the DIETRON model, which allows estimation of the mortality attributable to a set of diet-related diseases within the population. Below, we describe the sets of data and parameters used at each step as well as the empirical procedure used to simulate the adoption of various nutritional recommendations.

Food groups, household types and demand elasticities

Data on purchases and prices as well as estimates of demand elasticities are derived from the work of Allais et al. (2010) who estimated a complete food demand system for four French household income quartiles. The original data set is based on records of a French representative consumer panel of 19,000 households collected by KANTAR Worldpanel. It is a home-scan data set providing detailed information on all purchases of food products. Among other things, the

[7] This approach is similar to the one developed by Mouzon (de) et al. (2011) in a simplified framework (one good case) but extends it to the multiple good case.

data set provides characteristics of the good (brand, size, regular or diet product), quantity purchased, and related expenditure. The data set also provides information on each household's socio-economic characteristics, such as its demographic composition, socio-economic status and income class. Household consumption is aggregated into 22 food categories. Four household types based on income levels per unit of consumption, are considered in the analysis and henceforth referred to as: "Modest", "Lower average", "Upper average", and "Well-off". The food categories as well as the price and expenditure elasticities by household type which we used to calibrate our model are given in Allais et al. (2010, supplementary material).[8]

From household food consumption to adult individual intakes

To determine, for each of the four representative household types, intake variations at the individual level associated with the household's change in food consumption induced by compliance with a given recommendation, we assume that (i) the percentage changes in intakes are the same for all the members of a given household, and (ii) the percentage changes are the same for at-home and out-of-home consumption[9].

Assessment of nutrient contents

The nutritional contents of the 22 food categories are calculated using the food composition database associated with the INCA2 survey, which is a cross-sectional national survey carried out in 2006-2007 by the ANSES (French agency for food, environmental and occupational health

[8] http://ajae.oxfordjournals.org/content/suppl/2010/01/23/aap004.DC1/aap004supp.pdf
[9] The INCA2 database covers all the foods consumed by an individual whereas the Kantar database only covers at-home consumption.

safety)[10]. The ANSES database includes 1343 food products. The nutritional content of each of the 22 food categories is determined on the basis of the average consumption of a French adult as estimated in the INCA2 survey.[11] Recipes and edible parts for each food category are defined on that basis and used to formalize the nutritional constraints.

These nutritional coefficients are also used to determine the nutritional content of the consumption patterns observed at the baseline and after adoption of the recommendations as expressed by the left hand side of equation (1). The matrix of nutritional content of the 22 food groups is provided in the appendix (Table A.1).

Simulation procedure

We consider both nutrient-based and food-based dietary recommendations. We are looking for the impact of the recommendations in a Marshallian context. To do so we develop an iterative procedure based on (14) to (16). Given a specific recommendation, we first calculate the changes in Hicksian demand (14) induced by the adoption of that recommendation, hence assuming that the utility of the consumer remains constant. The quantities thus obtained and associated compensating variations (15) are then combined to calculate the changes in Marshallian demand (16). Next, we assess the compliance of this Marshallian solution with the targeted recommendation. If the consumption pattern is compliant, the computation is over. If not, we go back to the first step and calculate the impact of a revised norm in the Hicksian framework. The iterative process finishes when the Marshallian solution satisfies the constraint.

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

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

Assessment of health impacts

To assess the health impacts of consumption changes induced by the adoption of nutritional recommendations, we use the DIETRON model which evaluates the impact of changes in diets on mortality due to diet-related chronic diseases. As explained by Scarborough, Allender et al. (2012, p. 711): 'the DIETRON model uses age- and sex-specific estimates of relative risk drawn from meta-analyses of trials, cohort studies and case–control studies, to estimate the impact on chronic disease mortality of counterfactual population dietary scenarios'.

We use the INCA2 database to determine the baseline individual intakes for any of the 22 food aggregates and each of the now eight types of adult consumers (i.e., males and females in each of the four income categories, as DIETRON is sex-specific – see Table 1). Then we compute the absolute variation in individual intakes by applying to baseline intakes for the eight types of consumers the relative changes in consumption obtained from the economic model. Those absolute changes in food intakes are translated, using the matrix of nutritional contents for each type of adult consumer, into variations in nutrient intakes, which are needed for the evaluation of health effects by the DIETRON model[12]. The dietary input data for the health model are intakes of: total energy (MJ/day); fruit (g/day); vegetables (g/day); fibers (g/day); total fat (% total energy); mono unsaturated fatty acids (% total energy); polyunsaturated fatty acids (% total energy); saturated fatty acids (% total energy); dietary cholesterol (% total energy); salt (g/day) (Scarborough, Allender et al., 2012).

[Table 1 here]

[12] The DIETRON model takes into account the level of physical activity. We also consider this dimension in the computations but we assume that it is the same for all the types of consumers and it does not change when a nutritional recommendation is adopted. It also takes into account trans fats, but the INCA2 food database has no data for this nutrient.

Adapting the DIETRON model to France requires data on the numbers of deaths in France and their causes.[13] We mainly use data from INSERM on total mortality in France from the major diet-related diseases: ten types of cancers, strokes and CHD (Coronary Heart Disease). As it is not possible to get directly the mortality data for each income class, we determine the baseline number of deaths for each income class and each type of disease by relying on the Relative Inequality Index (RII) estimated by Saurel-Cubizolles et al. (2006). We limit the study to individuals between the age of 25 and 74 because the RII values are only available for this period of life. It means that our analysis focuses on the effects of consumption changes on premature deaths (i.e., occurring before the age of 75) rather than on total deaths in the French population. The baseline number of deaths according to each disease and each income class is given in Table 2, which shows that the diseases considered in DIETRON account for a bit more than one third of total French mortality. Large inequalities in health outcomes are also evident when comparing the mortality rates across income classes, which provides a strong justification for pursuing the analysis of equity effects of nutritional recommendations in the results section below.

[Table 2 here]

4. 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 baseline level, and the direction is chosen so as to increase dietary quality (i.e., to reduce the maximum permissible level of

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

relatively unhealthy nutrients/foods and increase the minimum permissible level of relatively healthy ones).

We consider 10 nutritional constraints, of which six are nutrient-based and four are food-based. We choose constraints which are frequently targeted in public health recommendations (WHO, 2003; Nordic Council of Ministers, 2013). Thus it is recommended to decrease consumption of fats, added-sugars and salt and to increase consumption of fibers. This defines the six nutrient-based constraints (as we distinguish three cases for fat consumption: total fat, saturated fatty acids (SFA) and cholesterol). Because implementing nutrient-based recommendations is difficult, more recently health policies have focused more on food-based recommendations. We selected four of those: an increase in consumption of fruits and vegetables (F&V) as well as decreases in consumption of salt-fat products, sugar-fat products and soft drinks. The last three recommendations focus on selected nutrients (salt, fat and added sugar), whereas the first one does not target a specific nutrient.

