The effect on the UK economy of health co-benefits associated with climate change mitigation strategies

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Abstract

Objectives

To assess the potential impact on the UK economy of health co-benefits from strategies to meet 2030 UK greenhouse gas (GHG) emission reduction targets.

Design

A computable general equilibrium model was utilised to assess the macroeconomic impacts of health co-benefits for a range of illnesses and injuries, including changes in morbidity, mortality, healthcare costs and social security costs. Three greenhouse gas reduction scenarios were considered: 'Active Travel', 'Housing Insulation and Ventilation', and 'Healthy Diet' over the period 2010-2030 with differing periods of implementation depending on potential feasibility.

Setting

The active travel scenario was assessed for England and Wales, the other scenarios assessed UK-wide interventions.

Main Outcome Measures

Macroeconomic measures include GDP and GDP per capita; demographic measures include labour force and number of dependents; and public budget measures include healthcare costs and social security payments.

Results

Health co-benefits were estimated to generate net economic gains of around £24bn overall, with active travel contributing approximately £19bn, healthy diet £5bn and housing insulation and ventilation control £450m by 2030. The combined scenarios yielded an estimated health-related expansion of the labour force of around 7,700 workers per year (154,000 accumulated worker years over the 20 year horizon), and an accumulated increase in dependents (non-working age people) of around 19,000 per year. Sensitivity analyses suggest that the results are reasonably robust to changes in assumptions.

Conclusions

Strategies to reduce GHG emissions will improve health, which in turn is likely to result in substantial and increasing positive contributions to the economy which may offset some potential economic costs and thereby be seen more favourably in times of economic austerity. Although the numerical estimates should be seen as indicative they do suggest that policies that combine greenhouse gas reductions and health co-benefits are likely to be more attractive to policymakers than when considered in isolation.

Introduction

Evidence suggests that, in the absence of policies to greatly reduce greenhouse gas (GHG) emissions, major climate change could take place during this century. At global mean temperature increases of 2°C or more above pre-industrial levels, the likelihood of a range of serious impacts is high[1]. It seems likely that the 2°C threshold will be exceeded, in view of current rates of emission increases[2], with one estimate[3] suggesting a 5% probability that the upper limit of warming from a doubling of carbon dioxide could exceed 7.1°C. At this point parts of the world may become effectively uninhabitable[4].

It is clear that deep cuts in GHG emissions are needed to avert 'dangerous' climate change, and the Committee on Climate Change in the UK concluded that for the UK an 80% cut in emissions by 2050, relative to 1990 levels, is an appropriate, although probably conservative, contribution to a 50% cut in global emissions[5]. More recently, the committee suggested a 46% cut over the next 20 years and a further 62% cut between 2030 and 2050 to reach the 2050 target[6].

Strategies to reduce GHG emissions are sometimes perceived as expensive and difficult to implement but there are a number of collateral benefits (co-benefits) which can offset increases in costs and make them more attractive to policymakers. In 2009 a series of papers indicated the likely health co-benefits associated with GHG reduction strategies in different settings, including three strategies in the UK: 'Active Travel and low carbon driving', 'Housing Insulation/Ventilation', and 'Healthy Diet (from reduced animal product consumption)'[7-12]. This paper builds on that work, to assess the financial impacts of such health co-benefits on the wider UK economy, using the same modelling methodology which has been previously published in the context of pandemic influenza and healthy diets[13, 14].

Methods

GHG reduction strategies assessed

The strategies previously reported were designed to be of the type and scale needed to meet locally-specific UK GHG mitigation targets for 2030 and used a number of different assumptions depending on the sector concerned.[7,8,10] The reductions in GHG emissions modelled were consistent with the recommendations of the UK's Climate Change Committee. In this article, three scenarios corresponding to the three strategies previously reported were selected in order to isolate the macroeconomic impact of the health co-benefits that might be achieved from these strategies. The scenarios are:

(i) ‘Active Travel and low carbon driving’ (transport sector) scenario: the health co-benefits of an assumed immediate (2011) 2.5 fold increase in walking and 8 fold increase in cycling in urban England and Wales;
(ii) ‘Healthy Diet’ (food and agriculture sector) scenario: the health co-benefits of an assumed immediate (2011) UK-wide 30% reduction in dietary animal source saturated fat consumption;
(iii) ‘Housing Insulation/Ventilation’ (household energy sector) scenario: the health co-benefits of an assumed gradual (2011-30) improvement in home insulation/ventilation control UK-wide to improve indoor temperature to an ‘optimal’ average of 18°C together with changes in the level of indoor pollutants phased over 20 years.

