Chronic Diseases: Chronic Diseases and Development 2

Health, agricultural, and economic effects of adoption of healthy diet recommendations

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Transition to diets that are high in saturated fat and sugar has caused a global public health concern, as the pattern of food consumption is a major modifiable risk factor for chronic non-communicable diseases. Although agri-food systems are intimately associated with this transition, agriculture and health sectors are largely disconnected in their priorities, policy, and analysis, with neither side considering the complex inter-relation between agri-trade, patterns of food consumption, health, and development. We show the importance of connection of these perspectives through estimation of the effect of adopting a healthy diet on population health, agricultural production, trade, the economy, and livelihoods, with a computable general equilibrium approach. On the basis of case-studies from the UK and Brazil, we suggest that benefits of a healthy diet policy will vary substantially between different populations, not only because of population dietary intake but also because of agricultural production, trade, and other economic factors.

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Introduction

Profound inequalities in access to food exist between the 1 billion people worldwide who are estimated to be undernourished and the many millions who have over-abundant access to diets that are rich in calories but low in mineral and vitamin density.[1] Concurrently, a transition to diets high in saturated fat (mainly meat and dairy foodstuffs) and sugar, and low in staple foods such as cereals, fruits, and vegetables, is occurring in all but the very poorest of countries.[2,3] This transition is causing global public health concern, because patterns of food consumption are a major modifiable risk factor for three of the most common types of chronic non-communicable diseases: cardiovascular disease, diabetes, and some cancers.[4]

Six risk factors related to nutrition (including high blood pressure, high blood glucose, overweight, and obesity) account for 19% of deaths worldwide.[5] A rapid increase in the burden of chronic disease is affecting populations at all stages of economic development, and 80% of all deaths from chronic disease now occur in low-income countries.[6] In response to rising burdens of these diseases, a major global health emphasis is needed to develop and implement policies to secure a healthy diet.[7]

Since the 1980s, the introduction of market-led agricultural policies, international emphasis on trade liberalisation, and increased foreign direct investment by large transnational food companies has profoundly altered the competitive dynamics of the worldwide food system, with effects globally, nationally, and locally.[8,9] Increased globalisation of **agri-food** systems has affected the availability and access to food through changes in food production and distribution, facilitating shifts in food culture, patterns of dietary consumption, and nutritional status.[8]

Investigations into the effects of population-scale change on diet have largely concentrated on outcomes related to health, with little regard for the agricultural and global trade systems that produce, distribute, and market foods. Indeed, agricultural and health sectors are largely disconnected in their priorities and policy objectives. Typically, agricultural priorities centre on production and processing systems, markets, and livelihoods, with concern for food safety only as it affects trade, rather than on broad public health issues. By contrast, public health traditionally centres on agriculture insofar as it affects food security and food safety, with only recent consideration of agriculture's potential role in prevention of non-communicable diseases.[7,10] Neither sector considers the complex inter-relation between agri-trade, food consumption patterns, health, and development.[11,12]

Reduction of the burden of chronic disease through consumption of healthier diets than are consumed at present will probably benefit the health of millions of people, especially the poorest. However, such improvement will necessitate changes in agricultural production and trade worldwide, resulting in various winners and losers between sectors of the economy, rural and urban

Key messages

- The transition to diets high in saturated fat and sugar is causing global public health concern, and a major global health emphasis is needed to develop and implement policies to secure a healthy diet
- Adoption of a healthier diet will affect population health and agricultural production, trade, the wider economy, and livelihoods
- Epidemiological and economic modelling applied to case-studies of the UK and Brazil suggest that the UK would accrue pronounced health benefits and associated low costs from adoption of a healthy diet, whereas Brazil would gain little health benefit but would experience far more substantial economic costs than would the UK
- Our analysis suggests that the benefits of a healthy diet policy will vary considerably between different populations, not only because of population dietary intake but also because of agricultural production, trade and other economic factors
- An understanding of the effects on both national health and wealth, and of the potential winners and losers, is crucial to secure a sustainable food policy to maximise the health benefits offered by dietary change while minimising potential risks

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Agri-food is the sum of all activities involved in the production and distribution of agricultural food products

communities, and regions and countries. Awareness of the effects and tradeoffs between policy sectors is a central challenge for decision makers in a globalising world.

We show the importance of connection of these perspectives by estimating both how the adoption of a healthy diet (achieved through reduction of consumption of foods from animal sources in a population to meet international dietary guidelines for saturated fat intake) will affect population health through reduction in risk of non-communicable diseases, and also the potential effect of such a policy on agricultural production, trade, the economy, and livelihoods.

What is a healthy diet for reduction of non-communicable diseases?

A systematic review[13] of dietary recommendations defined by expert panels and published between 1990 and 2004 for the prevention of nutritional deficiencies and infectious and chronic diseases, identified a broad consensus across 94 reports. Consensual expert opinion suggests that healthy diets should contain large amounts of cereals, vegetables, fruits, and pulses, while limiting the amount of red and processed meat, resulting in a high intake of dietary fibre and micronutrients and a low intake of fats, saturated fatty acids, added sugars, and salt.[13]

In addition to maintenance of energy balance (total caloric intake *vs* total energy expenditure) and healthy weight, a healthy diet to provide adequate population nutrition and reduce chronic disease risk consists of: 15–30% of total energy as fat, of which saturated fat should be less than 10% and *trans* fatty acids less than 1%; 55–75% of total energy as total carbohydrate, of which added sugars should be less than 10%; 10–15% of total energy as protein from mainly plant sources; less than 5 g per day of salt; and more than 400 g per day of fruits and vegetables.[14]

Population health

Outcomes

Adoption of healthy diets in high-income countries would have substantial effects on patterns of population dietary consumption and health. For example, adherence to WHO dietary recommendations in Organisation for Economic Co-operation and Development (OECD) countries would mean a substantial decrease in the consumption of vegetable oils (by 30%), dairy products (by 28%), animal fats (by 30%), meat (eg, pork by 13·5% or mutton and goat by 14·5%), and sugar (by 24%), and a substantial increase in the consumption of cereals (by 31%), fruits (by 25%), and vegetables (by 21%).[15] In the UK, if diets matched nutritional guidelines, 70 000 premature deaths could be prevented each year,[16] with a saving to the health service of £20 billion every year.