We start with the impact of the different recommendations on food consumption, focusing on the “lower average” income group of households (Table 3). The corresponding results for the other three household types are presented in the Appendix, Tables A.2-A.4. Each column of Table 3 corresponds to a different constraint and presents two sets of percentages: the baseline 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. For the first four constraints, which are food-based, it follows by construction that most of the baseline level of the constraint is accounted for by a narrow range of food products, even if we note that 7% of F&V consumption originates from ready meals and sugar-fat products. By contrast, in the case of some nutrients such as sodium, the contributions of the different food groups to the baseline level of the constraint are much more spread out in product space.

Turning to the results of the simulations, and 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). As shown in Table 3, 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%).[14] Hence, the relations of complementarity and substitutability 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 3, we note that some complex substitutions also occur within product groups. For instance, within the animal products group,[15] 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, which imply a modification of the ratio of

[14] Note that the increase in consumption of the F&V 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 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.

[15] In the table, this group does not include dairy products.

fresh to processed products consumed within the F&V group. 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).

[Table 3 here]

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.

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 fibers 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 4 for the same "lower average" household 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 salt-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 (6), 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 3), 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 salt-fat products is lower than those 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 imply 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.

[Table 4 here]

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 by 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 – for instance, the increase in F&V consumption represents an increase in consumption of about a quarter of a portion daily. Further, the relative magnitudes of the CVs match the levels of dietary adjustments described in Table 3 and the differences between shadow and actual prices described in Table 4. 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.

A first category of equity effects of the nutritional recommendations is evaluated by comparing the CVs of the constraints 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 capture the hedonic or taste cost of healthier diets, and will have to be weighed against their health effects for a full assessment.

[Figure 1 here]

The analysis of health impacts starts by converting the consumption changes described in Table 3 into the ten nutritionally-relevant inputs of the DIETRON model. The results are illustrated with reference to one gender (men) and one income class (lower average) in Table 5. They indicate that imposition of the constraints induces substantial but complex adjustments in the nutritional profile of the diet, with an ambiguous overall effect on dietary quality. Hence, while imposition of the F&V constraint results in nutritionally-desirable decreases in consumption of salt, 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 (+0.6g/day and +0.51MJ/day respectively). 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.

[Table 5 here]

Table 6 presents the simulated health effects of the constraints expressed as a number of deaths avoided (DA) within the whole population due to the reduced incidence of 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 (i.e., 5% change in the constraint level). 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 fibers constraint, which is simulated to actually *increase* mortality considerably. This last result 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. In other words, an understanding of consumers' behavioural response to dietary recommendations is crucial to evaluate the associated health effects accurately.

[Table 6 here]

The row of Table 6 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.[16] 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 their efficiency and equity. A first partial indicator of efficiency is the number of deaths avoided expressed, for each recommendation, relative to the welfare cost imposed on consumers.[17] On that basis, and even after excluding the fibers constraint, which increases mortality, the results in Table 7 indicate that the 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

[16] This is not surprising given the increase in energy reported in Table 5 when the cholesterol constraint is applied. However, when interpreting the results, the reader should keep in mind that Tables 3-5 relate to only one type of households or consumers, while Table 6 presents results for the whole population.

[17] This 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 and other measures aimed at modifying consumer behaviour through the provision of information. We return to this point below.

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. In other words, the utility cost of reducing soft drink consumption is minimal, so that even if that reduction produces relatively limited health gains, its overall cost-effectiveness is very high. 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). The constraints on total fat, saturated fat, added sugar and F&V display relatively similar levels of cost effectiveness (i.e., €119-185k/DA), while the constraints on sugar-fat products and cholesterol are highly cost-ineffective.

The cost-effectiveness of health interventions and policies is frequently reported in terms of their cost per Quality Adjusted Life Year (QALY). 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).[18] On the conservative basis of 10 QALY per DA (epidemiological data showing that the average number of Life Years Saved (LYS) per DA is larger than 10 for most causes of mortality covered by DIETRON), the threshold per DA thus amounts to € 240-360k.

[Table 7 here]

Against this yardstick, our results indicate that the taste costs of nutritional recommendations, which are reproduced in summary Table 7, 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

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

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.[19] Although we do not tackle the issue of campaign effectiveness here, this does not seem to be an unrealistic objective. Comparable calculations, reported in Table 7 in the row entitled "Max campaign", 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 the measures.[20] On the other hand, application of a similar logic leads to the conclusion that the recommendations targeting sugar-fat products, cholesterol and, of course, fibers would not be cost effective.

As shown by the ranking of the different recommendations in Table 7, the threshold value of the annual cost of intervention is strongly correlated with the number of DA and much less with the cost per DA. Using this threshold value as the key criterion to rank the alternatives, five recommendations seem particularly attractive: four are nutrient- based (salt, SFA, total fat, and added sugar) and one is food-based (F&V). We now pursue the analysis of the equity impact of those five recommendations by first presenting in Figure 2 the distribution of their health benefits, measured as the share of mortality avoided, across the four income classes. From a health point of view, the F&V recommendation is clearly progressive, as the simulated changes imply a reduction of more than 5% in mortality attributable to diet-related diseases for the "modest" income category, while the corresponding figure is less than 3% for the "well-off". The other four recommendations are regressive from a health point of view, with the recommendation

[19] The threshold cost of the intervention is calculated as (240-185)*2513 DA.
[20] Those calculations remain partial in the sense that variations in demand are likely to affect prices and, hence, producers' surpluses. However, this type of general equilibrium effects falls outside the scope of our paper.

targeting added sugar standing out: the share of mortality avoided by this recommendation is three times larger for “well-off” individuals than for “modest” ones.

[Figure 2 here]

The economic and health dimensions of the equity effect of the recommendations, presented in Figures 1 and 2, are combined by calculating the consumer cost per DA for different income classes in Figure 3. On the basis of that indicator, it is the economic component that dominates the overall equity effect of the recommendations. For instance, although the F&V constraint is progressive from a health point of view (Figure 2) and regressive as far as taste costs are concerned (Figure 1), the overall effect is regressive (Figure 3): the welfare cost of a death avoided by complying with the recommendation is more than three times larger for “modest” individuals that for the “upper average” or “well-off”. Similarly, the added sugar recommendation, although regressive from a health point of view, is the most equitable recommendation overall.

