Identifying sustainable diets compatible with consumer preferences

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Abstract

Because food choices have important implications for human health and the environment, consumers are increasingly urged to modify their purchasing and eating habits so as to comply with a set of norms (e.g., eat at least five portions of fruits & vegetables a day; reduce meat consumption). However, the effect of compliance with those norms on the composition of the entire diet is uncertain because of potentially complex substitutions. To lift this uncertainty, we propose a model which extends the theory of the consumer under rationing to the case of multiple linear constraints. The effect on the diet of compliance with norms is derived from information on consumer preferences (price and expenditure elasticities of demand), consumption levels, and technical coefficients for each food (e.g., nutritional composition, GHG emissions). The model is then used to simulate how the French diet would respond to a five percent increase in fruit and vegetable consumption, as well as the related changes in diet quality and greenhouse gas emissions.

Keywords: food choice; sustainability; rationing; sustainable diet; France

JEL: D11; D12; Q01; Q18; Q57

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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 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 as well as one product group (namely, fruits and vegetables) (Srinivasan et al., 2006). 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).

As noted by nutritionist Marion Nestle,[1] nutritional recommendations can take different forms depending on whether the message involves increasing or decreasing consumption. The 'eating more' messages usually encourage individuals to consume more food items within a product group, as illustrated by the '5-a-day' campaigns to promote the consumption of fruits and vegetables in many countries. On the other hand, the 'eating less' 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 FSA recently ran a campaign to encourage consumers to reduce salt intakes (Marshall et al., 2007) but, given that three quarters[2] 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.[3] Because consumers might have difficulties to put in practice nutrient based recommendations, the French 'Programme National Nutrition Santé' has formulated product based recommendations.

More recently, environmental impacts of food consumption have been put on the policy makers' agenda. Indeed, among the different household consumption categories, food is

[1] San Francisco Chronicle, 06 February 2011.
[2] FSA website, http://www.food.gov.uk/scotland/scotnut/salt/industry, consulted on 17/02/2011.
[3] For instance, with reference to the UK EatWell plate, the products with high-salt contents targeted for reduction would include canned vegetable soups in the fruits and vegetable group, bread in the starchy foods group, smoked fish in the protein group, salted butter in the dairy group, and biscuits in the fat & sugar group.

the most important in term of carbon foot print (as measured by the contribution to greenhouse gas emissions (GHGE)). According to Hertwich and Peters (2009), food consumption accounts for nearly 20% of the total GHG emissions. In order to explore the possibility to reduce GHG emissions from food, simulation exercises have been carried out. For example, Tukker et al. (2011) compared the impact of the European 'average' diet with alternative diets and in particular a reduced meat consumption diet. They found that a decrease in GHG emissions were possible with reduced meat diets. However, Vieux et al. (2012) concluded that 'In particular, when fruit and vegetables were iso-calorically substituted for meat, either null or even positive diet-associated GHGE variations were observed because the needed amounts of fruit and vegetables to maintain the caloric content of the diet were high'. This suggests that diet changes that may be desirable for health are not necessarily the best way of decreasing the carbon foot print of food consumption.

Hence, whether for nutritional or environmental issues, the modern food consumer is more and more supposed to make food choices and adapt his/her diet while being urged to comply with a whole range of norms or guidelines. Putting aside the political economy underlying the formulation of dietary recommendations, this article develops a novel approach to identify diets compatible with both nutritional or environmental 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 measuring the taste cost of complying with a particular nutritional or environmental 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, 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.[4]

A new framework is developed because we believe that experts in both public health and economics are currently ill-equipped to analyse the question of how nutritional and environmental norms might influence real-world consumers, as all available methods suffer from important shortcomings. First attempts to address this question build on linear

[4] 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.

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 et al. (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 obviously 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 of course been recognized and LP models have been modified accordingly through the addition of so-called 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) – and given that those additions seem rather arbitrary[5], LP models tend to produce results that are highly subjective[6] and largely driven by assumptions. 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.

Because of the shortcomings of existing methods, this article develops a new analytical framework which builds on the microeconomic theory of the consumer under rationing. Targeting the same objectives than Jensen *et al.* (2010), an unlike the programming approaches, our framework is solidly 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. In section 1, we present the theoretical model. In section 2, we present the data and the methods used for an application dealing with the adoption of a norm related to fruit and vegetable (F&V) consumption. In section 3, we present the simulation results. In section 4, we conclude.

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[5] 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.

[6] 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’.