In this study, we estimate the association of the adoption of healthy dietary intake of saturated fat, defined by WHO as a saturated fat intake of less than 10% of total energy intake[14]—with population cardiovascular disease risk. Although there are both animal and plant sources of saturated fat, the main dietary pathway towards reduction of saturated fat intake was assumed to be through changes in dietary intake of foods from animal sources, because these were the dominant sources of saturated fat in the diet in our case studies (table 1). Animal products account for 44% of the dietary fat (predominantly saturated fat) available for consumption globally,[19] although there are considerable regional variations. Cardiovascular disease is the world's leading cause of death, and although the number of deaths from such disease is highest in middle-income countries, it is rapidly becoming a major health burden in low-income countries.[20] Consistent laboratory and epidemiological evidence[14,21] links saturated fat intake with cardiovascular disease, largely via the fat's effect on serum cholesterol concentrations.

Modelling of case study countries

We did a modelling analysis for two representative case-studies: the UK, a high-income country, and Brazil, a middle-income country. The UK was chosen because there are reliable data for dietary intake, agricultural production, trade, and the economy. Estimates of average consumption of saturated fat for adults of working age (19–64 years) were obtained from the nationally representative National Diet and Nutrition Survey (NDNS),[17] which recorded the dietary intake of participants for 4 days with estimated portion sizes. NDNS data provide estimates of total saturated fat intake and source of dietary saturated fats organised by broad food category. For some food categories (eg, cereal-based products such as cake) the origin (plant or animal) of saturated fat was not known, and thus our estimates of saturated fat intakes from animal source are probably conservative.

	Age	Overall		All animal sources*		Meat and meat products		Dairy products	
		Present intake	Targeted reduction	Present intake	Targeted reduction†	Present intake	Targeted reduction‡	Present intake	Targeted reduction§
UK[17]	19–64 years	26·1 g per day (12·8% of daily calorie intake)	5·7 g (21·9%)	17·6 g (67·5%; 8·6% of daily calorie intake)	5·7 g (32·6%)	6·8 g (26·0%; 3·3% of daily calorie intake)	5·7 g (84·8%)	9·1 g (35·0%; 4·5% of daily calorie intake)	5·7 g (62·2%)
São Paulo, Brazil[18]	20–69 years	21·0 g per day (10·8% of daily calorie intake)	1·6 g (7·4%)	14·7 g (70·2%; 7·6% of daily calorie intake)	1·6 g (10·5%)	8·7 g (41·2%; 4·4% of daily calorie intake)	1·6 g (18·2%)	5·6 g (26·8%; 2·9% of daily calorie intake)	1·6 g (27·6%)

*The full list of animal sources of saturated fat used in the calculation was: milk and milk products, eggs and egg dishes, butter, meat and meat products, fish and fish dishes, and half the saturated fat in cereal and cereal products. †Non-animal sources of saturated fat intake remain constant. ‡Non-meat and meat product sources of saturated fat remain constant. §Non-dairy sources of saturated fat remain constant.

***Table 1:* Present saturated fat intakes and reductions needed to meet WHO guidelines of 10% calorie intake as saturated fat**

Brazil was chosen as the second case study because it is a mass agricultural producer and global exporter of food products, including animal food products, with a population that is undergoing a rapid dietary transition.[22] Brazil, along with the countries of the European Union (EU), China, and the USA, is one of the four major consumers and producers of meat (panel 1).[23] Brazil is the largest exporter of chicken and beef worldwide, and yet

Panel 1: Potential effect on Brazil of reduced meat consumption in high-income countries in quantities sufficient (<85%) to meet dietary guidelines

The nations of the European Union (EU), China, USA, and Brazil consume 66% of all global meat and produce 70% of the poultry, 83% of the pork, and 60% of beef worldwide.[23] However, shifts in global production and trade of meat between these players have been substantial, especially for Brazil.[24] In 1997–2007, Brazil's meat production increased by 130% for poultry, 96% for pork, and 58% for beef. In 2009, 27% of this meat was destined for export. Exports of poultry rose by 423%, pork by 641%, and beef by 858% from 1997 to 2007, resulting in Brazil becoming the largest exporter of chicken and beef worldwide.

With the globalised food system, the relation between meat consumption and production is complex. Reduced consumption of food from animal sources in some countries might have little or no effect on Brazil; for example, the UK is a fairly small market, and Brazilian exports could be reallocated elsewhere. Conversely, most Brazilian poultry exports go to China, where rates of consumption are increasing rapidly so relocation of resources might not be possible. Any effect of dietary change would depend on what meat and animal food consumption is reduced, and what the substitute food products are. If consumers started to eat less pork, the effect on Brazil would be substantially lower than it would be for reductions in beef and chicken. For example, because most exports of Brazilian chicken to the UK are of chicken used directly in food processing, a much larger negative effect would be seen if British consumers started to eat less processed chicken products and fast food than they do at present, and more lean chicken cuts as part of a healthier diet.