[Figure 3 here]

5. 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 a food-based (e.g., “5-a-day”) or nutrient-based norm (e.g., reduce salt consumption). By extending the theory of the consumer under rationing, we showed that adjustments in consumption can be estimated by combining data on food consumption, price and expenditure elasticities, as well as food composition data. The welfare implications of the adjustment are then straightforward to calculate as a standard compensating variation. Further, we linked the dietary changes simulated by the economic model to the DIETRON epidemiological model to simulate the impact of the recommendations on premature mortality attributable to diet-related chronic diseases. We demonstrated 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.

The results support the ranking of the recommendations based on their relative health, efficiency, and equity effects. Many of the nutritional recommendations currently promoted by public health experts are shown to be highly cost-effective, but our analysis concludes that targeting reductions in consumption of salt and SFA, as well as an increase in F&V consumption, represent particularly attractive options from an efficiency point of view. Moreover, those options, even if they result only in modest (5%) changes in consumption of the targeted food or nutrient, are likely to prevent in excess of 2100 deaths annually, or 3-4% of the premature deaths attributable to the diseases included in DIETRON (i.e., strokes, CHD and ten types of diet-related cancers). On the other hand, inciting consumers to increase their consumption of fibers or reduce their consumption of sugar-fat products and dietary cholesterol is unlikely to be socially desirable. This is explained by substantial unintended negative adjustments in other dimensions of the diet that reduce the health effect of those recommendations (e.g., total energy increases as a result of the fibers constraint) and/or significant taste costs. Regarding the growing debate on the need to intervene to reduce consumption of soft drinks, our analysis suggests that such an intervention is unlikely to generate large 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 consequently cannot be generalized to countries with very different dietary habits (e.g., UK).

Our analysis also reveals that nutritional recommendations can generate substantial equity effects, which are however complex because their economic and health components often operate in opposite directions. Except for the case of F&V, the consumer cost of complying with nutritional recommendations, expressed as a percentage of the food budget, is constant or increasing with income. Thus, contrary to taxes, which are clearly economically regressive, policies based on recommendations tend to be economically progressive or neutral.

However, the health benefits are also distributed unevenly across the income groups: the F&V constraint is progressive from a health point of view, while the SFA constraint is regressive and the salt constraint is almost neutral. Overall, as judged by the consumer cost per death avoided, most of the recommendations increase equity slightly, although the F&V recommendation represents a notable exception. When considering equity effects, it should also be acknowledged that we assume here that all consumers adapt their diets in order to comply with the recommendations. In practice, if those changes are linked to public information campaigns, some consumers will adjust their diets and others will not. It has been shown that highly educated people (who are generally high income consumers) tend to be more receptive to information (Drichoutis et al., 2005). If this is the case, the reduction in health inequalities would be lower than suggested by our analysis.

In most cases, in order to comply with the recommendations, consumers would make large adjustments to their diets, and those adjustments may have unintended consequences. For example, increasing the consumption of F&V leads to a decrease in fibers consumption. However, except for the case of the fibers recommendation, all other recommendations improve health (i.e, a positive number of deaths is avoided). A significant part of the net impact on health is due to a change in the calories intake resulting from the adjustment of daily diets. This suggests that a key parameter for healthier diet is related to the total intake of calories. This also suggests that simulations assuming a constant energy intake miss an important mechanism in the adjustment of diets.

Besides the ranking of different types of dietary recommendations, our analysis brings some additional insights for the formulation of healthy eating policies. Hence, the large differences between shadow and actual prices that we estimate for most of the recommendations suggest that fiscal measures are unlikely to be very effective in improving dietary quality unless the tax or subsidy rates applied differentially to healthy and unhealthy foods are substantial.

Our analysis presents some limitations, in particular in relation to the data. We assessed the substitutions among food categories and nutrients on the basis of consumption data, but estimated diet quality changes from a database on individual intakes. To connect the two, we applied the percentage variations in consumption to the corresponding individual intake data. This procedure may have introduced some inaccuracies which are difficult to estimate (but also to avoid). Elsewhere, we considered constraints only one at a time. It is clear, however, that it is difficult to achieve multiple nutritional goals with a single recommendation and that, hence, a multi-constraint approach would be superior. This issue will have to be considered in future research. Finally, we assumed that the consumer's utility was only a function of the quantities of the products consumed. As noted by Lusk and Schroeter (2012), however, this framework implicitly assumes that the consumer's utility and demand relationships are unaffected by health.

Even if we address this issue partially when valuing the QALYs gained from the policies, a more general framework linking explicitly nutritional recommendations to changes in consumers' preferences, and hence integrating other dimensions than price and quantity into the choice problem, remains to be elaborated.

There are many other directions in which the analysis presented in the paper can be developed. Extending the theoretical and empirical models to include several 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.[21]

[21] See Arnoult et al. (2010) for a recent study of how compliance with healthy eating guidelines might impact land use and farm production in England and Wales.

Baseline food intakes per 100g/day	Modest		Lower Average		Upper Average		Well-off	
	Men	Women	Men	Women	Men	Women	Men	Women
Meats	1.526	0.960	1.485	0.952	1.354	0.956	1.447	0.945
Fish & Eggs	0.412	0.416	0.446	0.434	0.502	0.452	0.531	0.496
Starchy products	3.106	2.164	2.877	1.957	3.033	1.911	2.973	1.846
F & V - Fresh	2.545	2.749	2.963	3.056	3.535	3.688	3.746	3.630
F & V - Processed or dry	0.431	0.474	0.534	0.514	0.562	0.593	0.461	0.595
Dairy products	2.212	2.009	2.230	2.136	2.158	2.300	2.166	2.290
Ready meals	1.422	1.080	1.536	1.038	1.254	0.969	1.274	0.923
Oil, margarine, condiments	0.200	0.210	0.205	0.216	0.257	0.243	0.236	0.232
Salt-fat products	0.258	0.264	0.260	0.259	0.304	0.239	0.237	0.251
Sugar-fat products	1.187	1.120	1.327	1.225	1.266	1.176	1.300	1.111
Soft drinks, F & V juices	1.658	1.377	1.414	1.115	1.198	1.135	1.148	0.907
Water, coffee, teas	10.430	11.624	11.519	11.957	11.855	12.319	11.560	13.953
Alcoholic beverages	1.978	0.412	2.264	0.640	2.837	0.739	2.754	1.054

Table 1: Baseline food intakes for men & women in each income class.