2. The Model

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 $\boldsymbol{x}=(x_1,\ldots x_H)$ to maximize a strictly increasing, strictly quasi-concave, twice differentiable utility function $U(x_1,\ldots x_H)$, subject to a linear budget constraint $p.x \leq M$, where $\boldsymbol{p}$ is a price vector and M denotes income. However, departuring from the standard model, we now assume that the consumer operates under N additional linear constraints corresponding to N maximum nutrient intakes.[7] 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. The constraints could also correspond to product group based constraints (such as recommendations on fruit and vegetables or on meat products).[8] The nutritional constraints are expressed by:

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

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 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 $\boldsymbol{r}$ the N-vector of maximum nutrient amounts. By definition of the vector of shadow prices $\tilde{p}$, the following equality follows:

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

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):

[7] The results can be generalised to minimum constraints without difficulty.

[8] 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 includes vegetables as well as dairy products).

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

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 the budget and nutritional constraints - or what Jackson (1991) calls the virtual price problem:

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

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

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

Assuming non-satiation so that all virtual prices are strictly positive, the Kuhn-Tucker conditions are:

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

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

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

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:

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

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.[9] 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:

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

The first set of equation implies that deviations between shadow prices and market prices are proportional to the nutritional coefficients of the goods entering the single nutritional constraint. This 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:

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

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

Plugging this expression back into (11) gives the corresponding *H-1* shadow price changes:

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

From which follows the change in demand for any of the *H* goods:

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

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. 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-a), that expression becomes:

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

A change in the constraint Δr_1 induces a change in the (vector) compensated demand Δh and from (15) we have CV=-p. Δh. Those changes are estimated in the compensated framework that is assuming the utility of the consumer remains constant. From those results, it is easy to calculate the changes in consumption in a Marshallian framework. We write:

$\Delta x = \Delta h + \tilde{h}.\varepsilon^R \frac{CV}{p.\tilde{h}}$ with $.\varepsilon^R$ the income (or expenditure) elasticity.

3. Data and methods

To estimate the changes induced by the adoption of a nutritional or environmental norm (e.g. a targeted level of F&V consumption, a maximum level of salt intake, etc.) by a consumer, we use the model presented in the previous section and an iterative procedure. First, we calculate the changes in consumption induced by the adoption of this specific norm according to the Hicksian demand functions and, hence, assuming that the utility of the consumer remains constant. The quantities thus obtained and the associated compensating variations are then used to calculate the quantity variations in a Marshallian framework. Next, we assess the compliance of this Marshallian solution with the targeted norm. If the consumption pattern is compliant, the computation is over. If it is not, we go back to the first step and calculate the impact of a revised norm in the Hicksian framework. The iteration process finishes when the constraint is verified in the Marshallian framework.

To compute the changes induced by the adoption of dietary constraints several datasets and parameters are needed: initial consumption patterns and prices; price and expenditure elasticities of demand; nutritional and environmental characteristics of food categories. The source of this information is reviewed below.

Food groups, consumers types and elasticities

Consumption and economic data used to predict changes in food consumption are based on the elasticities estimated by Allais et al. (2010). In that paper, the authors used a complete food demand system, which allowed them to consider a large set of interdependent demand relationships. To estimate a complete food demand model, they needed to have information (prices, expenditures, budget shares, etc.) over a large set of food items for all sampled households.

The purchase data are from Kantar World Panel. This panel is one of the main information on food purchases in France. Each annual survey contains weekly food acquisition data for approximately 12,000 households, with an annual rotation of one third of the participants. The households are selected by stratification according to several socioeconomic variables, and remain in the survey for a mean period of four years.

The purchases are aggregated into 22 food categories. Four consumer types based on the income levels are considered in the analysis and defined as “modest”, “lower average”, “upper average”, and “well-off”.

Food categories, consumer types and price and expenditure elasticities obtained from Allais et al. (2010) and used for calibrating our model are given in the appendix.

Assessment of the nutritional quality of the diet

Concerning the nutritional dimension, the technical coefficients have been obtained from the database joined to the INCA2 survey, a cross-sectional national survey carried out in 2006-2007 by the ANSES (French agency for food, environmental and occupational health safety)[10].

Nutritional content of each of the 22 food categories have been determined on the basis of the average consumption of a French adult as estimated in the INCA2 survey. Recipes and edible part for each food category have been defined on this basis and used for formalizing the nutritional constraints.

These technical coefficients have also been used for determining the nutritional quality of the consumption patterns observed before and after the adoption of the constraints. Denoting e_i^m the nutritional coefficient for any food category *i* and indicator *m*, the impact on nutritional indicator *m* of a diet $\boldsymbol{x}=(x_1,\ldots x_H)$ is given by $E_m = \sum_{i=1}^{H} e_i^m x_i$.