The effect on the Brazil meat economy would be striking if consumption declined across a range of high-income country markets in response to policies tackling unhealthy eating and non-communicable diseases. The EU, Canada, USA, and Japan consume 33% of chicken meat, 31% of pork, and 41% of beef. A reduction in consumption in these markets would have a substantial effect on the major world producers, including Brazil. Some of the present export volume could be shifted to growing markets such as China, Asia, Africa, and Latin America, but the price paid by consumers in low-income and transition-income economies is lower than that paid by consumers in high-income countries, affecting profitability.

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In Brazil, where 70% of meat production is for the domestic market, the greatest effect of dietary change in high-income countries would be felt by food companies that are reliant on exports. The effect of reduced meat exports will probably differ between regions and producers supplying these companies. In Brazil, meat production has become increasingly intensive and industrialised. By 1995, seven companies were responsible for 48% of the national production of broiler chickens.[23] For pigs and poultry, large companies control the entire production process, and contract small family farmers to raise livestock for slaughter. In the mid-west of Brazil, chicken is mainly produced in large industrial farms, which would be most affected by changed international demand. However, in the south of the country, where 68% of national poultry production is concentrated in four states, small family farmers would be most affected. Beef production is evenly distributed across Brazil compared with production of pork and poultry, with the bulk of export beef production concentrated on large farms, which would be disproportionately affected by shrinking international markets compared with small farmers who produce beef for the domestic market. Although reduction in demand for meat will affect all states to some extent, some areas might be more resilient because of an ability to shift agricultural production. However, regional differences in climatic conditions, soil, water, and other resources affect what alternative crops could be grown. For example, major Brazilian export crops such as cocoa, sugar, and coffee are mainly grown in coastal areas.

Because meat production and processing is a transnational business, Brazil could also be affected through its investments abroad. In Brazil, large meat companies have invested in overseas meat processing companies in the USA, Argentina, Paraguay, Australia, and the EU.[25]

There is substantial foreign direct investment in Brazilian livestock. For example, Tyson, the US poultry producer, and Frangosul Doux (France) are responsible for around 10% of Brazilian exports of chicken and 7% of pork.[26,27] This global web of investments can provide companies with the flexibility to absorb declines in some markets with gains in others, and to cut production costs even further to offset any losses caused by reduced consumption.

Meat production is an increasingly globalised industry, in which national supply is not only affected by imports and exports between countries, but also by direct foreign investment by transnational companies. The potential effect of health policies needs to be considered within the global environment of cost cutting, competition, and liberalisation of meat markets. Reduction of meat consumption in high-income countries could intensify competition to supply meat to markets in other parts of the world, and augment the imperative for companies to add value (via processing) to meat intended for consumption by consumers of small quantities of meat.

Panel 2: **Computable general equilibrium models**

History and use

Computable general equilibrium (CGE) models are not new. Applied general equilibrium models were pioneered by Scarf in 1967,[41,42] and models that used the broad techniques and data types akin to the one in our report have increased in popularity since the advent of the general algebraic modelling system (GAMS) in the mid-1980s. Advances in mathematical programming have produced fast and efficient solvers that, together with the advancement of computer hardware and software, have enabled the resolution of large systems of equations. These systems of equations are reliant on economic datasets that, in turn, are often derived from very large databases.

Nowadays, many different CGE models are in use, from one-country, comparative-static (non-time dependent) models to dynamic (time dependent) and multicountry trade models. CGE models have been applied in many areas, including tax, trade, climate change, agriculture, food, and health-policies.

Selection of a model

Although the CGE framework is flexible, increased detail is accompanied by increased complexity. The amount of detail can be increased by: use of household survey data to disaggregate household consumption to show within-region differences in socioeconomic status; use of dynamics to multiply the times at which effects are measured; or multiplication of the dimension of the model to incorporate many countries or regions. An increase in detail is only of benefit if data exist to inform the extra assumptions. For our preliminary application of CGE modelling to healthy eating, a one country, non-time dependent model with a sole aggregate household was chosen as this technique was sufficient to provide the indicative results intended and was ideally suited to the sparse detail available to inform the model assumptions.

Limitations of CGE modelling

As for any simplification of actual data, CGE modelling is restricted by underlying assumptions. The microeconomic theory that underpins CGE modelling is well established and variations in the endogenous and exogenous factors are used to test the model results with variations in model assumptions. Exogenous economic data (such as elasticities) and the underlying database establish the reliability of the model outputs and, thus, for the application in this study, have been obtained from the highest quality sources.

The scenario assumptions themselves are a further limitation of the model (in our study, consumption and labour effects). Sensitivity analysis of these factors can be used to increase the robustness of results and has been done as part of this study. Perhaps the greatest limitation of CGE modelling is the volatility of global and national economies. Although a CGE model can be used to assess the economic effect of a policy change within the economy, an assumption of the model is that all other factors remain equal, which in practice is never the case. Although this assumption ensures that the cost estimates produced exclude confounding factors external to the policy under assessment, it restricts the predictive power of the model and complicates validation of model outputs.

retains more than 70% of its production for the domestic market, making it one of the largest meat consumers in the world. We obtained unpublished estimates of total dietary saturated fat intake in adults aged 20–69 years from a Household Health Survey[18] that was done in São Paulo, Brazil, in 2003 with a 24 h dietary recall method. São Paulo is the largest city in Brazil, and, for this analysis, dietary intake data were assumed to be representative of the average Brazilian diet, because of the absence of nationally representative data. Analyses for both countries were done on the basis of average dietary intakes for the population, and did not allow for individual, socioeconomic, and geographical variations that exist in diets in these countries.