The different assumptions about the rate of implementation were made because changes in active travel and animal product consumption could in theory be made quite rapidly, whereas housing modifications would inevitably have to be implemented over substantial time periods.

The scenarios and assumptions underpinning them are detailed in fax A. The economic impacts of the three scenarios were measured using a macroeconomic Computable General Equilibrium (CGE) model. The modelled health co-benefits included changes in labour force and social security payments (reduced benefits for working age people and increased pension costs for the increased number of people living to pensionable age), and healthcare costs averted. The objective was to highlight the economic contribution of the health co-benefits of GHG emission strategies and not to model GHG emission abatement policies as a whole. Specifically, the abatement costs of the strategies (including increased investment costs for lower carbon driving and household insulation/ventilation, and policies to reduce animal-related production and consumption) were omitted from scenarios in order to isolate the health effects and their economic consequences.

Health impact analysis

The determination of the health impacts was based on the WHO comparative risk assessment (CRA) approach.[15] The previously reported health impacts [7,8,10] were translated in this paper into a sequence of changes in labour force, healthcare costs and social security payments and imposed on the UK CGE model. The economic shocks were derived from measures of disease/injury incidence, Years of Life Lost (YLL, mortality), and Years of healthy Life lost due to Disability (YLD, morbidity), and were assumed to occur immediately or with a time-lag (1-20 years, depending on the health outcome) between the scenario-related changes in exposure and the associated observable health effects (Table 1).

The calculated YLL and YLD health effects do not have an explicit time dimension. Dynamic health effect profiles (2011-30) therefore had to be developed. (Details of the assumptions used are outlined in detail in Appendix B and the specific parameters of the lag period for each health effect are published in[16]). Briefly, an increase in road traffic injuries was assumed to occur immediately upon exposure to increased active travel. With immediate scenario implementation (transport), a constant steady-state change in injuries was assumed to occur immediately and continue throughout 2011-30. With gradual scenario implementation (household energy), a constant population-wide steady-state reduction in indoor cold was only reached at the end of the time horizon in 2030. The reduction in prevalence of common mental disorders (CMD) attributable to alleviation of winter indoor cold[17] was assumed to apply immediately in winter months (conservatively, this impact was assumed to apply for only the first season following exposure). For all other health effects cause-specific sigmoidal lag curves were assumed, which allowed for an 'incubation period' of no/small impact (the duration of which varied from one exposure-cause-of-illness combination to another) followed by a gradual increase to a steady-state level impact after a 'transition period' of some years. The 1996 Global Health Statistics publication[18] was used to distribute the health benefits by age and sex, and adjustments to the calculated YLD and YLL values were made to account for effects that occur beyond our 20 year horizon and to capture future changes in disease burdens. Age specific statistics, together with labour force participation rates, were also used to determine the impact of morbidity and mortality on the labour force (15-64) and dependents (0-14 and 65+). The demographic effects were subsequently used to estimate the change in social security payments that will occur through improvements in health (including reduced benefit payments to healthy working age people and increased pension payments to old age people accounting for changes in life expectancy).

Finally, the potential cost savings to the health service were measured on the basis of estimates of reduced illness incidence. Data for the active travel scenario were imported from an earlier paper[16] in which the methods are described in more detail. All health cost estimates assumed a nominal discount rate of 3.5%, and an inflation rate of 2.9% p.a. which yields net present value calculations based on an implicit 0.6% real interest rate. Assumptions used in estimating the healthcare costs averted and labour force gains are outlined in the appendices.

Computable General Equilibrium (CGE) model

The model used is an extended version of the IFPRI standard CGE model, which has been used elsewhere[13,14] and is fully documented in[19]. More information on the model is included in appendix C. Briefly, an economy-wide dynamically-recursive CGE model was used to model the economic impact of the health benefits associated with the GHG reduction strategies outlined above.

Scenario-specific dynamic profiles of health-related economic shocks including changes in labour supplies, healthcare costs, and social security transfers were, in each case, imposed on the dynamic CGE model to reflect future changes in disease burden associated with each scenario. The model produces a variety of outputs, principally focused on changes in GDP. The distribution of impacts across the various sectors of the economy is also provided, to indicate where major losses or gains may be likely to occur.

Results

The health effects and health-related macroeconomic impacts for the three scenarios are presented in Tables 1 and 2.

