The macro-economic effects of health co-benefits associated with climate change mitigation strategies

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Summary

The UK government has specific targets for greenhouse gas (GHG) emission reduction to lower the risk of dangerous climate change. Strategies to reduce GHG emissions are sometimes perceived as expensive and difficult to implement but previous work has demonstrated significant potential health co-benefits from 'Active Travel and low carbon driving', 'Housing Insulation/Ventilation', and 'Healthy Diet' scenarios which may be attractive to policymakers. Here a Computable General Equilibrium model is used to assess the financial effects of such health co-benefits on the wider economy including changes in labour force, social security payments and healthcare costs averted. Results suggest that for all scenarios the financial impacts of the health co-benefits will be positive and increased active travel in particular is likely to make a substantial contribution, largely due to health care costs averted.

Strategies to reduce GHG emissions and improve health are 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.

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 above 2°C more than 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. These include health co-benefits. For example, improving insulation and ventilation of existing housing stock can reduce exposure to cold and to a number of indoor pollutants whilst reducing GHG emissions; reducing the use of private cars and increasing active travel through more walking and cycling can reduce the adverse health effects of a sedentary lifestyle; and decreasing consumption of animal products in high consuming economies can reduce saturated fat intake as well as reducing GHG emissions from ruminants[7-9].

The Lancet published a series of papers, just prior to the UN Climate Change Conference in Copenhagen in December 2009, which indicated the likely health co-benefits associated with GHG reduction which might be achieved through three strategies in the UK: 'Active Travel and low carbon driving', 'Housing Insulation/Ventilation', and 'Healthy Diet (from reduced animal product consumption)'[10-15]. This paper builds on that work, to assess the financial impacts of such health co-benefits on the wider economy, following an innovative approach previously applied with respect to agriculture and nutrition[16]. Especially within a context of economic austerity in many countries, strategies to reduce GHG emissions will be seen more favourably if the health benefits they yield are not just substantial in themselves but also make positive contributions to the economy to offset any potential economic costs of implementing such strategies.

Research in context panel

Interpretation

A number of new mitigation initiatives are necessary to achieve the planned 50% greenhouse gas (GHG) emission reduction targets for the UK by 2030. Our study assesses the macroeconomic effect of health co-benefits associated with interventions designed to meet sector-specific reduction targets in UK GHG emissions by 2030. Health co-benefits were based on increased active travel (walking and cycling) in urban areas, improved diets (reduced dietary cholesterol and saturated fat intake associated with reduced consumption of animal products), and improved housing insulation and ventilation control. The changes in disease burden were used to derive health effects on the UK labour force, healthcare costs, and social security transfers, and a Computable General Equilibrium model was employed to indicate the macroeconomic effects of these health co-benefits. Macroeconomic effects as a result of the improvements in health are positive and increase over time for all scenarios. These could offset some of the costs of implementing policies to reduce GHG emissions and make them more attractive to policymakers.

Methods

GHG reduction strategies assessed

The strategies previously reported in The Lancet 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.[10,11,13] The reductions in GHG emissions modelled were consistent with the recommendations of the UK's Climate Change Committee. In this current paper, 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) <u>'Active Travel and low carbon driving' (transport sector) scenario:</u> 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) <u>'Healthy Diet' (food and agriculture sector) scenario:</u> the health co-benefits of an assumed immediate (2011) UK-wide 30% reduction in dietary saturated fat consumption;
(iii) <u>'Housing Insulation/Ventilation' (household energy sector) scenario:</u> the health co-benefits of an assumed gradual (2011-30) improvement in home insulation/ventilation 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 be made quite rapidly, whereas housing modifications would inevitably have to be implemented over substantial time periods.

These scenarios and the assumptions underpinning them are detailed in Appendix A. The economic impacts of the three scenarios were measured using a Computable General Equilibrium (CGE) model. The modelled health co-benefits included changes in labour force, social security payments (reduced benefits for working age people and increased pensions for old age people), and healthcare savings. The objective of this exercise 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, abatement cost aspects of the strategies (including increased investment costs for lower carbon driving and household insulation/ventilation, and policies to reduce animal product production and consumption) were omitted from scenarios in order to isolate the health effects and their economic consequences.

Health impact analysis

The approach used to determine the health impacts resulting from these three scenarios is the WHO comparative risk assessment (CRA) approach.[17] The health impacts reported in the previous Lancet series[10,11,13] were translated in this paper into a sequence of labour force, social security and healthcare cost 'shocks' 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 included in Appendix C). 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 disorder (CMD) attributable to alleviation of winter indoor cold 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[19] 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. The estimates of healthcare savings in this article differ from the earlier article[19] for the following reason: This article discounts future healthcare savings by a 3.5% p.a. nominal interest rate, while the earlier article deflates future savings by a 2.9% inflation rate. Here, undiscounted healthcare savings are used as inputs to the CGE model, while net present value results are presented as outputs from the CGE model. 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 described in detail in Appendix D. 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 for health-related 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. This paper presents the results for the indirect macroeconomic impacts attributable to the health co-benefits only.