	All	Modest	Lower Average	Upper Average	Well-off
Population	37 102 259	10 017 610	10 017 610	9 275 565	7 791 474
All Causes of death	175 702	63 183	47 644	36 312	28 562
Dietron diseases	65 911	21 996	17 630	14 321	11 964
CHD	10 514	3 418	2 801	2 322	1 973
Stroke	6 521	2 581	1 782	1 248	910
Mouth/Larynx/Pharynx cancer	4 205	1 422	1 130	906	747
Oesophagus cancer	2 494	843	670	538	443
Lung cancer	19 024	6 371	5 101	4 126	3 426
Stomach cancer	2 188	726	586	477	399
Pancreas cancer	4 199	1 374	1 121	924	780
Colorectum cancer	6 596	2 159	1 761	1 451	1 225
Breast cancer	6 655	1 998	1 748	1 537	1 372
Endometrial cancer	1 836	550	482	425	379
Kidney cancer	1 503	498	402	328	275
Gallbladder cancer	176	55	47	40	34

Population : INSEE data 2006 for metropolitan France and persons between 25 and 74 years old
Populations per income class are calculated with households compositon data from KANTAR 1998-2001
Mortalities : INSERM data 2006 for metropolitan France and persons between 25 and 74 years old (in www.cepidc.inserm.fr)
Mortalities per income class are calculated with RII based on education level (in Saurel-Cubizolles & al, 2006)

Table 2: Population and mortality of adults between the age of 25 and 74 in each income class.

Lower Average	F & V		Salt-Fat Prod.		Sugar-Fat Prod.		Soft Beverage		Fibers		Na		Total Fat		SFA		Cholesterol		Added Sugar	
	+5%		-5%		-5%		-5%		+5%		-5%		-5%		-5%		-5%		-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 3: Changes in food consumption induced by the imposition of nutritional constraints (percentage on the right in each column) & baseline contribution of each food group to the constrained nutrient/food (percentage on the left in each column) for the "Lower-average" consumer 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 4: Relative change between shadow price and actual price of each food group for the ten nutritional constraints ("Lower-average" consumer type).

Lower Average - Men		F & V	Salt-Fat Prod.	Sugar-Fat Prod.	Soft Beverage	Fibers	Na	Total Fat	SFA	Chole sterol	Added Sugar
Fruits	g/day	1.31	0.13	-2.06	0.62	-0.92	0.44	-6.61	-9.76	-1.38	0.77
Vegetables	g/day	13.23	0.51	-1.61	0.09	0.90	4.03	7.18	20.33	5.23	-1.68
Fibers	g/day	-0.49	-0.04	-0.14	-0.03	1.47	-1.02	0.01	0.02	0.20	-0.21
Total Fat	% energy	0.34	0.04	0.09	0.04	-1.30	0.90	-0.87	-0.51	0.07	0.00
MUFA	% energy	0.23	0.03	0.08	0.02	-0.49	0.40	-0.45	-0.13	0.09	0.05
PUFA	% energy	0.19	0.02	0.11	0.01	-0.13	0.17	-0.29	-0.04	0.14	0.08
SFA	% energy	-0.05	-0.01	-0.10	0.01	-0.58	0.25	-0.11	-0.36	-0.14	-0.14
Cholesterol	% energy	0.00	0.00	0.00	0.00	-0.01	0.01	0.00	0.00	-0.01	0.00
Salt	g/day	-0.41	-0.04	-0.04	-0.02	0.59	-0.65	-0.05	-0.30	0.04	-0.09
Total Energy intake	MJ	-0.24	-0.01	-0.05	-0.02	0.51	-0.42	-0.13	-0.24	0.02	-0.13

Table 5: Changes in the ten nutritional components of Dietron resulting from the imposition of the constraints for men in the lower average income class.

	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%

Table 6: Population-level health effects of the nutritional constraints

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

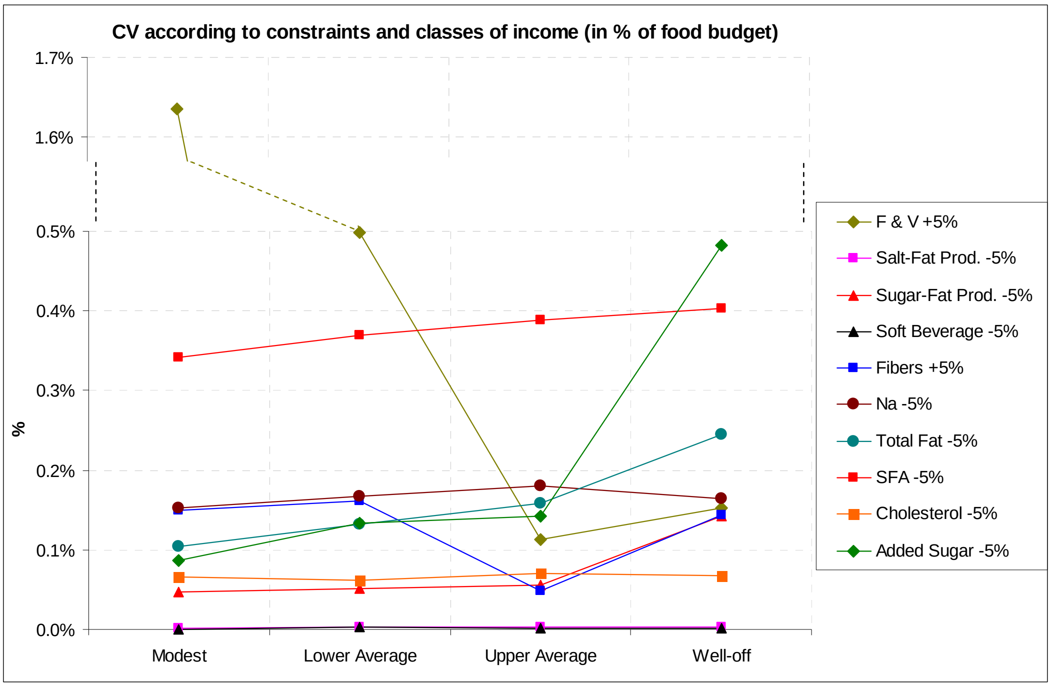

Figure 1: Compensating variations associated with the imposition of all ten nutritional constraints, for each of the four types of consumers