Tables 1 and 2 about here

The results suggest that health effects, which are positive for most forms of scenario-related changes in exposure, also have positive net effects on the economy. Table 2 indicates that health co-benefits have the potential to generate net economic gains of around £24bn overall, with active travel contributing £18.9bn, healthy diet contributing £4.7bn and housing insulation and ventilation contributing £448m by 2030 (although with larger net gains projected after this date due to accumulating health benefits).

Taken together, the three scenarios were estimated to result in a health-related expansion of the labour-force of around 7,700 workers per year (154,000 accumulated worker years over the 20 year horizon) together with an accumulated increase in dependents of around 19,150 per year (where *dependents* are defined as those members of the population who are not of working age). Nonetheless, the majority of economic benefits came from costs averted to the healthcare system, as indicated in Table 1. The reductions in healthcare costs can either be taken as reductions in government expenditure on the health service (standard way of calculating the opportunity cost of public expenditures, and the approach taken here) or more likely by redirecting the healthcare costs averted to other priorities within the NHS budget. Either way, the healthcare savings result in welfare gains for the UK population, which increase over time as health co-benefits accumulate (see Table 2). However, since the mortality reductions are weighted towards those of pensionable age rather than working age (increasing the number of dependents), the population increase in non-workers is proportionally larger than the GDP gains for some scenarios and so yields negative GDP per capita effects in these cases.

Scenario specific macroeconomic effects are tabulated in Table 2 and illness specific contributions to the economic benefits are presented in Appendix B (Table B). Reductions in disease burdens from Diabetes, Ischaemic Heart Disease (IHD), and Depression make the largest contributions to healthcare costs averted, while reduced disease burdens from IHD, Cerebrovascular disease and Depression make the largest contributions to the labour force expansion. In the case of social security costs, reduced IHD and Cerebrovascular disease burdens amongst older people result in increases in social security costs due to increased survival in old age.

For the housing insulation/ventilation scenario, gradual implementation of GHG interventions (exposure) coupled with the time lag for health effects (response), means that healthcare costs averted and other health co-benefits are considerably delayed and do not reach their maximum until *after* the 2011-2030 modelling period. The economic impact attributable to health effects is thus not directly comparable with the scenarios for the other sectors. Note also that cold-related mortality and morbidity were only partially accounted for in the housing insulation/ventilation scenario because the evidence base for such quantifications was considered limited. Furthermore, there is only limited evidence on the mental health impact of the alleviation of indoor cold, and the estimate included here was therefore based on a conservative assumption that mental well-being would be improved only in the first year after the intervention.

Three economic sensitivity analyses were undertaken (details of which are available from the authors). These analyses test the sensitivity of results to variations in assumptions concerning: (i) the substitutability of labour for other factors of production; (ii) the effectiveness of the interventions; and (iii) changes in the discount rate (the present value of the economic impacts). The analyses show that the degree to which the economy is able to absorb the additional labour supply resulting from health co-benefits could influence the overall economic gains by a factor between -4% to +8%. In addition, if only half the anticipated level of active transportation is achieved, the reduction in economic impact would be roughly proportional. Finally, a lower discount rate (3%) may increase macroeconomic benefits by 7%, while a higher discount rate (4%-5%) may lower the cumulative GDP impact by 7%-18%. Overall, the core results may be considered relatively robust to changes in these three factors.

Discussion

Statement of principal findings

This article emphasises the macroeconomic importance of public health impacts associated with strategies to reduce UK GHG emissions. Previous research[7,8,10] outlined potential health co-benefits, including both morbidity and mortality effects, that may arise from such strategies. The current article adds health co-benefits in the form of changes in healthcare costs and social security transfers, and demonstrates that potentially significant overall macroeconomic benefits may arise. Successfully implementing policies that lead to changing diet and travel behaviour, for example, can facilitate a societal change to a healthier, more environmentally conscious life-style. This, in turn, can result in further health and environmental benefits, on top of those estimated in our analysis.

