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Modelling the likely impact of healthy eating guidelines on agriculture in England & Wales

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Abstract— Household food consumption data is used to estimate likely changes in diet under healthy eating guidelines, and the consequences this would have on the agricultural sector in England and Wales. The first step entails imposing nutrient restrictions on food consumption following dietary recommendations. The resulting diet is then used as a proxy for demand in agricultural commodities, to test the impact of such a scenario on agricultural land use and production.

Results of the diet optimisation indicate a severe drop in foods rich in saturated fats and sugar, essentially cheese and sugar-based products, along with lesser cuts in fat and meat products. Conversely, consumption of fruit & vegetables, cereals, and flour would increase to meet dietary fibre recommendations. Such a shift in demand would dramatically affect production patterns: the margin of England and Wales agriculture would rise, due to increased production of high market value and high margin crops. Some regions would however be negatively affected, mostly those regions dependent on beef and sheep production that could not benefit from an increased demand for cereals. The effects of these changes would also be felt in upstream industries such as feed suppliers.

Keywords— Dietary guidelines, land use, agricultural production.

I. INTRODUCTION

We apply linear programming techniques to household food consumption data to estimate likely changes in diet under healthy eating guidelines, and the consequences this would have on the agricultural sector in England and Wales. The first step entails imposing nutrient restrictions on food consumption following dietary recommendations suggested by the Department of Health. The resulting diet is used in a second step as a proxy for demand in agricultural commodities, to test the impact of such a scenario on

agricultural land use and production in England and Wales.

II. DATA

A. Healthy eating

There is no fundamental difference between recommendations on healthy eating given by different government agencies (DoH [1], USDA [2], WHO [3]), and divergences can be attributed to the difficulty to give guidelines that would suit every situation of age, gender, physical activity, *etc.* They are summarised in Table 1 below.

Total fat is restricted to a third of energy intake, with attention given to specific fatty acids, like saturated (SFAs) and trans fatty acids (TFAs), which increase the levels of blood lipids and the risk of coronary heart disease. Cholesterol, which is source of the same kind of condition, is restricted as well.

Table 1 Nutrient intake recommendations (DoH [1])

Nutrient	Amount
Total fat	33%
Saturated fatty acids (SFAs)	10%
Monounsaturated fatty acids (MUFAs)	12%
Polyunsaturated fatty acids (PUFAs)	6 to 10%
Trans fatty acids (TFAs)	< 2%
Glycerol	3%
Cholesterol	< 300mg.day ⁻¹
Protein	10 to 15%
Total carbohydrate	50%
Free sugars	< 10%
Salt (sodium equivalent)	< 6 g.day ⁻¹ (<2.36 g.day ⁻¹)
Fruits and vegetables	≥ 400g.day ⁻¹
Total dietary fibre	≥ 18g.day ⁻¹

Conversely and to offset the intake of those fatty acids, levels of mono- or polyunsaturated fatty acids (MUFAs and PUFAs) are kept high. Protein and sugar (either free or as total carbohydrates) are restricted too, and so is sodium (salt), one of the very few minerals for which guidelines are given. Fruit and vegetables on the contrary are encouraged, as are dietary fibre. Although physiological requirements vary with age, gender, *etc.*, suggestions for men are 2,500 kcal per day, and 2,000 for women.

B. Household consumption

Household consumption is provided by Defra [4]; it has been collected through the Expenditure & Food Survey (EFS) for 2003-2004, a UK-wide survey of around 7,000 households recording individuals' food consumption, including meals eaten out, soft drinks, confectionery, *etc.* Data is presented as a weekly average of food consumption at the individual level for 24 major food groups (*e.g.*, all milk and cream), which are further subdivided into 167 minor food groups (*e.g.*, infants milk).

Conversion tables are available, which allow estimation of specific nutrient intakes from the quantities of food consumed.

III. MODELS

A. Food consumption

Following Srinivasan *et al.* [5], we use a quadratic programming model, assuming that consumers will adhere to the recommended nutrient intakes by minimising the changes this would imply for their existing diet. The rationale is that dramatic changes would not be realistic, as observed diets are a reflection of people's preferences. Besides, minimal changes would entail only minimal expenditure changes, thus allowing omitting any budget constraint.