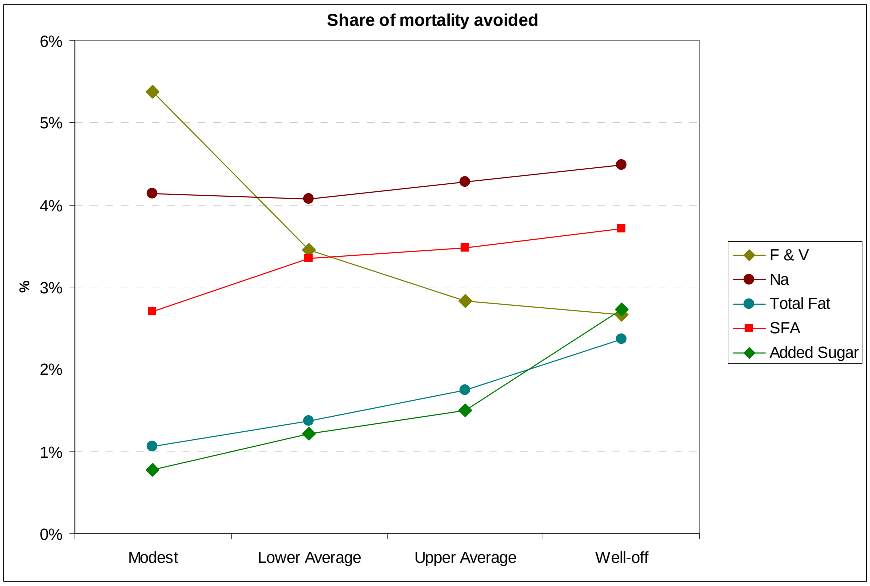

Figure 2: DA as a share of total mortality due to the diseases included in DIETRON by income class for the five most efficient constraints.

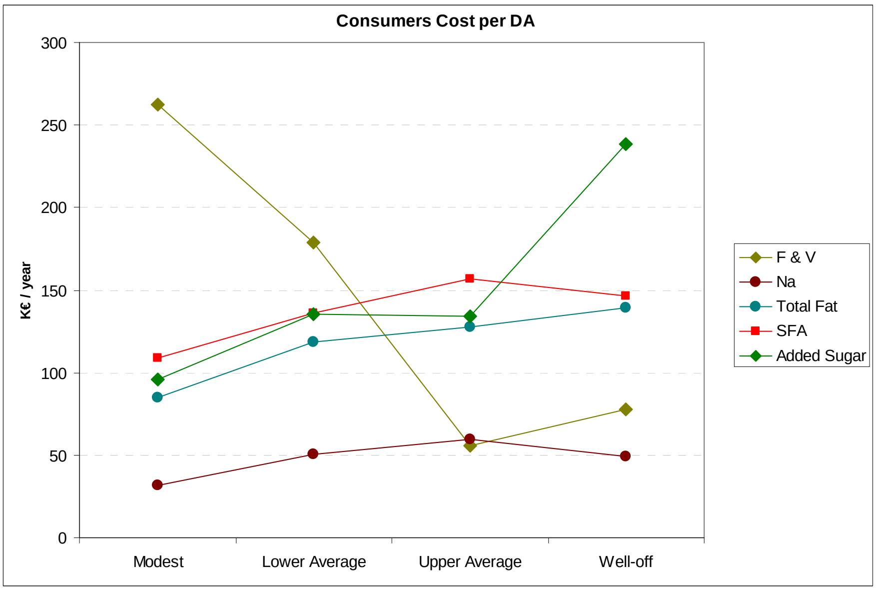

Figure 3: Consumer cost per DA by income class for the five most efficient constraints

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Appendix

	Unit	Red meat	Other meats	Cooked meats	Fish	Eggs	Grains	Potatoes	Fruits fresh	Fruits process.	F & V juices	Veget. fresh	Veget. process.	Fruits dry	Milk products	Cheese Butter Fresh cream	Ready meals	Oil Margarine Condiments	Salt-fat products	Sugar-fat products	Soft drinks	Mineral or spring Water	Alcoholic beverages
Nutritional values*																							
Energy	kcal	192.6	188.0	251.6	144.2	162.9	224.9	116.4	49.7	84.2	43.3	29.8	47.1	404.2	60.3	399.4	157.8	633.9	104.5	307.6	38.0	0.1	67.3
Water	g	62.4	63.1	57.3	69.9	72.8	40.9	70.5	85.2	77.4	88.7	91.2	84.5	19.0	86.2	43.2	66.7	23.3	78.9	35.1	90.7	99.9	89.8
Proteins	g	25.8	25.3	18.7	19.3	11.6	6.9	2.3	0.6	0.3	0.6	1.4	2.7	11.1	4.2	15.9	7.9	0.2	2.1	4.6	0.2	0.0	0.2
Available carbohydrates	g	0.2	0.2	1.6	2.9	0.8	45.3	19.4	10.9	20.2	9.3	4.1	7.0	26.0	6.6	1.0	14.2	1.3	8.8	46.2	8.9	0.0	1.8
Sugars	g	0.0	0.2	0.9	0.4	0.8	2.3	1.0	10.5	19.2	9.3	2.6	2.8	18.8	6.5	0.7	2.1	0.8	1.8	30.6	8.7	0.0	1.1
Fibers	g	0.0	0.0	0.1	0.1	0.0	2.6	1.9	1.9	1.4	0.2	1.7	3.2	7.1	0.1	0.1	1.4	0.0	1.1	1.6	0.1	0.0	0.0
Total Fat	g	9.1	9.8	18.6	6.2	13.2	1.8	3.5	0.2	0.3	0.2	0.8	1.0	28.6	1.8	36.6	7.5	75.0	6.8	11.7	0.1	0.0	0.0
SFA	g	3.8	2.9	6.9	1.2	4.1	0.4	1.3	0.0	0.0	0.0	0.1	0.2	3.7	1.1	23.8	2.6	11.7	2.0	5.6	0.0	0.0	0.0
MUFA	g	3.6	3.5	8.2	2.0	4.9	0.5	0.8	0.0	0.0	0.0	0.4	0.2	10.1	0.5	9.3	2.7	36.7	2.2	3.5	0.0	0.0	0.0
PUFA	g	0.6	1.3	2.1	1.9	2.1	0.6	0.5	0.1	0.1	0.0	0.2	0.2	12.7	0.1	1.3	0.9	22.9	1.9	1.1	0.0	0.0	0.0
Cholesterol	mg	70	87	101	62	374	1	5	0	0	0	0	0	0	6	109	31	2	8	45	0	0	0
Na	mg	96	104	899	365	169	436	59	2	3	4	67	294	96	51	481	405	333	867	153	6	5	3
Ca	mg	13	15	16	45	77	35	15	10	7	12	31	36	83	122	401	62	8	29	65	5	17	6
Fe	mg	3	2	3	1	2	1	1	0	0	0	1	2	3	0	0	1	0	1	1	0	0	1
Added Sugars	g	0.0	0.1	0.4	0.1	0.2	0.7	0.0	0.1	15.1	1.1	0.0	0.2	0.3	2.0	0.0	0.4	0.0	0.5	25.7	8.0	0.0	0.7
Free Sugar	g	0.0	0.1	0.4	0.1	0.2	0.7	0.0	0.1	15.1	9.3	0.0	0.2	0.3	2.0	0.0	0.4	0.0	0.5	26.7	8.6	0.0	0.7
Other Values																							
Edible Part		0.97	0.83	0.98	0.68	0.90	1.29	0.93	0.82	1.00	1.00	0.88	1.00	0.75	1.00	0.99	0.98	1.00	2.54	1.00	1.00	1.00	1.00
F & V constraint coefficients on purchases							0.012		0.820	0.860	0.250	0.842	0.846	0.613			0.250			0.112			
F & V constraint coefficients on intakes							0.012		1.000	0.860	0.250	0.721	0.869	0.834			0.250			0.112			

* per 100g consumed

Table A.1: Matrix of nutritional content and other values of the 22 food groups.