Strengths and weaknesses of the study

The illustrative nature of this study does not permit the precise model outputs to be used as definitive cost estimates for policy analysis. In addition, there are some necessary differences between scenarios which make them less comparable. These include immediate implementation of active travel and healthy diet interventions, but phased implementation of housing insulation interventions; and that health effects were estimated for England and Wales in the active travel scenario, but for the UK in the other two scenarios. These assumptions were necessary in order to produce realistic, although conservative, estimates of effect. Variations in data availability meant that fewer health effects have been estimated for the healthy diet scenario compared with the home insulation and active travel scenarios. Another limitation is that, whilst sector specific GHG targets may be met for the specific sectors targeted, reductions of emissions in one sector could, for certain intervention types, be counterbalanced by some increases in other sectors. Nonetheless, the primary purpose, and the unique contribution, of the modelling undertaken here was to provide potential economic magnitudes of health co-benefits and thereby highlight the importance of looking at the economic contribution of the health co-benefits of GHG emission strategies across a number of sectors. This is important as it enables assessment of: (i) sectors and population groups likely to ‘win’ and/or ‘lose’ from specific strategies; and (ii) types of GHG mitigation measures likely to be most beneficial in health and economic terms. This evidence may then be used to: (i) support the case for acceleration of mitigation policies; (ii) aid the improved design and implementation of such policies to maximise positive and minimize adverse economic or health consequences of GHG reductions; (iii) address urgent national and international public health priorities through measures targeted outside the health sector, specifically in urban transport, household energy and food and agriculture sectors; and (iv) further demonstrate the value of taking integrated, multi-sectoral, approaches to the evaluation of significant and complex social interventions[20].

Strengths and weaknesses in relation to other studies

Previous studies of the wider macroeconomic impacts of GHG reduction strategies have focussed narrowly on health co-benefits from air pollution effects. To our knowledge this is the first study to assess a range of health co-benefits of GHG reduction strategies, including the healthcare costs averted, in a macroeconomic modelling framework.

Meaning of the study: possible explanations and implications for clinicians and policymakers

Despite the conservative measurement of the health effects, which would continue beyond our 20 year horizon, our results clearly show that health co-benefits can substantially influence the macroeconomic effects of GHG mitigation strategies and the threshold at which a specific policy may become cost-effective. Our sensitivity analyses also show that, whilst the absolute magnitude of the health co-benefits of this study may vary with the ability of labour to substitute for other production factors, the effectiveness of the underlying intervention and the choice of discount rate, the impacts remain strong enough to warrant close attention by policymakers when considering the best approach to achieving the deep cuts in emissions that will be necessary to reduce the risks to societies posed by climate change.

Unanswered questions and future research

The analyses presented here are subject to a number of uncertainties. These include, for example, whether healthcare savings are spent on medical research and treatment or invested in physical/human capital accumulation or other research and development, whether the labour force increases are diluted by reduced immigration, and whether improved health outcomes leads to increased labour productivity when at work. Nevertheless, highlighting both the health and economic effects together illustrates the need to consider the systems interaction between different policy sectors, and at different levels of impact (i.e. individual, regional, national, international) in developing upstream policies to tackle GHG emissions. Questions also remain concerning many aspects of scenario design. In the UK, it is not known how to achieve large changes in cycling and walking, and therefore a significant reduction in motor vehicle kilometres driven is unknown. Also, the difference in effects and appropriateness of interventions across different countries, together with the spillover effects of emissions through global trade, represents a global issue and requires a global solution. Future research would be well served by conducting a wide scope of analysis across a number of alternative scenarios to find points at which the balance of their GHG emission reductions, health and economic impacts may be optimized. In addition, there is a need to address these limitations of this study by improved epidemiological modelling. This could be accomplished using explicit dynamic life tables and by integrating the calculation of health effects within the CGE framework to improve the accuracy of estimates and capture the interaction between health and the economy.

Acknowledgements

We thank Colin Mathers of WHO for his advice about the use of the WHO CRA approach and gratefully acknowledge funding from the Department of Health Policy Research Programme

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Table 1. Aggregate Health and Macroeconomic Effects)

	Individual Scenarios			Combined Scenario
	Healthy Diet	Active Travel	Housing Insulation	
Public Budget Total				
Public Budget Net costs averted [1]	**2,435**	**15,010**	**-37**	**17,408**
Public Budget Breakdown				
Social Security Costs Averted [1]	-716	-912	-80	-1,709
- Social Security Costs Averted (labour force)	12	124	18	153
- Social Security Costs Averted (dependents)	-728	-1,035	-98	-1,861
Healthcare Net Costs Averted [1]	3,152	15,922	43	19,117
Population/Labour Totals				
Total Person years increase (accumulated years)[2]	**184,669**	**256,229**	**24,238**	**465,135**
Labour Force increase (accumulated years)[2]	**48,948**	**95,174**	**10,375**	**154,496**
Population/Labour Breakdown				
Years Lived with Disability (accumulated years)[2]	12,014	110,906	8,867	131,788
- Working age change	4,554	49,083	6,927	60,564
- Labour force change[3]	3,322	35,204	4,938	43,464
- Dependents change[4]	7,460	61,823	1,940	71,224
Years of Life Lost (accumulated years)[2]	184,669	256,229	24,238	465,135
- Working age change	62,635	83,106	7,544	153,286
- Labour force change[3]	45,626	59,970	5,436	111,032
- Dependents change[4]	122,033	173,122	16,694	311,849

NB: [1] Net Present Value over 2011-2030 (2010 prices); [2] Accumulated population and work-years over 2011-2030 without discounting, equivalent to the sum of the working age and dependents change; [3]Labour force is the subset of individuals of working age who are in employment [4]Dependents are defined as members of the population outside working age (mostly those surviving into retirement).