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 generated net economic gains of around £24·0bn overall, with active travel contributing £18·9bn, reduced meat and dairy consumption £4·7bn and housing insulation and ventilation £448m by 2030 (although with larger net gains projected after this date due to accrued 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. 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 B2). Reductions in disease burdens from Diabetes, Ischaemic Heart Disease (IHD), Depression, and Cerebrovascular disease make the largest contributions to healthcare savings, while reduced disease burdens from IHD, Cerebrovascular disease and depression and Diabetes make the largest contributions to the labour force. In the case of social security costs, IHD and Cerebrovascular disease make substantial contributions.

Figure 1 shows that for each scenario the *health-related* impacts on the economy (due to increased labour force participation, healthcare costs averted, and increased social security costs) were positive throughout the period of modelling. The substantial and growing positive health-related impacts on GDP for the active travel and healthy diet scenarios are mainly attributable to healthcare costs averted which are large and cumulative over time. The gradual implementation of the housing insulation/ventilation scenario, which contrasts with the assumed immediate implementation of the active travel and healthy diet scenarios, coupled with the time lag for health effects (which, for this sector, do not reach their maximum until *after* the 2011-2030 modelling period), means that its health-related effects on the economy are considerably delayed. For all scenarios, different lag periods for individual health outcomes lead to differences in YLDs averted and, through changes in labour force participation and social security costs, to differences in macroeconomic health effects.

Figure 1 about here

Note that the economic impact attributable to health effects from the housing insulation/ventilation intervention are thus not directly comparable with the scenarios for the other sectors because the underlying assumptions differ, especially in relation to the time course of implementation. Note also that cold-related mortality and morbidity were only partially accounted for here because the evidence base for such quantifications was considered limited. Furthermore, there is only very 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.

In addition, three sensitivity analyses were undertaken (as outlined in detail in Appendix E). 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 intervention; and (iii) changes in the discount rate. 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 were 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

This paper further emphasises the importance of considering the public health impacts of reducing GHG emissions. The previous Lancet series[10-15] highlighted the health co-benefits that may arise from policies to reduce GHG emissions. This paper demonstrates that these health co-benefits can result in significant macro-economic gains, which may be important when considering the costs and benefits of mitigation strategies.

Clearly, the analysis undertaken here was designed to be illustrative rather than definitive, and there are a number of critical caveats. First, the results relate only to the effects on the economy of the immediate or near-term health impacts of mitigation. Abatement costs and other benefits of the mitigation measures were therefore not part of the analysis. Second, the scenarios assessed were different in their specifications; particularly with assumptions of immediate changes for the active travel and healthy diet scenarios, but a much slower, phased implementation for the housing insulation/ventilation scenario. This was done because in theory changes in active travel and animal product consumption could be made quite rapidly, whereas housing modifications would inevitably have to be implemented over substantial time periods. The rapidity with which health and economic benefits accrue depends on the speed of implementation of strategies and assumptions about the lag periods between interventions and changes in health. In a previous paper[19] sensitivity analyses were undertaken to illustrate the effects of varying lag periods.

Other scenario specifications can be expected to yield results which differ in their detail, perhaps showing substantially greater or lesser health and/or economic impacts. 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 more evidence is needed about how to achieve large changes in cycling and walking, and a significant reduction in motor vehicle kilometres driven, in the UK. It is likely that, in order to achieve the increased active travel, a large cultural shift would also be needed. However, there is considerable variation in how much people walk and cycle in different cities and countries and a number of cities have achieved large increases in cycling from a range of starting points. These include those starting from a low level (Barcelona, London, Paris, New York), a middling level (Berlin) and from a high level (Copenhagen).

There are, as we have demonstrated previously[13], likely to be wider variations in the health and economic impacts of policies between different countries with different economic structures; most significantly between countries at different stages of economic development. It is highly likely that there will be different profiles of desirability between policies according to the country of analysis. There is the further complication of the interdependency between countries through global trade that needs greater exploration; important especially as reducing GHG emissions to prevent dangerous climate change is a global issue and requires a global solution.

Although there may be an element of double counting, for example of IHD co-benefits from both 'healthy diet' and 'active travel' scenarios, it is quite likely that the health benefits were underestimated. Thus, for instance, the health effects for housing insulation/ventilation are likely to be much higher than those indicated in the tabulated results because the peak impact on health would occur well after 2030 when full implementation has been achieved. Hence, due to gradual phasing-in, further (lagged) health co-benefits from that intervention would continue beyond the period we have modelled. We have also not included the health-related economic benefits arising from reduced urban local air pollution in the active travel scenario. Furthermore, the active travel scenario was limited to England and Wales. Increased active travel in urban parts of Scotland and Northern Ireland would result in additional health and economic benefits but these have not been estimated as it was felt that the lower density of urban areas and climatic differences in Scotland and Northern Ireland would require a different parameterisation. Similarly, there were fewer diseases modelled for the healthy diet scenario than would likely be affected, together with no impact from substitution to, for example, increased fruit and vegetable consumption. If pensionable age increases in the future, then the projected increases in pension costs would also be reduced. Also if reductions in healthcare costs were reinvested in the NHS to provide additional care this would clearly reduce the direct benefits to the economy but would provide additional indirect benefits as a result of further improvements in health or investment in medical innovation.