Modest	F & V		Salt-Fat Prod.		Sugar-Fat Prod.		Soft Beverage		Fibers		Na		Total Fat		SFA		Cholesterol		Added Sugar	
	+5%		-5%		-5%		-5%		+5%		-5%		-5%		-5%		-5%		-5%	
Red meat	0%	-17.3%	0%	0.3%	0%	1.0%	0%	0.3%	0%	-0.9%	1%	1.9%	3%	0.1%	3%	-0.4%	6%	-2.5%	0%	4.8%
Other meats	0%	13.0%	0%	0.4%	0%	1.8%	0%	0.4%	0%	2.0%	2%	4.9%	5%	4.5%	4%	14.5%	13%	0.7%	0%	4.0%
Cooked meats	0%	-6.5%	0%	0.0%	0%	-1.6%	0%	-0.1%	0%	-2.8%	18%	-2.2%	9%	-2.5%	8%	-3.1%	13%	-2.0%	0%	-1.7%
Fish	0%	24.0%	0%	0.1%	0%	1.9%	0%	0.1%	0%	-5.9%	3%	8.4%	1%	3.8%	1%	8.7%	4%	2.9%	0%	3.3%
Eggs	0%	-14.2%	0%	1.4%	0%	-2.4%	0%	0.5%	0%	-6.6%	1%	4.9%	3%	1.7%	2%	-14.8%	19%	-21.7%	0%	-0.6%
Animal pdts	0%	2.2%	0%	0.3%	0%	0.4%	0%	0.2%	1%	-1.8%	27%	3.2%	21%	1.6%	18%	3.8%	55%	-2.5%	1%	2.1%
Grains	0%	-11.1%	0%	-0.5%	0%	-0.6%	0%	-0.2%	18%	22.1%	15%	-16.1%	1%	1.4%	1%	-0.6%	0%	0.8%	1%	0.3%
Potatoes	0%	-46.7%	0%	-0.6%	0%	5.2%	0%	-1.5%	7%	6.0%	1%	-2.6%	2%	-4.0%	1%	3.3%	1%	3.3%	0%	-1.2%
Starchy food	0%	-26.8%	0%	-0.5%	0%	2.0%	0%	-0.8%	25%	15.0%	16%	-10.1%	3%	-1.0%	2%	1.1%	1%	1.9%	1%	-0.4%
Fruits - Fresh	40%	-6.8%	0%	0.0%	0%	-1.4%	0%	0.4%	20%	-1.7%	0%	0.0%	0%	-2.5%	0%	-5.3%	0%	-0.9%	0%	0.8%
Fruits - Processed	3%	51.2%	0%	1.1%	0%	0.0%	0%	1.0%	1%	-1.3%	0%	2.4%	0%	-29.7%	0%	-29.0%	0%	-4.5%	4%	-3.9%
F & V juices	7%	4.6%	0%	0.2%	0%	5.9%	0%	0.8%	1%	-4.4%	0%	4.0%	0%	3.1%	0%	4.7%	0%	-0.2%	2%	9.6%
Vegetables - Fresh	31%	10.6%	0%	0.5%	0%	-1.3%	0%	0.1%	14%	-6.0%	3%	7.7%	1%	5.3%	0%	16.3%	0%	3.8%	0%	-1.3%
Vegetables - Processed	11%	33.1%	0%	0.2%	0%	0.8%	0%	0.5%	11%	13.3%	5%	-3.0%	0%	2.9%	0%	10.6%	0%	1.9%	0%	4.0%
Fruits - Dry	0%	-12.0%	0%	0.4%	0%	1.1%	0%	-1.7%	1%	7.2%	0%	12.4%	0%	-6.3%	0%	-4.6%	0%	7.5%	0%	-13.3%
F & V	92%	6.1%	0%	0.2%	0%	0.4%	0%	0.4%	49%	-1.9%	8%	2.8%	2%	0.7%	1%	4.0%	0%	0.8%	6%	2.1%
Milk products	0%	-8.1%	0%	0.2%	0%	0.6%	0%	0.4%	2%	-4.1%	7%	2.9%	6%	-1.5%	9%	-4.4%	5%	0.6%	15%	0.3%
Cheeses, butters, fresh creams	0%	-5.5%	0%	-0.7%	0%	-1.5%	0%	-0.1%	0%	-0.4%	15%	-3.7%	27%	-0.2%	43%	-7.4%	22%	-2.3%	0%	-2.9%
Dairy pdts	0%	-7.6%	0%	0.0%	0%	0.2%	0%	0.3%	3%	-3.4%	21%	1.7%	33%	-1.3%	52%	-5.0%	27%	0.0%	15%	-0.3%
Ready meals	5%	-21.6%	0%	-0.2%	0%	-0.2%	0%	-0.5%	7%	2.7%	10%	-7.0%	4%	-2.7%	4%	-4.5%	5%	0.5%	1%	-2.8%
Oil, margarine, condiments	0%	19.4%	0%	1.3%	0%	4.5%	0%	0.4%	0%	-0.3%	4%	4.2%	24%	-20.1%	9%	-5.6%	0%	8.1%	0%	3.3%
Salt-fat products	0%	-33.0%	100%	-5.0%	0%	6.7%	0%	-1.2%	2%	6.5%	7%	-26.5%	1%	5.4%	1%	-25.0%	0%	6.9%	0%	4.9%
Sugar-fat products	3%	2.2%	0%	0.2%	100%	-5.0%	0%	0.2%	13%	0.7%	6%	-0.3%	11%	0.0%	13%	-4.9%	12%	-1.7%	58%	-4.1%
Soft drinks	0%	-28.0%	0%	-0.7%	0%	4.2%	100%	-5.0%	0%	1.1%	0%	-4.0%	0%	3.9%	0%	4.1%	0%	3.8%	16%	-17.1%
Water	0%	-36.1%	0%	-0.7%	0%	1.2%	0%	-0.2%	0%	-9.6%	1%	1.6%	0%	2.6%	0%	9.5%	0%	9.1%	0%	5.8%
Alcoholic beverages	0%	33.4%	0%	0.2%	0%	2.8%	0%	-0.2%	0%	2.9%	0%	1.1%	0%	1.4%	0%	4.2%	0%	0.6%	2%	1.8%

Table A.2: Changes in food consumption induced by the imposition of nutritional constraints (percentage on the right in each column) & baseline contribution of each food group to the constrained nutrient/food (percentage on the left in each column) for the "modest" consumer type.