To go a step further and assess the nutritional quality of the new consumption patterns, we used as proposed by Vieux et al. (2012), three indicators of nutritional quality: the Mean Adequacy Ratio (MAR), the Mean Excess Ratio (MER) and the dietary Energy Density (ED).

The MAR is used as an indicator of good nutritional quality. It is calculated as the mean percentage of daily recommended intakes for 19 key nutrients[11] as follows:

$$MAR = \frac{1}{M}\sum_{m=1}^{M} Min\left[\left(\sum_{i=1}^{H}\frac{100.e_i^m x_i}{RDA_m}\right),100\right]$$

where RDA_m is the French Recommended Dietary Allowance for nutrient *m*, and x_i the consumption of product *i*.[12]

The MER is used as an indicator of bad nutritional quality. It is calculated as the mean daily percent of maximal recommended values (MRV) for three harmful nutrients, namely saturated fatty acids, sodium and free sugars, as follows:

[10] The INCA 2 survey is made 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

[11] The 19 nutrients are: proteins, fiber, retinol-equivalent, thiamin, riboflavin, niacin, vitamin B6, folates, ascorbic acid, vitamin E, vitamin D, calcium, potassium, iron, magnesium, zinc, copper, iodine and selenium.

[12] Some of the nutrients *m* might also enter nutritional constraints as represented in (1).

$$MER = \left[\frac{1}{K} \sum_{k=1}^{K} Max \left[\left(\sum_{i=1}^{H} \frac{100.e_i^k x_i}{MRV_k} \right), 100 \right] \right] - 100$$

The dietary energy (ED) density is also an indicator of bad nutritional quality because decreasing the energy density of the diet is recommended by several public health authorities to prevent obesity and obesity-associated disease conditions. The dietary energy density is defined as the ratio between energy intake and diet weight and is expressed in kcal/100g.[13]

Assessment of the environmental quality of the diet

As regards the environmental issues, we used a database elaborated by Vieux et al. (2012) which include 390 widely consumed items in each food categories. These 390 representative foods represented around 70% of total weight intake in the INCA2 population. An environment consultancy—Greenext—assigned values of GHGE to the 390 foods[14]. Life cycle analysis as recommended by the ISO14040-44 standards and by the French guide BP X 30-323, i.e. from cradle to grave, was used to assess the indicators. The assessment included all the recommended steps, except for transportation by consumers from the retail centers to home, using a range of life cycle inventory databases. Only conventional and most frequent production and distribution processes in France were considered and the variability related to alternative production processes (organic for instance) at the farm level or alternative location of production activities (short-distance circuits for instance) was not taken into account. The final values of GHGE reflected the average food product as consumed on the French market. Considering the 390 foods, we calculated the mean GHGE value for each of the 22 food categories.

4. Results

In this section, we analyze the dietary changes induced by imposing a constraint on the level of F&V consumption. The potential effects on the diets of the four representative consumers are analyzed by simulating the changes in food consumption induced by a 5% increase in F&V consumption. The changes in consumption are analyzed both within the F&V category (i.e., for fresh fruits, processed fruits, dried fruits, fresh vegetables, processed vegetables, and prepared meals containing F&V) and outside of it (e.g., for meat consumption) .

In addition to the changes in consumption, we also estimate the associated shadow prices and the additional cost of the diet that corresponds to the amount of compensation that the consumer would require in order to maintain his utility following the introduction of

[13] As used in Vieux et al . (2013) , only items typically consumed as foods, including soups, were included in the calculation of energy density, whereas foods typically consumed as beverages, such as milk, juices, and sugar-based and non-sugar-based drinks, were excluded.

[14] The Greenext method is presented in more details on their website: www.greenext.eu

the constraint. Finally, we assess the variations in the MAR, MER, DE indicators, as well as the GHGE impact associated with the consumption changes.

Changes in consumption patterns

Let us note that the constraint of a 5 % increase in F&V consumption corresponds to a daily consumption increase that ranges between 22 and 29 g/day according to the consumer type (around a quarter of a portion).

As shown on Figures 1a, 1b and 1c for the 'modest' consumer type, important changes in consumption are observed: a decrease in red meat and cooked meat consumption and an increase in the consumption of other meats; an increase in consumption of fish and sugar-fat products; a decrease in consumption of drinks, starchy foods (grain and potatoes), milk, and salt-fat products. The increase in F&V consumption is not similar within the subcategories of the F&V group (Figure 1c). It is greater for the processed fruit and vegetable categories than for the fresh categories, meaning a modification in the fresh/processed F&V ratio.

It is worth noting that, even for a relatively small change in F&V consumption imposed exogenously, we obtain large relative adjustments for many food categories within and outside of the F&V group. Those adjustments are complex and would not have been possible to anticipate at the outset, hence giving relevance to our whole-diet modeling approach. The changes in consumption also suggest that the health and environmental effects of the change are far from straightforward but require further analysis, a point to which we return below.