The objective function to be minimised over the 167 minor food groups is:

$$\min [x_i^*] = \sum_{i=1}^F \alpha_i \left(\frac{x_i^* - x_i}{x_i} \right)^2, \text{ with } \alpha_i = \left(\frac{e_i x_i}{\sum_{i=1}^F e_i x_i} \right) \quad (1)$$

where x_i represents the actual consumption of food item $i = 1, \dots, F$, and x_i^* is its optimised level; α_i is

the contribution of food item i to the total existing energy intake, computed from the consumption level of item i and its caloric coefficient e_i . Equation (1) is thus the weighed sum of the squared deviations expressed in percentage, between existing and optimised levels of consumption.

This optimisation problem is constrained by the different dietary requirements detailed above: given the food consumption in grams per person and per week for each food item, we compute the energy equivalent derived from their content in fat, protein and sugar. Further constraints are added such as constant energy and alcohol intakes (alcohol being a fat-free, calorie-dense item).

B. The Land Use Allocation Model (LUAM)

In the LUAM, agriculture in England and Wales is perceived as if it were a 'single' farm, employing a variety of production activities to produce the various outputs using a range of inputs and resources, on different types of land. Land has been partitioned into 15 Land Classes and, within each of these, four major land types are distinguished: arable, leys, permanent pasture and rough grazings. While the model offers a limited possibility of 'converting' land from one type to another, land of any type is not transportable across Land Classes.

The mathematical structure of the LUAM is that of an ordinary LP model, that is:

$$\max Z = cx, \quad \text{subject to } \begin{cases} Ax \leq b \\ x \geq 0 \end{cases}, \quad (2)$$

where Z is the objective function given as the scalar product of c and x vectors, b is the resource endowment and input availability vector, c is the vector whose elements are returns and costs, and x is the output vector. A is the matrix of input/output coefficients a_{ij} representing the amount of input i required per unit of output j .

Within each Land Class a range of possible activities and associated inputs is available. Altogether, the model considers over 600 agricultural production activities and, for each Land Class, such activities 'contribute' to and 'draw upon' the England and Wales outputs and input use as reflected in the annual Government estimates. Thus, the aggregate output and the input quantities and resources needed to

produce it are specified as 'balance equations' which 'close' the model. This means that a given volume of output must be produced, but it is up to the model to distribute production over the various Land Classes. Further details can be obtained from the authors or from the literature (Hossell *et al.* [6], Jones *et al.* [7]).

IV. RESULTS

A. Consumption under healthy guidelines

Regarding nutrient intake, there is no marked difference between English regions and Wales for most nutrient groups; protein and cholesterol are within the suggested levels, fats are slightly over the limit, mainly due to SFAs which are over 14% for all regions, the recommended maximum being 10%. Sugar levels are also over the suggested limit of 10%. Dietary fibre intake does not reach the recommended level of 18g per day, the average hovering around 13g. The fruit and vegetables intake is under recommendations as well, Wales being 100g below guidelines, the East being the highest, still reaching only 350g per day. Wales has a slightly higher fat, sugar and sodium intake than England as a whole.

Concerning consumption changes, food groups that would see a decrease are predominantly cheese (down by almost 80% in Wales), then sweet products like confectionery (down by 35%). Fats are reduced by about 20%, while biscuits, other foods, carcass meat, soft drinks, and dairy hover around -15%. Cakes, non-carcass meat and eggs are reduced by around 5%.

Increased consumption would occur for all fruit and vegetables groups including potatoes (from 55% for potatoes and fresh fruit, to over 80% for fresh vegetables). Cereals would increase by about 30%, processed vegetables and fish by more than 30%, bread by 40%, flour by 50%.