Upper 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%	-6.4%	0%	0.3%	0%	1.1%	0%	0.3%	0%	-1.2%	1%	1.7%	3%	-0.3%	3%	-0.9%	7%	-2.3%	0%	6.8%
Other meats	0%	4.0%	0%	0.4%	0%	2.2%	0%	0.4%	0%	2.0%	3%	4.5%	6%	5.6%	4%	13.7%	14%	0.5%	0%	5.4%
Cooked meats	0%	-2.4%	0%	0.0%	0%	-3.2%	0%	-0.1%	0%	-2.8%	19%	-2.5%	9%	-4.3%	9%	-4.3%	13%	-2.1%	0%	-4.3%
Fish	0%	4.6%	0%	0.1%	0%	2.2%	0%	0.0%	0%	-5.7%	4%	6.7%	2%	4.8%	1%	8.1%	5%	2.3%	0%	4.5%
Eggs	0%	-5.4%	0%	1.4%	0%	-4.4%	0%	0.4%	0%	-7.0%	1%	4.8%	3%	0.9%	2%	-16.4%	20%	-20.9%	0%	-2.4%
Animal pdts	0%	0.0%	0%	0.3%	0%	0.2%	0%	0.2%	1%	-1.9%	29%	2.9%	23%	1.8%	19%	3.3%	58%	-2.3%	1%	2.5%
Grains	0%	-4.6%	0%	-0.6%	0%	-2.2%	0%	-0.3%	14%	23.6%	13%	-16.9%	1%	0.6%	1%	-3.5%	0%	0.2%	1%	-1.2%
Potatoes	0%	-19.5%	0%	-0.6%	0%	7.5%	0%	-1.5%	8%	6.6%	1%	-3.0%	2%	-5.8%	2%	2.4%	1%	3.1%	0%	-2.7%
Starchy food	0%	-12.2%	0%	-0.6%	0%	2.7%	0%	-0.9%	22%	14.9%	14%	-9.8%	3%	-2.7%	2%	-0.5%	1%	1.7%	1%	-2.0%
Fruits - Fresh	42%	2.1%	0%	0.0%	0%	-1.7%	0%	0.3%	25%	0.5%	0%	0.3%	0%	-2.3%	0%	-3.7%	0%	-0.4%	0%	0.9%
Fruits - Processed	2%	17.4%	0%	1.2%	0%	-0.7%	0%	1.0%	1%	-1.8%	0%	1.9%	0%	-40.2%	0%	-33.0%	0%	-5.0%	4%	-5.1%
F & V juices	5%	2.5%	0%	0.1%	0%	8.6%	0%	0.8%	1%	-4.6%	0%	3.6%	0%	3.6%	0%	3.9%	0%	-0.4%	3%	15.0%
Vegetables - Fresh	36%	8.3%	0%	0.4%	0%	-1.5%	0%	0.1%	19%	-2.6%	4%	5.7%	1%	6.6%	0%	14.0%	0%	3.2%	0%	-1.5%
Vegetables - Processed	8%	11.8%	0%	0.2%	0%	0.5%	0%	0.5%	9%	13.8%	4%	-2.9%	0%	3.1%	0%	10.2%	0%	1.6%	0%	5.7%
Fruits - Dry	0%	-3.4%	0%	0.3%	0%	1.3%	0%	-1.4%	1%	7.8%	0%	10.2%	1%	-8.7%	0%	-3.8%	0%	6.1%	0%	-16.9%
F & V	94%	5.2%	0%	0.2%	0%	0.3%	0%	0.3%	57%	-0.5%	9%	2.5%	3%	1.3%	1%	3.9%	0%	0.9%	7%	2.6%
Milk products	0%	-3.2%	0%	0.2%	0%	0.1%	0%	0.5%	2%	-4.6%	6%	3.0%	5%	-3.5%	8%	-6.4%	4%	0.3%	16%	-0.1%
Cheeses, butters, fresh creams	0%	-2.2%	0%	-0.8%	0%	-3.1%	0%	-0.1%	0%	-0.1%	15%	-4.3%	28%	-0.5%	45%	-7.2%	22%	-2.3%	0%	-6.6%
Dairy pdts	0%	-3.0%	0%	0.0%	0%	-0.6%	0%	0.4%	2%	-3.7%	21%	1.5%	33%	-2.9%	53%	-6.6%	26%	-0.2%	16%	-1.4%
Ready meals	4%	-8.1%	0%	-0.3%	0%	-1.0%	0%	-0.6%	6%	3.2%	9%	-7.9%	4%	-5.0%	4%	-6.4%	5%	0.4%	1%	-6.3%
Oil, margarine, condiments	0%	8.4%	0%	1.5%	0%	7.1%	0%	0.4%	0%	0.4%	4%	6.0%	23%	-19.5%	9%	-0.4%	0%	8.9%	0%	4.2%
Salt-fat products	0%	-15.0%	100%	-5.0%	0%	10.9%	0%	-1.4%	2%	7.6%	7%	-28.1%	1%	5.9%	1%	-29.4%	0%	7.3%	0%	7.9%
Sugar-fat products	2%	1.5%	0%	0.2%	100%	-5.0%	0%	0.2%	10%	1.0%	5%	-1.2%	10%	-0.9%	11%	-6.6%	10%	-2.2%	57%	-3.8%
Soft drinks	0%	-14.7%	0%	-1.1%	0%	7.8%	100%	-5.0%	0%	3.3%	0%	-8.0%	0%	3.7%	0%	0.8%	0%	4.1%	13%	-22.7%
Water	0%	-13.6%	0%	-0.6%	0%	1.5%	0%	-0.2%	0%	-9.0%	1%	1.5%	0%	4.1%	0%	9.1%	0%	7.5%	0%	7.9%
Alcoholic beverages	0%	6.5%	0%	0.1%	0%	3.3%	0%	-0.2%	0%	1.5%	0%	1.4%	0%	2.7%	0%	4.9%	0%	0.9%	3%	2.1%

Table A.3: Changes in food consumption induced by the imposition of nutritional constraints (percentage on the right in each column) & baseline contribution of each food group to the constrained nutrient/food (percentage on the left in each column) for the "upper average" consumer type.