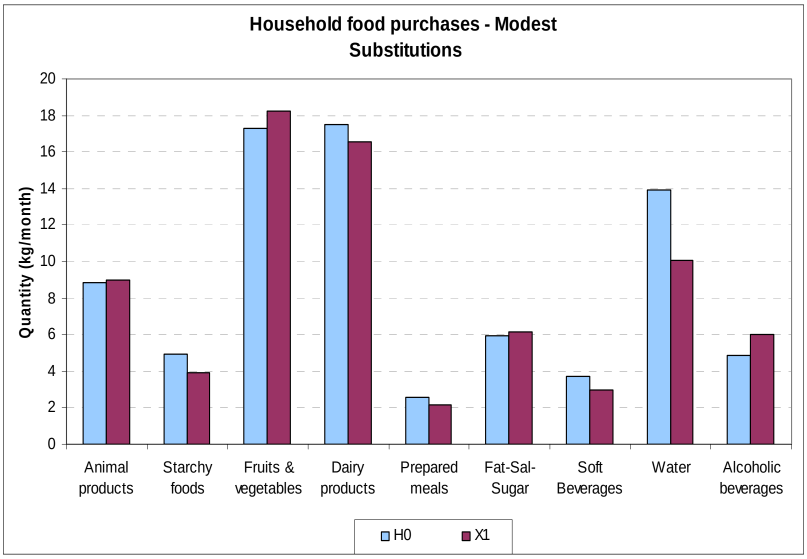

Figure 1a. Variations (in kg/month) in consumption for the 'modest' consumer type

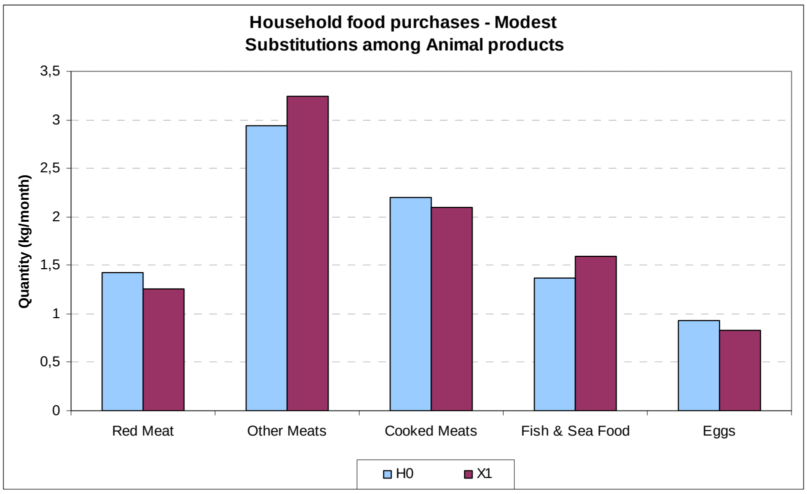

Figure 1b. Variations (in kg/month) in animal product consumption for the ‘modest’ consumer type

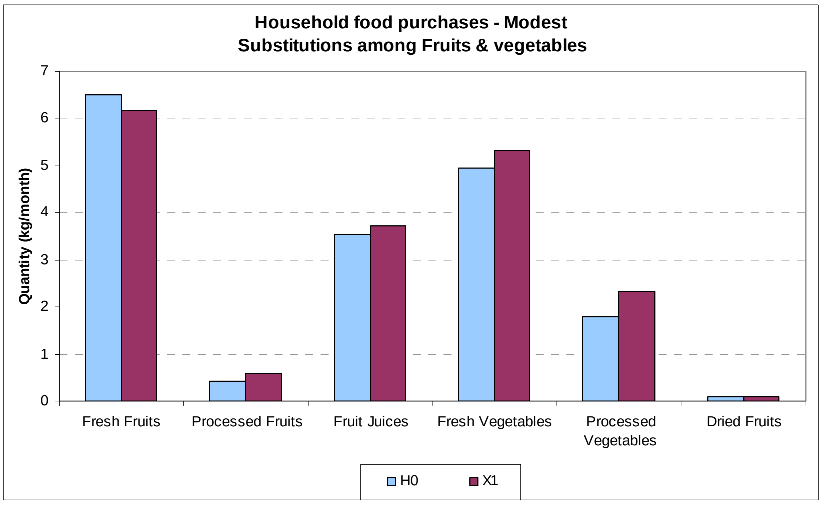

Figure 1c. Variations (in kg/month) in F&V consumption for the ‘modest’ consumer type

As shown in Table 1, the magnitude of the changes in consumption patterns depends on the consumer type. Generally speaking, the magnitude of dietary adjustment is greater for the lowest income categories, meaning that the 5% increase in F&V consumption is much more difficult to achieve for those categories.