B. From food products to farm commodities

In order to supply the LUAM with a shift in demand for agricultural products, the above household consumption figures have to be converted into equivalent production volumes. In the case of unprocessed food groups such as fruit and vegetables or meat, the conversion is straightforward. Processed

foods or food groups including diverse food items require, however, a more practical approach based on existing literature (McCance and Widdowson [8]) and data from food manufacturers and retailers retrieved from the internet. The result is a conversion matrix from household consumption into a range of farm-gate commodities. Table 2 reports consumption changes for different products.

C. Ensuing production changes

1. *Scenarios assumptions:* Concerning prices and technology, the Reference run of the model is based on 2006 plus any institutional price changes anticipated as a consequence of the implementation of the 2003 reform of the CAP. The scenario provisions address the issue of supply and demand directly: for demand, the scenario supposes that there is a significant consumption shift towards healthier foods, in order to achieve a more balanced diet. Therefore, the model's restraints have to be adjusted to reflect new upper maxima for each commodity. Demand is thus exogenously set, while supply is endogenously determined, based on resource availabilities and economic margins. Furthermore, it is assumed that the proportion of domestic demand met by domestic supply remains unchanged.

Table 2 Demand changes for various commodities under healthy eating guidelines.

	Reference	Scenario	Change
Milk	7,727	4,447	-42.20%
Beef & Veal	444	377	-15.46%
Mutton & Lamb	128	93	-28.16%
Pork	435	350	-18.23%
Poultry	518	577	9.81%
Eggs	18	16	-9.61%
Fish	251	352	35.88%
Cereals	2,415	3,134	29.76%
Sugar	684	454	-31.38%
Oils & Fat	355	339	-5.24%
Potato	3,010	3,791	23.41%
Green Vegetables	913	1,421	55.62%
Other Vegetables	1,334	2,215	66.08%
Fruit	1,766	2,696	52.69%

Units: g, ml or eggs per person per week.

Table 3 Production volumes and area under reference and scenario runs

Enterprise	Volumes (€m)			Land use (1,000ha)		
	Ref.	Sc.	Δ%	Ref.	Sc.	Δ%
Wheat	1,082	1,082.0	0%	1,685	1,685	0%
Barley	272	276.9	1.8%	624	635	1.8%
Oats	30	35.9	19.5%	104	124	18.6%
Other cereals	2	3.3	64.5%	46	76	-27.5%
Peas & beans [†]	70	56.0	-20.0%	228	183	-20.9%
Potatoes	425	524.5	23.4%	133	164	23.5%
Sugar beet	168	115.2	-31.4%	124	85	-40.2%
Oilseeds	289	274.3	-5.1%	497	472	-4.7%
Field veg.	865	1,223.1	41.4%	169	239	48.2%
Top fruit	250	391.0	56.4%	29	45	54.3%
Soft fruit	220	442.6	101.2%	8	16	104.6%
Milk	1,929	1,115.0	-42.2%	1,763	1,019	-42.2%
Beef (meat)	1,358	1,147.5	-15.6%	1,977	1,671	-11.2%
Sheep (meat)	634	455.2	-28.2%	1,724	1,238	-27.6%

[†]Assumption based on a rise in demand for milling wheat, cancelled out by a large fall in demand for feed wheat.

[‡]For stock feed only.

2. *Output volumes and land use:* While the changes in production volume are largely reflected in the changes observed in the national area of each enterprise, Table 3 shows some interesting anomalies. Driven by increased demand, the volume of Other cereals (*e.g.*, rye, triticale) increases by 64% while the area falls by a little over 27%: this is achieved by the transfer of existing production away from some regions, particularly the North and Midlands, into others *e.g.*, the East, where yields are higher. In the case of field vegetables, the volume of output increases by 41%, while the area produced increases by 48%. This is explained by the fact that a significant part of additional production takes place in regions more marginal for vegetable production where yields are lower than those found in the East.

3. *Production by sector:* In gross volume terms, there is only a very modest rise in the supply of cereals. This occurs because the large percentage increase in demand for milling wheat is cancelled out by a drop in demand for feed wheat. Also, the large percentage rises in demand for other cereals are applied to very small base areas. As a consequence there is little pressure to readjust production of cereals over the regions. Concerning oilseeds, the production area is projected to decline only marginally (-4.7%),

and so no major regional distributional changes are expected.