Modelling interventions

We estimated that, to meet WHO healthy eating guidelines of no more than 10% of dietary energy as saturated fat, adults in the UK would need to reduce dietary saturated fat consumption by 22%, and adults in São Paulo by 7% (table 1). The potential effects of these dietary changes on the burden of adult ischaemic heart disease have been modelled by use of hazard ratios from a meta-analysis[28] of pooled data from 11 cohort studies that quantified the exposure–response relation between isocaloric replacement of dietary saturated with polyunsaturated fatty acids and ischaemic heart disease morbidity and mortality. Although the association between saturated fat intake and such disease is an area of some controversy,[29,30] consensus is emerging that replacement of saturated fat with polyunsaturated fats is beneficial for heart health.[31,32] Whether the benefits accrue from reduced saturated fat or increased polyunsaturated fat intake is unknown.[32]

We made no assumptions about, and did not model, the sources of dietary fat replacement, whether isocaloric replacement is possible, or whether the proposed dietary changes would result in potentially beneficial changes to diet such as an increased consumption of fruits or vegetables. Furthermore, to simplify the model and the main messages about the effect of dietary change, we assumed that changes would be adopted by the whole population immediately, and ignored temporal transitional effects. We did the modelling with the WHO comparative risk assessment methods,[33] and calculated health effects from the modelled changes in saturated fat intake relative to baseline values, relative risks of associated diseases, and baseline disease burdens, which were taken from WHO projections[34] for 2010 without time discounting or age weighting.

In the UK, a 22% decrease in population dietary saturated fat consumption could reduce the years-of-life lost from ischaemic heart disease by 7% and the years-of-life lived with disability from such disease by 4%. These figures equate to reductions of 7% in disability-adjusted life years and 3270 (3%) premature deaths averted in 1 year in the UK. In Brazil, a 7% reduction in dietary saturated fat consumption could reduce the years-of-life lost from ischaemic heart disease by 3% and years-of-life lived with disability by 2%. These figures equate to reductions of 3% of disability-adjusted life years and 2800 (2%) premature deaths averted in 1 year in Brazil.

Agriculture, trade, and the economy

Outcomes

Agriculture is a strategic sector in most countries, not only because of its role as a producer of food but also because it is a key contributor to the economy. In 2007, the three biggest export food commodities worldwide were fruit and vegetables (accounting for 24·3%

[US$151 billion] of total global food exports), cereals (19·2% [$119 billion]), and meat (14·8% [$88 billion]).[35] China and the EU are the biggest global producers of food by agricultural output and trade volume, although agriculture contributes less than 10% of their gross domestic product (GDP). By contrast, in many low-income countries, agriculture is the biggest sector of the economy, contributing 30–77% of GDP in many countries in sub-Saharan Africa and southeast Asia.[36] Agriculture is crucial for rural development, accounting for more than 50% of rural household income in many parts of the world. In low-income countries agriculture forms a large part of the labour force, with more than 1·3 billion people employed in agriculture worldwide, 97% of whom live in low-income countries.[35] In 2006, more than 50% of the total workforce in Africa and Asia was employed in agriculture, compared with only 2% in western Europe and North America.[35]

Agricultural products are traded worldwide, and national health policies or other interventions (eg, fat taxes or fruit and vegetable subsidies) that substantially shift national patterns of food consumption would affect not only domestic production but also international production and demand for food commodities. For example, a public-health policy aimed at reduction of dietary intake of saturated fat in the EU would lead to a decline in domestic demand for food from animal sources (and thereby production or import), and increased demand for substitute foods. Moreover, a reduction in imports of food from animal sources into the EU could alter the global demand for imports from Brazil, which would result in either increased domestic consumption, increased export to other countries, or reduced overall Brazilian production. These alternatives, especially reduced production, could have a substantial effect on the Brazilian economy (panel 1).

Simultaneous analysis of the health and economic effects of change in national dietary consumption patterns has not, to our knowledge, been previously attempted. We aim to show the importance of this holistic approach by analysis of the effect of meeting healthy dietary recommendations on agricultural production, employment, trade, and the economy. Our analyses are descriptive of the general effects of public health interventions nationally, and their relevance to policy development for dietary change.

Modelling approach

Our economic analysis was done on the basis of a computable general equilibrium (CGE) model of Brazil and the UK. Such a model specifies the economy in terms of several entities, including households, producers, and governments, from data in the form of a social accounting matrix for income and expenditure in the economy by sector (more on the application of CGEs to health is described elsewhere[37–39]). Our data are for 2004 and were taken from the Global Trade Analysis Project database.[40] The baseline model for every country approximates the present economy, and hence the amount of food production, employment, and trade, and the health effects of ischaemic heart disease on the labour supply and health service. Panel 2 describes the history and use of CGE modelling and the webappendix contains details of the CGE procedure.