	Modest	Lower average	Upper average	Well-off
Animal products	1,6%	0,6%	0,1%	-0,1%
Starchy foods	-21,0%	-14,7%	-11,7%	-10,2%
Fruits and Vegetables	5,5%	5,4%	5,4%	5,5%
Dairy products	-5,5%	-3,5%	-2,8%	-2,4%
Prepared meals	-15,5%	-10,4%	-7,7%	-6,1%
Fat-salt-sugar products	2,9%	2,5%	2,0%	1,9%
Beverages *	-12,7%	-8,9%	-6,8%	-5,7%

* including fruit juices

Table 1. Variations in consumption (%) for the four consumer types (aggregated food categories)

Shadow prices and consumer's surplus

The variations between the shadow prices related to the new consumption patterns and the actual prices are given in Table 2. As expected, all the shadow prices of the F&V categories are lower than actual prices in order to encourage consumption. We note that the magnitude of the difference between shadow and actual prices is large for several F&V groups.

It is interesting to note that the difference between shadow and actual prices depends on the F&V category. For a given consumer, the shadow price of a product is a function of a) the cost of the constraint (that is μ_1), b) the content in F&V, and c) the actual price of the product. Then the difference between shadow and actual prices is greater for fresh produce (these two products represent more than 50% of the consumption of fruit and vegetables) than for processed F&V. It is very small for prepared meals as their content in F&V is low.

We also note that the difference between shadow and actual prices is decreasing with household income, meaning that the decrease in F&V prices would have to be greater to reach a 5% F&V consumption increase in the low-income consumer types.

	Modest	Lower average	Upper average	Well-off
Fresh Fruits	-43,0%	-30,3%	-22,5%	-18,6%
Processed Fruits	-30,1%	-21,2%	-15,8%	-13,0%
Fruit Juices	-20,4%	-14,4%	-10,7%	-8,8%
Fresh Vegetables	-44,1%	-31,1%	-23,1%	-19,1%
Processed Vegetables	-32,0%	-22,5%	-16,7%	-13,8%
Dried Fruits	-9,7%	-6,9%	-5,1%	-4,2%
Prepared Meals	-4,1%	-2,9%	-2,2%	-1,8%

Table 2: Variation between shadow and actual price of fresh F&V according to the consumer types (%)

The welfare cost of satisfying the F&V constraint is given by the compensating variation shown in Table 3. The difference between the initial expenditure and the expenditure that maintains the utility constant in the nutritionally-constrained problem ranges from 0.91% to 0.15% of the food budget from the modest to the well-off category.

Modest	Lower average	Upper average	Well-off
-0.91	-0.41	-0 .10	-0.15

Table 3. Compensating variation according to the consumer types (% of food budget)

Nutritional impacts

Tables 4 and 5 show the impacts of the dietary changes on the consumption of nutrients. The variations in nutrient consumption differ across consumer categories. Some of them may have positive impacts on health (reduction in consumption of energy, sodium, saturated fats,), others may have negative impacts (fibers, lipids, calcium…).

	Modest	Lower average	Upper average	Well-off
Energy	-1,3%	-0,8%	-0,6%	-0,5%
Proteins	-2,4%	-1,6%	-1,3%	-1,2%
Available carbohydrates	-5,0%	-2,9%	-2,0%	-1,3%
Fibers	-2,1%	-0,4%	0,5%	1,2%
Lipids	0,3%	0,3%	0,1%	0,0%
Saturated fatty acids	-2,8%	-1,8%	-1,5%	-1,3%
Na	-4,2%	-2,8%	-2,2%	-2,0%
Ca	-5,4%	-3,4%	-2,6%	-2,2%
Free sugar	-1,1%	-0,3%	-0,3%	-0,2%

Table 4. Variations (%) in nutrient consumption

When seeking to aggregate this information into indicators of dietary quality, we find that the total impact of the consumption changes on nutritional quality is ambiguous. For the "modest" category, a decrease in the MER indicator indicates a favorable variation from a health point of view, mainly due to the reduction in salt-fat products, prepared meals, soft drinks, and cheese-butter consumption. On the other hand, the increase in F&V consumption is not sufficient to compensate the decrease in starchy foods, leading to a slight decrease in the MAR indicator. For the well-off category, the three indicators vary positively from a health point of view.

These results suggest that, at least for the lowest income categories, the adoption of only one constraint related to the F&V consumption, is not sufficient to guarantee an unambiguous improvement in dietary health.