Driven by a 42% fall in demand for milk, livestock numbers fall by a similar percentage, affecting most regions. Production holds up relatively well in the traditional dairy heartlands of Wales, with the most extreme losses seen in the East and West.

Demand for beef falls by 15%, driving an 11% fall in the size of the national herd. Losses occur in the major producing regions, particularly the North, but production holds up in Wales and in the West. It is possible that beef numbers are holding up best in mixed farming environments and suffering where specialist beef farming predominates.

Lamb consumption falls by 28%, driving a similar reduction in the national flock. Production is lost from the North and West, while it is maintained in the East.

D. Farm labour & financial performance

The cost of labour is £2,103.3M in the Reference run, falling to £1,835.7M (a drop of 12.7%) under the Scenario run. This fall is largely due to the significant reductions in the production of livestock, particularly dairy, as these are labour intensive enterprises.

The Gross Margin of England and Wales agriculture, excluding Pillar I and agri-environment schemes, is £331.3M under the Reference run. This rises under the scenario conditions to £766.5M, an increase of 131.4%. This increase is largely due to the fact that the demand changes that drive the scenario cause a contraction in production of low margin enterprises such as beef and sheep and an increase in production of higher margin enterprises. As these expanded horticultural enterprises tend to be in the East, this will result in a divergence in performance in England and Wales agriculture. The East will see farm incomes and labour use maintained and even rise, while the remaining regions, particularly those traditionally depending on livestock, will fare badly.

V. DISCUSSION

A. Household consumption

To a large extent, results for food groups are as could have been expected, given the existing amounts

of nutrient intakes: protein and cholesterol levels are within the limits, and so are total fats, but SFAs are quite over the limit, and so is sugar. Finally, intake in fruit and vegetable and dietary fibre is insufficient.

As a consequence, consumption of foods rich in fibres and unsaturated fats increases (fruit and vegetables, cereals, fish). Bread and flour see a large consumption increase, as they are a good source of carbohydrates, with almost no fat, protein or sugar content. Conversely, consumption of food groups rich in saturated fats, protein or sugar, decreases: the most dramatic change is for cheese, followed by soft drinks and confectionery. Fats and meat products are somewhat less affected.

B. Consequences for agriculture

Regions more heavily dependent on beef and sheep production would be the hardest hit. The loss of demand for livestock is however compounded by other factors. First, there would be increased competition for market share from lowland dairy producers who would take up sheep to make use of slack pasture. Second, these more remote, pasture dominated regions are not well suited to the production of arable crops, or fruit and vegetables, and so alternatives to livestock production are limited. Existing arable production in these regions tends to be dominated by feed crops and will thus not benefit from growth in demand for cereals, which is confined to milling varieties.

C. Conclusions

The margin of England and Wales agriculture would rise as a consequence of a switch to a health conscious diet due to increased production of high market value and high margin crops. However, large parts of British agriculture, *i.e.* livestock producers and those in agronomically less-favoured regions, would not be able to capitalise on these opportunities and would experience loss of markets and low prices. Structural change in these areas would likely be extreme, with declines in the number of farm businesses and average farm sizes increasing. If land prices fell far enough, it would be economical for land to be bought for extensive livestock production, *i.e.* ranching. However, it is also possible that land prices would remain high due to demand for land from urban

dwellers for hobby farming and lifestyle reasons. Under these circumstances, existing farmers would be priced out of the market and the farming landscape would become very fragmented, with large numbers of small non-commercial holdings. Loss of farm labour in these areas would have significant detrimental effects on local rural economies and migration pressure to urban areas would increase.

The effects of these changes would be felt also in upstream industries, particularly feed suppliers. With fewer livestock to feed, it will be feasible to introduce more grass-based production systems, particularly in the West and Wales, where stocking rates will have to decline. There may be environmental gains arising out of this, but in more marginal upland areas and on calcareous grasslands in southern regions, problems may arise due to a lack of grazing management. Environmental gains are unlikely in the East, where horticulture will expand, together with the use of poly-tunnels and irrigation.

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