See Online for webappendix

To estimate the effect of changes in dietary behaviour, the baseline model was modified (shocked) by one of three possible health strategies (reducing consumption of all foods from animal sources, only meat products, or only dairy products to meet WHO dietary guidelines for saturated fat intake; table 1). The shocks mainly affect the model in terms of labour supply, which increases because of reduced ischaemic heart disease mortality, and was

	UK	Brazil
Reduction in morbidity with adoption of a healthy diet*	4%	2%
Reduction in mortality with adoption of a healthy diet*	3%	2%
Employment rates[43–45]		
Overall	75% (men); 69% (women)	··
15–29 years	··	84% (men); 49% (women)
30–44 years	··	96% (men); 52% (women)
45–59 years	··	84% (men); 38% (women)
60–64 years	··	65% (men); 23% (women)
Working population[46,47]	25 245 000	74 361 808 (assuming average linear growth from 1997)
Number of working days per year	220 (52 weekends, 8 bank holidays, 33 days of entitled leave or other absence)	220 (52 weekends, 8 bank holidays, 33 days of entitled leave or other absence)
Number of working days lost[48,49]	1 152 000 (used for UK morbidity shock)	Average number per head: 43 (used for Brazil morbidity duration)
Reduction in animal source foods†	33% (domestic)	11% (domestic); 33% (international)
Reduction in meat and meat products†	85% (domestic)	18% (domestic); 85% (international)
Reduction in dairy products†	62% (domestic)	28% (domestic); 62% (international)

*Estimates from this analysis. †See table 1. ··=no data.

Table 2: **Assumptions made for estimation of effects of dietary change**

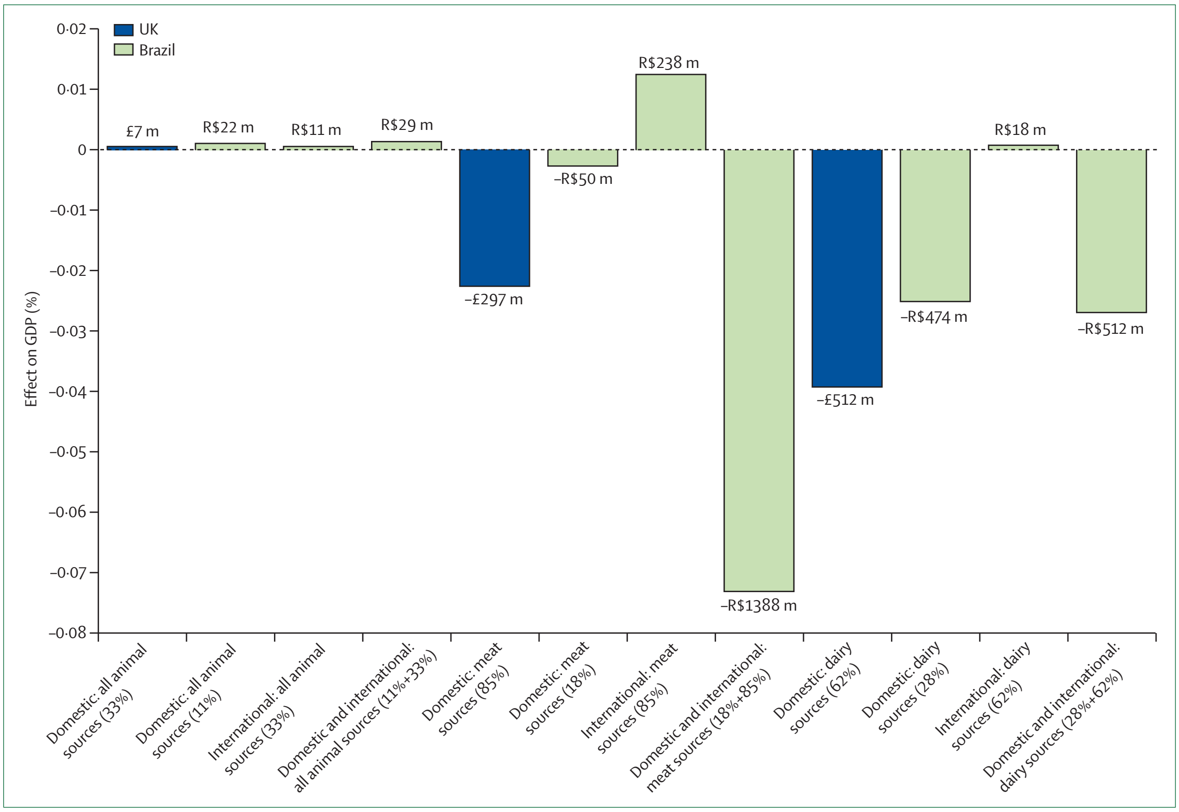

***Figure 1:* Effect of dietary changes with three policy strategies for reduction of foods from animal sources and four effect scenarios on GDP for UK and Brazil**
0·01% loss in GDP is equal to about £130 million for the UK and R$190 million for Brazil. Numbers are net costs and percentages in parentheses are modifications (shocks) made to the four economic effect scenarios.

adjusted for the demographic and sectoral profile of the country; labour productivity, which increases because of reduced ischaemic heart disease morbidity, and was adjusted; domestic consumption of agricultural products, in which production of meat and dairy falls; and imports and exports of agricultural products, in which production of meat and dairy also falls.

Model scenarios

Our estimates for labour effects were derived from data for absence because of sickness in both countries and the outputs from the comparative risk assessment models detailed previously: percentage reduction in mortality in the working-age population to estimate labour supply effects and percentage reduction in years-of-life lived with disability to estimate labour productivity effects (table 2). Domestic consumption and import and export estimates are endogenous to the model (economic activity in other sectors was adjusted automatically as a response to a change in agricultural demand). Economic data were triangulated with national sources of agricultural production and trade data. Reduction in consumption of foods from animal sources was assumed to result in reductions of the same magnitude in the production of livestock and other products from animal sources. This assumption is necessarily simplistic because various interconnected factors affect agricultural production, including international trade, waste, food prices, and sociocultural practices. However, the assumption provides a reasonable first approximation of the data.