	Modest	Lower average	Upper average	Well-off
MAR	-0.3	-0.2	-0.1	0.0
MER	-6.1	-3.5	-3.2	-2.3
ED	1.2	0.2	-0.5	-0.8

Table 5. Variations in nutritional indicators (%)

GHGE impacts

As shown in Table 6, the adoption of the F&V constraint induces a decrease in the level of GHGE. The decrease rate is greater for low-income consumers than for the well-off. This result may be surprising as the absolute variation in F&V consumption is smaller for the lowest income classes. It is likely due to greater decreases in red and cooked meats, milk and cheese consumption for those consumer groups.

Modest	Lower average	Upper average	Well-off
-1.8	-1.3	-1.0	-0.9

Table 6. Variations (%) in GHG emissions

Impact of the constraint level

In Table 7, we compare the effects of various constraint levels for the modest consumer category. First, we note that the compensating variation strongly increases when the constraint moves from 5 to 7.5%.

The increase in the constraint strengthens the decrease in the MER indicator but also the decrease in the MAR indicator and the increase in the energy density of the consumption basket. This result reinforces the conclusion that for the lowest income categories, the adoption of only one constraint related to the F&V consumption is not sufficient to guarantee non-ambiguous positive health impacts. Combining several constraints may be needed, but this may also lead to a strong increase in the compensating variation and welfare cost.

Level of F&V constraint	+ 2,5%	+5%	+ 7,5%
CV	-0,21%	-0,91%	-2,40%
Energy	-0,6%	-1,3%	-2,3%
Proteins	-1,1%	-2,4%	-4,3%
Available carbohydrates	-2,4%	-5,0%	-8,3%
Fibers	-1,0%	-2,1%	-3,4%
Lipids	0,2%	0,3%	0,2%
Saturated fatty acids	-1,2%	-2,8%	-4,9%
Na	-2,0%	-4,2%	-7,0%
Ca	-2,5%	-5,4%	-8,9%
Free sugar	-0,4%	-1,1%	-2,5%
MAR	-0,1%	-0,3%	-0,5%
MER	-2,7%	-6,1%	-11,0%
DE	0,6%	1,2%	1,9%
GHGE	-0,9%	-1,8%	-3,1%

Table 7. Comparison of the effects of 3 different F&V constraint levels for the ‘Modest’ consumer type

5. Conclusion

Given the growing evidence that food choices have a profound impact on human health and the environment, consumers are increasingly urged to modify the foods and nutrients that they purchase and eat. However, designing policies for sustainable consumption 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 analyse 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 dietary (e.g., “5-a-day”) or environmental norm (e.g., eat less meat).

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 and/or environmental impact data. The welfare implications of the adjustment are then straightforward to calculate as a standard compensating variation. We demonstrate the practicality of the approach by investigating how food consumption, dietary quality and greenhouse gas emissions would respond if French consumers increased their consumption of fruits and vegetables by five percent.

The results, though only illustrative at this stage, generate important insights. First, consumers would make large adjustments to their consumption of foods outside of the F&V group and, even within the F&V group changes in consumption would not be uniform across product categories. Hence, policies for the promotion of sustainable food choices, as an increase in the F&V consumption, should beware of unintended consequences, because *a ceteris paribus* assumption is not appropriate when foods substitute one another. Second, the large differences between shadow and actual prices of the F&V products suggest that fiscal measures are unlikely to be very effective in promoting F&V consumption, as large subsidies would have to be applied to generate small consumption changes. In these times of tight budget discipline, such high subsidy rates probably lie beyond the domain of the politically feasible. Third, promotion of F&V consumption on its own has an ambiguous effect on dietary quality, at least for some socio-demographic groups. This requires further investigation but also invites caution in the formulation of policies for the promotion of healthy and environmentally-friendly eating. Such policies may have to be more sophisticated than the appealingly simple "5-a-day" message.

There are many 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 sustainability goals. At another level, the model could also be used to infer consumers' willingness to pay for food products with modified nutritional properties.

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Appendix

Food categories

The 22 food categories are defined as follows: red meat (beef and veal); other meats (poultry, pork, lamb, etc.); cooked meats (ham, pâté, sausages, bacon, etc.); fish and seafood; eggs; grain products (bread, pasta, rice, wheat flour, and cereals); potatoes; fresh fruits; processed fruits; dried fruits; fresh vegetables; processed vegetables; milk products (milk, yoghurt, dairy desserts, etc.); cheese, butter, and cream; prepared meals (pizza, sauerkraut, etc.); oils; salt-fat products (finger food, chips, crackers, appetizers); sugar-fat products (candy, chocolate, cookies, pastry, ice cream, jam, etc.); mineral and spring waters; fruit and vegetable juices; other soft drinks (sodas, lemonade, syrups, etc.); and alcoholic beverages (including wine).