Table 2. Health-related Macroeconomic Effects

	Per capita GDP (£; 2010 prices) [1]			GDP (£million; 2010 prices)†,[1]
	2015	2020	2030	NPV (2011-2030)
All Health outcomes Combined Scenarios	**-0.90**	**6.58**	**23.91**	**23,960**
All Healthy Diet Scenario health outcomes	-1.72	-0.57	1.85	4,658
All Active Travel Scenario health outcomes	0.75	7.19	22.67	18,854
All House Insulation Scenario health outcomes	0.06	-0.04	-0.60	447

NB: [1] Net Present Value over 2011-2030 (2010 prices); † GDP gains can be positive even when *per capita* GDP gains are negative because of population growth.

Appendix A: detailed description of scenarios modelled

In this paper we focus on the economic impact of the health co-benefits of increased active travel, housing insulation with ventilation control and healthier eating but we do not consider the overall costs of policies to reduce greenhouse gas emissions.

Active travel scenario

The 'active travel' scenario is designed to calculate the health-related economic benefits that would result from increased walking and cycling in urban England and Wales. Previous research suggested a permanent 35% reduction in urban motorized vehicle use is required to make a proportionate contribution towards meeting specific GHG targets outlined by the UK's Climate Change Committee, and this reduction in urban vehicular transportation would yield a complementary increase in non-motorized physically active transportation modes, with associated health benefits. In 2008, 38% of the total distance travelled by car in the UK was in urban areas (excluding urban motorways)[1]. The overall effect will therefore be a 13.3% reduction (35% of 38%) in the total distance travelled by car in the UK. Although people living in urban areas outside London drive more than those who live in London, much of this driving will not be in urban areas[2].

The health effects from the transportation scenario are generated from increased physical activity, and negative health effects from increased road accidents and injuries due to increased use of non-motorized active travel modes. Based on the findings of a range of systematic reviews of the effects of sedentary lifestyle on health, previous work[1] shows that increased active travel reduces the disease burden and premature deaths due to diabetes, Alzheimers disease, hypertensive heart disease, ischaemic heart disease (IHD), cerebrovascular disease, breast cancer, colorectal cancer and depression. However, the increased number of pedestrians and cyclists will also increase the number of road traffic accidents, leading to higher injury rates, including short-term and long-term intracranial injuries and spinal cord injuries.

Health effects associated with each of the above diseases and injuries were determined by the WHO comparative risk assessment approach[1,3,4], and distributed in this analysis over a 20 year horizon (Appendix B). The resulting dynamic patterns of health effects, including Years

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of healthy Life lost due to Disability (YLD) and Years of Life Lost (YLL), were used to derive: (1) changes in the effective labour force (based on reduced YLD and YLL for the working age population corrected for gender-specific labour market participation rates); and (2) changes in social security transfers including reduced labour market payments (based on reduced YLD for the working age population) and increased pension payments (based on reduced YLL for the old-age population). In addition, changes in healthcare costs were measured on the basis of actual incidence numbers and details of the calculation of these healthcare costs are provided another paper[16]. The two types of health interventions (increased walking and cycling and increased road traffic accidents), together with the healthcare costs constitute the full range of 'active travel' scenario shocks which are reported in this paper and the intervention is assumed to have immediate implementation.