For our model, we assumed that changes of a permanent nature in diet would result in changes to the structure of the economy specifically centred about what will substitute for the reduced production and consumption of meat and dairy products. In the absence of any data for this substitutive (and hence structural) effect, consumption shocks were implemented by use of a change in the domestic budget share. In our study, expenditure by households on the commodity that was shocked (eg, meat) was reduced by the required percentage, expenditure on the alternative unhealthy sectors (eg, food from all animal sources and dairy) was frozen, and the savings made from the reduction in spending on the shocked commodity shared across the remaining sectors. Similarly, export shocks, in which the quantity of domestic output overall was maintained and the burden of lost output was shifted to exports, resulted in a forced reduction in exports while domestic rates of output to the domestic market were maintained. This approximation is unrealistic, but provides a suggestion of the imperative for more evidence on these structural effects.

Our analysis was done to show four possible economic effect scenarios based on the application of the three animal source food based strategies (table 1): UK domestic effect (assumption of an effect only on UK domestic demand for food from animal sources); Brazil domestic effect (assumption of an effect only on Brazilian domestic demand for food from animal sources); Brazil international effect (assumption of an effect only on export demand for Brazilian food from animal sources); and Brazil combined domestic and international effect (effect on both Brazilian domestic and export demands for food from animal sources). A scenario in which UK domestic consumption remained constant but export demand fell was not modelled because it was not believed to be realistic.

Effect of dietary change

Effects of dietary change on overall GDP differed substantially by dietary strategy and effect scenario (figure 1). Reductions in dietary intake of foods from all animal sources has little effect, whereas changes in dairy product consumption have the most substantial effects, which epitomise the stringent cuts required in dairy production (compared with food from all animal sources) to meet health policy. The effect on GDP in Brazil is far greater than it is in the UK, which is intuitively correct, since the animal sector forms a smaller percentage of household expenditure in the UK (<0·08%) than in Brazil (0·17%). Furthermore, the health benefits to Brazil from the comparative risk assessment models to counterbalance costs to the agricultural sector are much smaller than they are in the UK.

The combination of domestic and international shocks seems to have the most severe effect in Brazil. Any reduction in domestic consumption of food from all animal sources, meat, or dairy leads to a reduction in expenditure by households. The savings resulting from this reduced expenditure are assumed to be spent equally between all sectors apart from the so-called unhealthy ones. In the international-only shock, there is a domestic increase in consumption of unhealthy products to absorb some of the surplus created through lost exports. This increase in consumption of unhealthy products results in a less drastic change in the economy than is noted in the other scenarios. In reality, this scenario would yield a large effect on Brazilian morbidity and mortality, which has not been modelled. However, our policy scenarios for meeting the healthy eating recommendations have small (<1%) effects on overall GDP.

However, the effects of the dietary strategy differ by sectors of the UK and Brazilian economies (figure 2). Consistent with the effect on overall GDP, policies associated with reduced consumption of all foods from animal sources have a smaller effect than those with reduced meat and dairy intake, which is again indicative of the different size of cuts required to meet the health policy. An overall negative effect on most sectors and a