Data

	Price €/kg	Purchase / household (kg/month) *			
		Modest	Lower average	Upper average	Well-off
Red Meat	9,56	1,42	1,76	1,69	1,56
Other Meats	6,06	2,94	3,49	3,35	2,88
Cooked Meats	8,96	2,20	2,46	2,29	1,93
Fish & Sea Food	8,16	1,37	1,70	1,96	2,03
Eggs	2,63	0,93	1,02	1,02	0,87
Grain Products	2,11	2,75	2,69	2,44	2,08
Potatoes	0,88	2,17	2,33	2,54	1,96
Fresh Fruits	1,64	6,51	7,78	9,32	9,80
Processed Fruits	2,45	0,43	0,51	0,46	0,40
Fruit Juices	1,05	3,55	3,93	3,96	3,57
Fresh Vegetables	1,72	4,95	6,07	7,72	7,25
Processed Vegetables	2,59	1,78	1,83	1,63	1,30
Dried Fruits	6,58	0,10	0,12	0,15	0,16
Milk Products	1,43	14,22	14,64	13,33	11,25
Cheese, Butter &Cream	6,22	3,27	3,54	3,46	3,13
Prepared Meals	5,22	2,58	2,62	2,59	2,53
Oils & Margarin	2,63	1,43	1,43	1,36	1,11
Salt-Fat Products	6,67	0,35	0,36	0,35	0,31
Sugar-Fat Products	5,74	4,16	4,12	3,68	3,01
Soft Beverages	1,06	3,72	3,37	2,75	1,98
Mineral And Spring Water	0,28	13,93	17,05	19,03	17,56
Alcoholic Beverages	3,73	4,84	6,00	7,00	7,51

* per consumption unit

<u>Initial prices and consumption according to the consumer types (data from Allais et al. 2010)</u>

Expenditure elasticities for 'Modest'

	Red Meat	Other Meats	Cooked Meats	Fish & Sea Food	Eggs	Grain Prod.	Potat.	Fresh Fruits	Proc. Fruits	Fruit Juices	Fresh Veget.	Proc. Veget.	Dried Fruits	Milk Prod.	Chees. Butter Cream	Prep. Meals	Oils & Margar.	Salt-Fat Prod.	Sugar-Fat Prod.	Soft Bev.	M. & S. Water	Alc.. Bev.
Modest	1,151	1,117	0,970	0,527	1,376	1,282	1,177	1,390	1,996	0,684	0,646	1,329	0,064	1,264	0,749	1,996	0,627	0,397	1,228	0,810	0,937	-0,051

Price elasticities for 'Modest'