Well-off	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%	-5.4%	0%	0.3%	0%	1.2%	0%	0.3%	0%	-1.2%	2%	1.5%	4%	-1.1%	4%	-1.5%	7%	-2.6%	0%	12.2%
Other meats	0%	3.5%	0%	0.4%	0%	3.0%	0%	0.4%	0%	2.5%	3%	4.5%	6%	7.6%	4%	14.2%	14%	0.6%	0%	8.7%
Cooked meats	0%	-1.9%	0%	-0.1%	0%	-6.1%	0%	-0.1%	0%	-2.9%	18%	-2.5%	9%	-6.4%	8%	-5.1%	13%	-2.4%	0%	-10.2%
Fish	0%	2.4%	0%	0.1%	0%	3.1%	0%	0.0%	0%	-5.6%	5%	5.9%	2%	6.1%	1%	7.6%	6%	2.0%	0%	7.6%
Eggs	0%	-4.5%	0%	1.5%	0%	-7.8%	0%	0.5%	0%	-7.4%	1%	5.0%	3%	0.1%	2%	-17.3%	19%	-21.0%	0%	-6.6%
Animal pdts	0%	-0.1%	0%	0.3%	0%	-0.2%	0%	0.2%	1%	-1.9%	29%	2.9%	23%	2.2%	19%	3.1%	58%	-2.3%	1%	3.7%
Grains	0%	-3.9%	0%	-0.6%	0%	-4.4%	0%	-0.3%	13%	24.0%	12%	-17.0%	1%	-0.4%	1%	-4.6%	0%	-0.1%	1%	-3.3%
Potatoes	0%	-17.0%	0%	-0.6%	0%	12.6%	0%	-1.7%	6%	3.8%	1%	-3.3%	2%	-7.4%	1%	3.2%	1%	3.4%	0%	-6.3%
Starchy food	0%	-10.2%	0%	-0.6%	0%	3.8%	0%	-1.0%	19%	14.2%	13%	-10.3%	3%	-3.8%	2%	-0.8%	1%	1.6%	1%	-4.8%
Fruits - Fresh	46%	4.1%	0%	0.0%	0%	-2.3%	0%	0.3%	29%	2.0%	0%	0.7%	0%	-1.7%	0%	-2.3%	0%	-0.1%	0%	1.4%
Fruits - Processed	2%	13.2%	0%	1.2%	0%	-1.7%	0%	1.1%	1%	-2.1%	0%	1.7%	0%	-49.3%	0%	-34.5%	0%	-5.6%	4%	-6.6%
F & V juices	5%	1.9%	0%	0.1%	0%	13.2%	0%	0.8%	1%	-4.7%	0%	3.5%	0%	4.1%	0%	3.4%	0%	-0.5%	3%	26.1%
Vegetables - Fresh	35%	7.1%	0%	0.4%	0%	-2.2%	0%	0.1%	20%	-1.9%	5%	5.1%	1%	8.5%	1%	13.1%	0%	3.2%	0%	-2.9%
Vegetables - Processed	6%	8.7%	0%	0.3%	0%	-0.1%	0%	0.6%	8%	13.5%	4%	-2.5%	0%	3.5%	0%	10.0%	0%	1.4%	0%	10.1%
Fruits - Dry	1%	-2.3%	0%	0.3%	0%	1.9%	0%	-1.1%	2%	7.9%	0%	8.5%	1%	-11.6%	0%	-3.1%	0%	5.5%	0%	-23.6%
F & V	94%	5.1%	0%	0.2%	0%	0.4%	0%	0.3%	60%	0.3%	9%	2.4%	3%	1.9%	1%	3.7%	0%	0.9%	8%	4.1%
Milk products	0%	-2.6%	0%	0.3%	0%	-0.6%	0%	0.5%	2%	-4.9%	6%	3.0%	5%	-5.5%	8%	-7.3%	4%	0.2%	16%	-1.9%
Cheeses, butters, fresh creams	0%	-2.0%	0%	-0.8%	0%	-5.2%	0%	-0.1%	0%	-0.2%	16%	-4.4%	29%	-1.4%	46%	-7.4%	22%	-2.4%	0%	-12.8%
Dairy pdts	0%	-2.5%	0%	0.0%	0%	-1.6%	0%	0.4%	2%	-3.8%	22%	1.4%	34%	-4.6%	54%	-7.3%	26%	-0.4%	16%	-4.3%
Ready meals	4%	-6.2%	0%	-0.3%	0%	-1.9%	0%	-0.6%	7%	3.0%	11%	-7.7%	5%	-6.8%	4%	-6.4%	5%	0.3%	1%	-11.2%
Oil, margarine, condiments	0%	7.4%	0%	1.6%	0%	11.9%	0%	0.4%	0%	0.8%	4%	7.4%	21%	-17.5%	8%	3.8%	0%	9.9%	0%	6.9%
Salt-fat products	0%	-12.5%	100%	-5.0%	0%	17.6%	0%	-1.5%	2%	7.8%	7%	-28.3%	1%	4.8%	1%	-30.6%	0%	7.6%	0%	16.0%
Sugar-fat products	2%	1.5%	0%	0.3%	100%	-5.0%	0%	0.2%	9%	1.0%	5%	-1.6%	9%	-1.9%	10%	-7.4%	9%	-2.6%	57%	-3.1%
Soft drinks	0%	-14.2%	0%	-1.4%	0%	14.9%	100%	-5.0%	0%	5.2%	0%	-11.0%	0%	3.0%	0%	-1.8%	0%	4.7%	12%	-29.3%
Water	0%	-10.8%	0%	-0.6%	0%	1.9%	0%	-0.2%	0%	-9.1%	1%	1.3%	0%	5.6%	0%	8.5%	0%	7.5%	0%	13.7%
Alcoholic beverages	0%	3.5%	0%	0.1%	0%	4.5%	0%	-0.1%	0%	0.6%	0%	1.6%	0%	3.9%	0%	5.0%	0%	1.1%	4%	3.4%

Table A.4: Changes in food consumption induced by the imposition of nutritional constraints (percentage on the right in each column) & baseline contribution of each food group to the constrained nutrient/food (percentage on the left in each column) for the "well-off" consumer type.