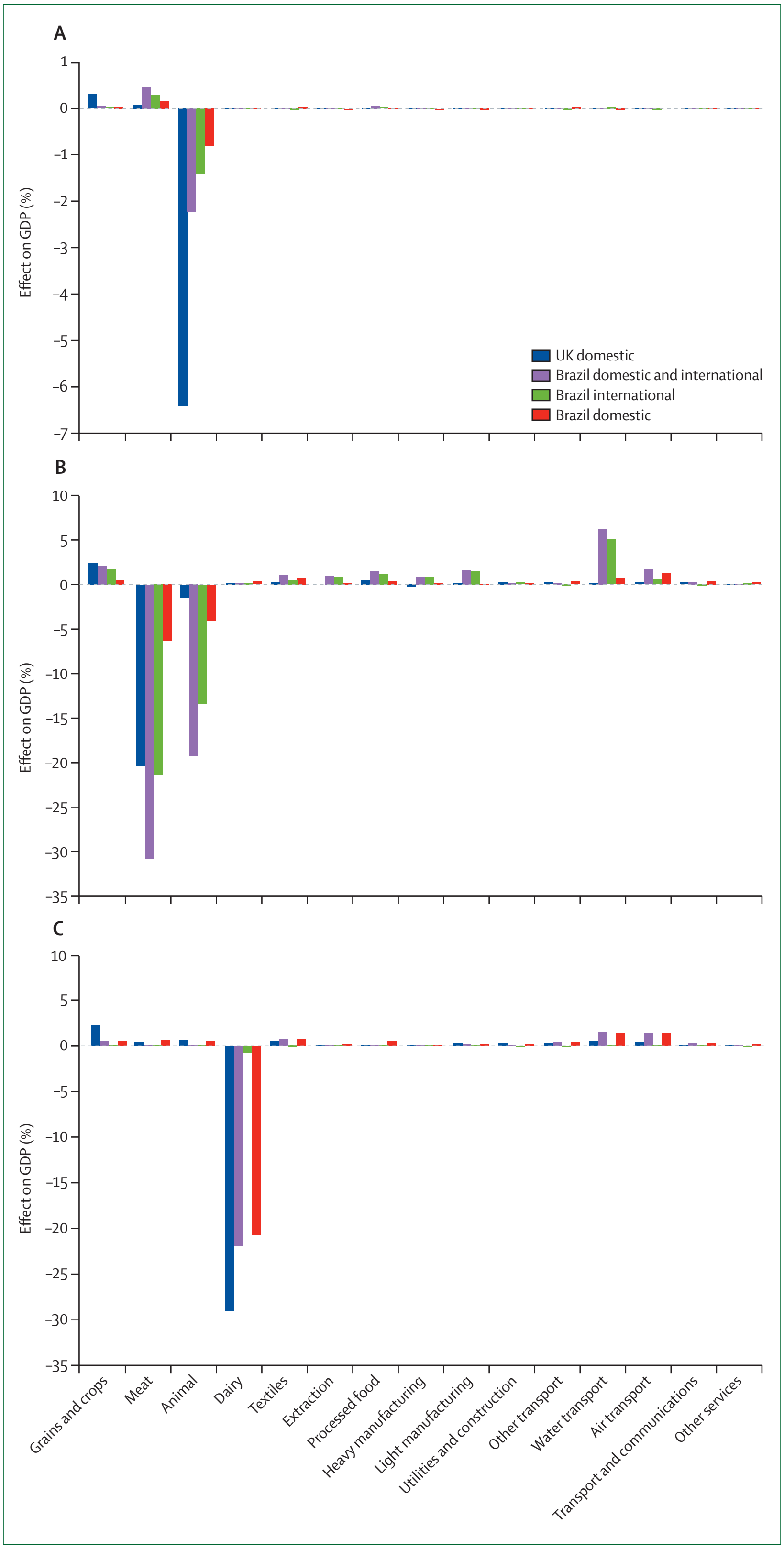

Figure 2: **Effect on GDP by sector of three dietary policy scenarios**
(A) All foods from an animal source. (B) Only foods from meat sources. (C) Only foods from dairy sources.

small increase in economic productivity of the grain and crop sector is consistent for all policies. For Brazil, effects on the relative contribution of each sector to GDP are largest for health policies that reduce meat consumption, whereas in the UK policies that reduce consumption of dairy products have the greatest effect. For a small number of sectors, adoption of a healthy diet would have a beneficial effect on GDP.

We did a sensitivity analysis of our estimations (webappendix pp 8–10), which suggested that changes in the model parameters yielded proportional changes in economic effect for all apart from the most extreme shocks and that variation of consumption and labour supply effects by 10% did not alter our conclusions.

Panel 1 shows a descriptive analysis of the potential effects to Brazil of reduced consumption and production of livestock and animal products, to show some possible outcomes and areas for policy and further research.

Discussion

We show the potential importance to public health of reduction of saturated fat intake to meet WHO healthy eating guidelines at a population scale. We suggest that the benefits of such a healthy diet policy will vary between populations, not only because of population dietary intake but also because of agricultural production, trade, and economic factors. Extrapolation of our case study results suggests that the potential direct health benefits of meeting recommended dietary guidelines might be greater in high-income countries than in lower income countries. However, our analyses show that the broad economic effects of such a policy will be unevenly distributed.

Although these overall effects might seem small compared with other severe economic events that have affected global diets (eg, the global financial crisis or recent food price spikes[50]), our analysis shows severe effects to individual sectors, especially agriculture in Brazil, which would result in large reductions in labour force requirements for that sector. Changes in spending concurrent with healthy eating would dictate which sectors grow in response to dietary change, such as fruit and vegetable production. The mobility of resources—particularly labour—from declining to increasing sectors will determine rates of employment and losses to people working in the affected sectors (notwithstanding the associated indirect threats to health and development of loss to livelihoods). Joint consideration of undernourishment in low-income countries and dietary overconsumption in middle-income and high-income countries could help with the transition between consumption patterns, minimise losses, and improve health benefits of dietary change.

Knowledge of the effects of dietary change on both national health and wealth, and of winners and losers from policy change, are essential to secure a sustainable food policy to maximise health benefits and minimise potential risks. Although our analyses are necessarily simplistic, our emphasis on combined health and economic effects shows the need to consider interactions between different policy sectors at different scales (ie, individual, regional, national, and international) in developing upstream non-health-sector policies to tackle non-communicable diseases. For instance, our analysis suggests that the UK would acrue substantial health benefits and associated low costs from adoption of a diet low in saturated fat from animal sources. Conversely, Brazil would experience little health benefit but far more striking economic costs from such a policy. Our analysis also suggests that health policy centred on reductions in intake of all foods from animal sources would create a smaller economic effect, and hence opposition, than would policies centred only on reduction of meat or dairy products. For the UK, in terms of secondary policy areas, a reduction in meat intake appears to have a smaller economic effect than a reduction in dairy intake, although this does not seem to be the case for Brazil.