	Red Meat	Other Meats	Cooked Meats	Fish & Sea Food	Eggs	Grain Prod.	Potat.	Fresh Fruits	Proc. Fruits	Fruit Juices	Fresh Veget.	Proc. Veget.	Dried Fruits	Milk Prod.	Chees. Butter Cream	Prep. Meals	Oils & Margar.	Salt-Fat Prod.	Sugar-Fat Prod.	Soft Bev.	M. & S. Water	Alc.. Bev.
Red Meat	-1,627	0,127	0,214	0,218	-0,058	-0,121	-0,031	0,255	0,000	0,039	-0,177	-0,024	0,008	0,125	-0,085	-0,176	-0,013	0,048	-0,061	0,039	0,130	0,019
Other Meats	0,098	-0,945	0,105	-0,035	0,002	-0,035	-0,017	-0,146	-0,017	-0,007	-0,095	-0,113	0,007	-0,126	0,196	0,059	-0,022	0,067	-0,006	0,057	0,062	-0,207
Cooked Meats	0,158	0,108	-0,649	-0,010	-0,047	0,049	-0,015	-0,041	-0,010	-0,074	0,019	0,025	0,003	0,065	-0,051	-0,096	-0,035	-0,017	-0,211	-0,030	-0,001	-0,109
Fish & Sea Food	0,297	-0,005	0,024	-1,699	0,057	0,179	0,046	-0,360	0,011	-0,056	-0,053	0,037	-0,030	-0,083	-0,093	0,978	-0,019	0,013	0,065	0,004	-0,030	0,188
Eggs	-0,329	-0,005	-0,407	0,215	-0,591	-0,015	0,040	-0,067	-0,039	-0,047	0,103	0,010	0,031	-0,034	-0,543	0,046	0,200	0,263	-0,315	0,064	0,177	-0,133
Grain Products	-0,288	-0,120	0,136	0,308	-0,005	-0,959	0,008	-0,059	0,039	0,124	-0,028	0,004	0,016	0,184	-0,220	-0,181	0,044	-0,105	-0,179	-0,056	0,110	-0,057
Potatoes	-0,226	-0,172	-0,179	0,249	0,056	0,029	-0,549	-0,042	0,052	-0,321	0,810	-0,010	-0,003	0,073	0,240	-0,580	-0,108	-0,126	0,211	-0,313	-0,255	-0,012
Fresh Fruits	0,298	-0,259	-0,113	-0,419	-0,015	-0,034	-0,009	-0,057	-0,015	0,033	-0,065	0,014	-0,010	-0,070	-0,282	0,109	-0,040	-0,017	-0,245	0,048	0,078	-0,319
Processed Fruits	-0,053	-0,353	-0,269	0,039	-0,095	0,188	0,081	-0,184	-0,608	-0,031	-0,098	-0,170	-0,073	0,558	-0,532	-0,343	-0,606	0,199	-0,219	0,155	0,618	-0,199
Fruit Juices	0,171	0,002	-0,361	-0,180	-0,023	0,210	-0,155	0,134	-0,002	-0,868	0,039	-0,006	0,033	0,203	-0,087	-0,075	0,028	0,023	0,305	0,143	0,035	-0,253
Fresh Vegetables	-0,244	-0,156	0,073	-0,076	0,038	-0,002	0,180	-0,044	-0,005	0,017	-0,204	0,008	0,026	-0,140	0,242	0,264	-0,056	0,098	-0,161	0,015	-0,010	-0,511
Processed Vegetables	-0,082	-0,451	0,072	0,048	0,006	0,004	-0,005	0,036	-0,037	-0,017	-0,012	-0,952	0,007	0,089	0,054	-0,076	-0,036	0,028	-0,091	0,062	0,122	-0,097
Dried Fruits	0,239	0,291	0,174	-0,508	0,135	0,180	0,002	-0,104	-0,116	0,202	0,370	0,079	-1,694	-0,942	-0,118	1,053	0,054	0,086	0,068	-0,328	0,212	0,602
Milk Products	0,075	-0,122	0,035	-0,086	-0,003	0,053	0,006	-0,031	0,034	0,027	-0,084	0,021	-0,033	-0,837	-0,139	0,036	-0,044	0,029	-0,100	0,061	-0,019	-0,142
Cheese, Butter &Cream	-0,030	0,202	-0,028	-0,064	-0,059	-0,048	0,026	-0,119	-0,022	-0,017	0,098	0,025	-0,006	-0,090	-0,303	0,001	0,051	-0,156	-0,182	-0,031	0,012	-0,009
Prepared Meals	-0,231	0,005	-0,236	0,753	0,001	-0,099	-0,088	0,058	-0,028	-0,044	0,115	-0,041	0,044	-0,016	-0,118	-1,377	-0,046	-0,072	-0,233	-0,129	-0,036	-0,179
Oils & Margarin	-0,012	-0,062	-0,152	-0,064	0,140	0,087	-0,049	-0,078	-0,170	0,029	-0,128	-0,029	0,007	-0,179	0,286	-0,076	-0,556	0,244	0,221	0,063	-0,074	-0,077
Salt-Fat Products	0,325	0,569	-0,091	0,069	0,288	-0,235	-0,093	-0,027	0,101	0,041	0,368	0,075	0,022	0,339	-1,312	-0,305	0,395	-1,038	0,389	-0,245	-0,236	0,204
Sugar-Fat Products	-0,039	-0,014	-0,197	-0,007	-0,031	-0,042	0,016	-0,104	-0,006	0,038	-0,082	-0,016	-0,002	-0,082	-0,202	-0,082	0,024	0,029	-0,476	0,023	-0,009	0,033
Soft Beverages	0,157	0,285	-0,135	-0,005	0,047	-0,069	-0,145	0,165	0,050	0,134	0,027	0,085	-0,056	0,363	-0,165	-0,365	0,057	-0,152	0,185	-0,990	-0,048	-0,235
Mineral And Spring Water	0,468	0,300	-0,005	-0,110	0,119	0,177	-0,121	0,245	0,182	0,030	-0,034	0,155	0,033	-0,067	0,043	-0,058	-0,078	-0,151	-0,021	-0,052	-1,855	-0,138
Alcoholic Beverages	0,091	-0,113	-0,027	0,154	-0,002	0,018	0,009	-0,126	-0,002	-0,041	-0,224	0,004	0,022	-0,040	0,067	-0,008	-0,005	0,033	0,189	-0,037	-0,013	0,101

Expenditure and price elasticities for 'Modest' consumer type (for the other types, see Allais et al., 2010)