Housing insulation/ventilation scenario

The health co-benefits from housing insulation are assumed to result from a strategy to reduce GHG emissions through increased home insulation, improved air-tightness and mechanical ventilation with heat recovery (MVHR is installed in the 20 % of dwellings which are the most tightly sealed) together with fuel switching. As for the active travel scenario many of the health effects were determined by the WHO comparative risk assessment approach as outlined elsewhere.[4] However, the effects modelled in the housing scenario included YLL benefits for cardiopulmonary disease from exposure to PM2.5, lung cancer from exposure to PM2.5, cardiovascular disease from exposure to cold and lung cancer from exposure to radon and YLL harms from cerebrovascular disease from exposure to environmental tobacco smoke (ETS) and, ischaemic heart disease from exposure to ETS. In addition there were YLD harms for asthma from exposure to mould. We also added estimates for reduction in the prevalence of common mental disorder, using the limited evidence from observational studies. Our interpretation of that evidence was that a 0.4 degree Celsius rise in temperature (the average increase under the model assumptions) would result in a 4% relative reduction in CMD prevalence, a benefit which we conservatively assumed would apply in the winter period for only the first year after the intervention. In order to calculate the healthcare savings from reducing disease burden, we assumed the percentage reduction in YLDs was equivalent to a percentage reduction in cases (-0.02% for Asthma). In the case of the home insulation/ventilation, although we only focus on the health effects rather than the wider abatement scenario, the investment required in construction and the work that would need to be carried out is too great for the full abatement intervention to be applied immediately and therefore a staged implementation of the health effects for this scenario is used. A lag of 20 years was assumed between the introduction of insulation and the full reduction in disease burden. Annual costs of treatment were then multiplied by the total number of cases to obtain an estimate of annual costs averted. Future costs were discounted at 3.5%.

Healthy diet scenario

The health benefits, like the other scenarios, are based on a GHG reduction strategy but only the health co-benefits are considered in this paper. The GHG reduction strategy is to modify current eating patterns which contain large amounts of animal-source foods that have high associated GHG emissions (for example because of the emission of the potent GHG methane from ruminants) and are high in saturated fat. A 30% reduction in the production of processed meat and dairy products (in order to achieve GHG emission targets) is assumed and it is assumed further that the reduction in consumption of dietary saturated fat and cholesterol takes place in the initial period, i.e. without the need for gradual phasing-in of the scenario.

Health benefits are assumed to occur through reduced consumption of livestock-related food products which would be assumed to yield a health co-benefit by reducing the burden of IHD and stroke. YLLs and YLDs were calculated from[3] for ischaemic heart disease from exposure to saturated fat, and YLLs for stroke from exposure to dietary cholesterol were also used. The YLDs for stroke were calculated using the YLL and YLD ratios from the WHO Global Burden of Disease and we calculated health care savings using the same method as described in the Housing Insulation scenario. However, we assumed a five year time lag for full effects of dietary change on IHD and stroke in this scenario.

Adjustment for life expectancy and duration

The estimates of YLL and YLDs used in the modelling scenarios were adjusted to capture only those effects which occur within the 20 year period of the model. The sources of these estimates were primarily taken from the original series of 2009 articles[7-12] or were adjusted from the relative burden of YLLs vs YLDs as outlined in WHO Global Burden of Disease.

Appendix B: detailed health impact analysis

Health effects

Health effects in the model (benefits and harms) were captured in three ways. (i) *Changes in labour supply*: by estimating changes in YLD (morbidity) and YLL (mortality) in those of working age (15-64) the supply of labour available for productive use in the economy was adjusted. (ii) *Healthcare savings*: estimates of the change in healthcare savings/expenditure were estimated[2] and, since a revenue-neutral government budget closure is assumed, the reduction in government expenditures translates into a reduced public sector deficit which lowers government crowding-out and increases savings for productive private investment purposes. (iii) *Social security*: changes in social security payments from changes in working age morbidity and retirement age mortality are calculated and leads to reduced government crowding-out and increased savings for productive private investment purposes in a similar way to healthcare savings (as above)

Lagging health effects

In addition to this, an adjustment has been made to the health effects to account for the 20 year period of the model, since the YLL and YLD values previously reported do not account explicitly for the timing of those health benefits/harms. Health effects for all interventions (except for road traffic accidents) have been staggered using a sigmoid function (defined by the cumulative distribution function of a normal distribution) to account for both the delay before health effects start to accrue and the lag time until the full health effects are realised. The timing of the delay and lag is determined by the parameters of the sigmoid function (i.e. the mean and standard deviation of the normal distribution) and these are available from the authors on request. In the case of road traffic accidents, it is assumed that accidents occur at a constant rate over time.

20 year cut off

A further adjustment to the YLL and YLD was also made since the CGE model is run over a 20 year time period. For this reason the YLL values had to be adjusted, taking account of life expectancies, to remove any health effects that would be experienced beyond the timescale of the model. Similarly, YLD values were adjusted to account for durations that extend beyond the scope of the model timescale. Finally, the health effects were disaggregated by age and sex using WHO Global Burden of Disease incidence data[18] and the CGE model utilised the UK ONS mid-year population projections[3] and employment statistics to calculate the proportion of working age adults to which the health effects apply in each period.