Our study is an initial attempt to quantify the public health, agricultural, and economic effects of strategies to meet healthy diet recommendations for non-communicable diseases, and our analyses contain a number of limitations and assumptions. Some of these might have resulted in underestimates of the effect of dietary change on public health. For example, our health modelling was restricted to pathways leading from consumption of saturated fat to ischaemic heart disease, and we did not model the possible results for other health outcomes such as obesity, diabetes, and cancers related to diet. With our selected health outcome, our modelling was done only for adults. Although we have a recent source of nationally representative data for the UK, no similar national data were available for Brazil. The São Paulo survey was done in 2003 and, with the persisting dietary transition, might have underestimated present consumption of saturated fat. Our model did not consider the effect of various substitute foods—some of which, such as polyunsaturated fats, fruit and vegetables—will lead to additional reductions in cardiovascular disease.[31,51] Additionally, diet-related policies to reduce risk of obesity or non-communicable diseases are unlikely to focus solely on reduction of saturated fat intake but target a number of healthy eating recommendations that would further increase the health effect. For example, in Brazil, population intake of *trans* fatty acids or fruits and vegetables do not meet WHO dietary guidelines.[52,53]

Some of our assumptions might have overestimated benefits to health. We made no allowance for the variation in amounts of different saturated fatty acids in meat and dairy products, which have different effects.[54] We did not model the longitudinal effects of the dietary strategies, but assumed that implementation would result in immediate dietary change, although in reality the effect on disease burden will occur in time.[55] Finally, the effects should be considered against the present declining trends for cardiovascular disease in the UK[56] and Brazil.[57] However, for much of the world, rates of cardiovascular disease are rising,[20] and the effect for population health of such diet strategies will be large.

Our economic model also has limitations, most fundamental of which was the estimation of the long-term structural implications of changes in diet. For example, the effect on exports to Brazil had to be scaled back from 85% to 74% because that was the maximum rate that the model could interpret, suggesting that rates above 74% entailed fundamental change to the structure of the economy that cannot be resolved with movements between sectors. This finding suggests that change in a diet of a permanent nature will result in changes to the structure of the economy specifically centred on what will substitute for the reduced production and consumption of meat and dairy products. For instance, will such products be substituted by other foodstuffs or other goods and services? Will substitutes represent an equivalent domestic, import, and export profile?

Influences on these structural changes will encompass domestic and foreign consumer preferences, and the diversity of agricultural production and potential of the sector to adapt—which will itself depend on factors such as climate, soil, water, access to technology, and alternative production practices. Such a radical change in global consumption does not present an insurmountable problem for economic modelling per se, but rather is a challenge of securing data upon which to base structural adjustments.

Another major area for development is to allow for the gradual nature of change, as the temporal nature of dietary change and associated effect has been compressed (and hence treated as instantaneous) and thus not captured the real-time evolution of economic effects during several years. We also assumed that the reduction in dietary intake of foods from animal sources would result in directly commensurate reductions in production. This assumption is an oversimplification, because livestock products are globally traded commodities and various scenarios could result from reductions in domestic and international consumption (panel 1). A further area for development is the closer integration of comparative risk assessment and economic models, so that they encompass feedback loops; for example, the negative health effects associated with lost livelihoods. At present, our economic model simply takes the mortality and morbidity outputs of the comparative risk assessment model to be used as an input, creating a static, unidimensional, causal relation.

However, our analysis was designed to be illustrative and, despite these limitations, shows the importance of taking a more holistic assessment of strategies to reduce burden of non-communicable diseases. Although this is the first time CGE models have been used to value the macroeconomic effect of dietary policies on chronic non-communicable diseases, such models are widely used for policy analysis across sectors in many countries, including a range of public health issues such as acute infectious disease threats,[58] the health and economic effect of increased cigarette taxation,[59] and valuing ecosystem-mediated health benefits of climate change mitigation policies.[60]

Agriculture and trade policies are crucial determinants of what food is produced, sold, and consumed. To identify how agricultural policies can usefully contribute toward promotion of healthy diets and tackle non-communicable diseases related to diet, public health policy makers need to judge whether present agriculture and trade are contributing to—or detracting from—efforts to attain dietary goals, and how agricultural policy interventions could help achieve dietary goals. Concomitantly, policy makers also need to consider the broader trade-offs of such polices.

Awareness and assessment of where losses and gains accrue from policy, and the magnitude and timing of these changes, is crucial to secure policy coherence around agriculture, trade, development, and health agendas. For example, one report[61] explored the combined potential public health and climate change benefits of reduction of consumption of meat and products from an animal source. However, this study has not incorporated the wider effect of decreasing livestock production on economic development, especially effects on the rural economy and livelihoods of those employed in agricultural production. Policy priorities are likely to differ between countries dependent on a range of factors, including amount of economic development; strenght of markets; rural employment and income; population health; climate and the potential for production of substitute crops for both consumption and trade.[62] The public health community needs to address a range of economic, social, environmental and health objectives so that dietary recommendations are not just healthy but also sustainable which, taking account of the UN definition of sustainability, requires reconciliation of environment, social, and economic factors.

To achieve this aim requires advances in research. A shift needs to occur from traditional concerns related solely to health towards a more holistic assessment.[63] Development of new approaches is needed, and adaptation of existing approaches to help policy makers understand the trade-offs will have to be considered to achieve sustainable diets. Our research methods will need to be expanded to develop better cross-sectoral models that can take account of the potential health, trade, agriculture, and environmental implications of changes in diet for different policy scenarios. Interdisciplinary research is needed to reconcile the present methods of valuing and measuring outputs between the different sectors.

Contributors

KL, RDS, and ADD led the conceptual development of the study; ADD and KL developed the nutrition scenarios; ZC did the comparative risk assessment modelling; RDS supervised, and MKB did the computable general equilibrium modelling; GP and CH led the descriptive analysis of Brazilian agriculture; and KL wrote the first draft of the report. All authors contributed to the intellectual guidance, analysis, and subsequent drafts of the report.

Conflicts of interest

We declare that we have no conflicts of interest.

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