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[3] For a detailed explanation of the methodology used in national population projections, see papers available on the National Population Projections section of the ONS website at www.statistics.gov.uk/StatBase/Product.asp?vlnk=8519

CRA Adjustment

The standard comparative risk assessment method is a static tool for estimating health effects and does not account for the increasing burden of illness that is expected to occur over the 20 year simulation period. In order to account for this shortcoming, WHO projections of mortality and burden of disease 2004-2030[4,5] were used to estimate annual increases in our YLL and YLD estimates. Standard DALY estimates for Europe were undiscounted and average rates of change for the 2010-2015 and 2016-2030 periods were calculated for each health effect and used to adjust the phased YLL and YLDs.

Healthcare Savings

Estimation of scenario and disease specific changes in healthcare savings are documented elsewhere[16]. In that paper we discuss the possibility that the costs averted could either be reinvested in the NHS to buy additional health care or taken as savings by the Government. In this analysis we assume they are taken as savings. These changes are imposed on the model but because of the revenue-neutral government budget assumption, the flexible tax rate ensures that government revenues remain unchanged. Consequently, when current expenditures are reduced, the budget deficit is also reduced and overall savings are increased. These increased savings can then be used for productive investment.

Social Security

In a similar way, once adjusted as described above, the health effects were used to estimate the reductions in benefit payments (morbidity changes) and increases in pension payments (mortality changes) that result from each scenario and resulting changes in social security payments are reported in the results section. Changes in benefit payments were calculated as the change in YLDs for those of working age (15-64), multiplied by the yearly benefit payment estimate (£3146 per year). Changes in pension payments were calculated as changes in YLLs for those of retirement age (over 65) multiplied by the yearly pension payment estimate (£5312 per year).

Table B demonstrates the contributions to the economic benefits of each of the health outcomes. Reductions in disease burden from Ischaemic Heart Disease (IHD), Dementia and

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[4] http://www.who.int/healthinfo/global_burden_disease/projections/en/

[5] Mathers C and Loncar D, Projections of Global Mortality and Burden of Disease from 2002 to 2030.PLoS Med. 2006 Nov;3(11):e442

Diabetes make the largest contributions to health care savings, while reduced disease burden from IHD, Cerebrovascular disease and depression make the largest contributions to the labour force. In the case of social security costs, IHD and Cerebrovascular disease make substantial contributions.

Appendix C: The Extended IFPRI Standard CGE Model

The model used is an extended version of the IFPRI standard CGE model, which has been used elsewhere[13,14] and is fully documented in[19]. There are four main forms of economic 'agents' in the model: firms, consumers, government, and foreign agents. Firms seek to combine resource inputs to maximize profits, while consumers aim to allocate their income between consumption and savings in order to maximize their welfare. Production technologies are assumed to consist of nested Leontief functions (intermediate inputs) and Constant Elasticity of Substitution (CES) functions (primary factor inputs) with a CES function top-nest, while consumer welfare are based on utility functions which consists of nested Stone-Geary utility functions for non-energy goods and a CES function top-nest which allows for (low) substitution between energy demand and composite non-energy demand. The government levy taxes, distribute benefits, and purchase goods directly, while foreign agents interact with domestic agents through goods trade (firms), unrequited transfers and foreign lending and borrowing (households and government). Imperfect substitution is assumed in goods trade through an Armington (CES) specification on the import side and a Constant Elasticity of Transformation (CET) specification on the export side

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A baseline CGE model is calibrated on the basis of data from a given year, and therefore replicates the economy at a specific time point. Specific impacts or policy interventions are then modelled as external 'shocks' to the economy, following which the model adjusts to the shocks and produces a new equilibrium solution. In the current case, the model was calibrated on the basis of a 2004 Social Accounting Matrix (SAM) for the UK, which was taken from the GTAP database version 7[6].

Following the calibration of the static model, factor stock updating equations were added, including labour growth and capital accumulation equations, to turn the static model into an enhanced dynamically-recursive CGE model framework.

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[6] Badri Narayanan G. and Terrie L. Walmsley, Editors (2008). *Global Trade, Assistance, and Production: The GTAP 7 Data Base*, Center for Global Trade Analysis, Purdue University.

Table B Disease-specific Health - Related Macroeconomic Effects

Scenario		**Changes in Morbidity & Mortality (Accumulated; 2011-2030)**				**Net Social Security & Healthcare costs (£million; 2010 prices)[1]**		**Per capita GDP (£; 2010 prices)[1]**			**GDP (£million; 2010 prices)† [1]**
		YLD	YLL	Labour force[2]	Dependents[3]	Social Security	Healthcare	2015	2020	2030	NPV (2011-2030)
Combined	**All Combined Diseases**	**131,788**	**465,135**	**154,496**	**383,073**	**1,424.2**	**-19,116.6**	**-0.90**	**6.58**	**23.91**	**23960.2**
Healthy Diet	**All Healthy Diet related Diseases**	**12,014**	**184,669**	**48,948**	**129,494**	**597.2**	**-3,151.9**	**-1.72**	**-0.57**	**1.85**	**4658.8**
	Ischaemic Heart Disease (saturated fat, dietary cholesterol)	11,595	182,136	48,265	127,485	588.9	-3,095.5	-1.70	-0.58	1.81	4577.8
	Stroke (dietary cholesterol)	420	2,533	683	2,008	8.3	-56.4	-0.02	0.01	0.04	80.9
Active Travel	**All Active Travel related Diseases**	**110,906**	**256,229**	**95,174**	**234,945**	**759.9**	**-15,921.8**	**0.75**	**7.19**	**22.67**	**18853.9**
	Diabetes (Active travel)	17,136	7,265	9,189	11,681	-1.2	-7,598.1	0.75	3.70	13.45	7146.1
	Alzheimer (Active travel)	29,481	7,474	6,981	27,207	10.7	-260.4	0.00	0.00	0.97	386.1
	Hypertensive Heart Disease (Active travel)	820	5,501	1,588	4,142	17.4	0.0	-0.06	-0.07	-0.10	49.8
	Ischaemic Heart Disease (Active travel)	21,850	150,578	43,304	112,998	476.8	-4,698.5	-0.57	1.38	5.00	6368.0
	Cerebrovascular Disease (Active travel)	23,451	73,133	22,352	65,572	232.4	-1,550.5	-0.23	0.43	1.19	2504.7
	Breast Cancer (Active travel)	3,203	18,198	6,843	11,513	44.5	-247.4	0.00	0.00	-0.38	375.9
	Colorectal Cancer (Active travel)	891	5,404	1,504	4,218	16.8	-70.2	0.00	0.00	-0.22	86.9
	Depression (Active travel)	18,672	24	11,907	1,981	-35.0	-2,146.7	1.28	2.45	3.82	3138.2
	Long-term Intracranial Injuries (Traffic)	-741	-2,937	-1,907	-1,081	-1.7	61.7	-0.04	-0.06	-0.09	-159.4
	Short-term Intracranial Injuries (Traffic)	-3,390	-6,922	-5,388	-2,960	-0.6	263.2	-0.17	-0.30	-0.46	-568.8
	Spinal Cord Injuries (Traffic)	-468	-1,489	-1,198	-325	-0.2	325.0	-0.20	-0.34	-0.49	-473.0
House Insulation	**All House Insulation related Diseases**	**8,867**	**24,238**	**10,375**	**18,634**	**67.1**	**-43.0**	**0.06**	**-0.04**	**-0.60**	**447.7**
	Cerebrovascular Disease (ETS)[4]	-491	-2,960	-788	-2,358	-9.6	2.8	0.01	0.03	0.08	-29.9
	Ischaemic Heart Disease (ETS)[4]	-403	-4,006	-1,099	-2,901	-12.7	7.8	0.01	0.04	0.10	-45.9
	Cardiopulmonary Disease (PM2.5)	2,848	28,309	7,095	21,312	93.3	-72.9	-0.11	-0.28	-0.74	311.3
	Lung Cancer (PM2.5)	15	921	243	607	2.8	0.0	0.00	0.00	-0.09	9.9
	Cardiovascular Disease (cold)	282	2,283	641	1,686	7.2	26.1	-0.01	-0.04	-0.11	-0.9
	Lung Cancer (Radon)	-5	-309	-82	-203	-1.0	0.0	0.00	0.00	0.03	-3.4
	Asthma (Mould)	-523	0	-189	-261	0.5	3.0	0.00	-0.01	-0.02	-10.6
	Depression (Cold)	7,144	0	4,552	753	-13.6	-9.7	0.16	0.22	0.14	216.9

NB: [1] Net Present Value over 2011-2030 (2010 prices); [2] Accumulated work-years over 2011-2030 without discounting; [3] Dependents are defined as members of the population outside working age (mostly those surviving into retirement), [4]IHD and stroke increase because of the increased air tightness in some homes † GDP gains can be positive even when *per capita* GDP gains are negative because of population growth