Nonetheless, the primary purpose, and the unique contribution, of the modelling undertaken here was to 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. It is important to note though that in the absence of an overall policy framework to promote abatement of GHG emissions across the world economy, reductions of emissions in one sector would likely be counterbalanced by increases in other sectors.

The analyses presented here are relatively simplistic and 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.

Conclusion

It is clear that considering the health co-benefits of greenhouse gas mitigation strategies can substantially influence the macroeconomic effects of GHG mitigation strategies and the threshold at which a specific policy may become cost effective. While the calculation of dynamic health profiles, represents an approximation, the (sometimes) long lag periods, which implies that health effects (oftentimes) occur outside our 20 year time horizon, means that our results are likely to be conservative estimates of the total macroeconomic effects and should be considered as illustrative of what could be achieved. Future research should seek to address these limitations by improved epidemiological modelling based on 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. Our sensitivity analyses also showed 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, these 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.

Finally, 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.

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Table 1. Aggregate Health and Macroeconomic Effects 2010

	Individual Scenarios			Combined Scenario
	Healthy Diet	Active Travel	Housing Insulation	
Public Budget Net costs averted [1]	**2,435**	**15,010**	**-37**	**17,408**
Social Security Costs Averted [1]	-716·4	-911·6	-80·4	-1,708·5
- Social Security Costs Averted (labour force)	11·8	123·5	17·6	152·9
- Social Security Costs (dependents)	728·2	1,035·1	98·1	1,861·4
Healthcare Net Costs Averted [1]	3,151·9	15,921·8	43·0	19,116·6
Population increase (accumulated years)[2]	**48,948**	**95,174**	**10,375**	**154,496**
Labour Force increase (accumulated years)[2]	**184,669**	**256,229**	**24,238**	**465,135**
YLD (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	3,322	35,204	4,938	43,464
- Dependents change[3]	7,460	61,823	1,940	71,224
YLL (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	45,626	59,970	5,436	111,032
- Dependents change[3]	122,033	173,122	16,694	311,849

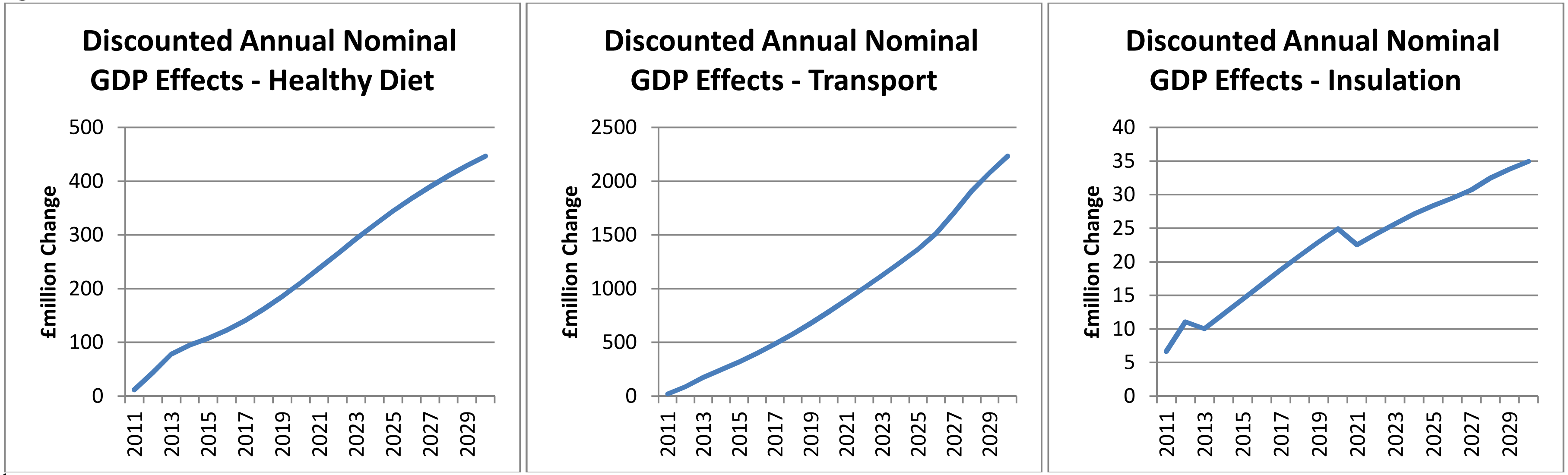
NB: [1] Net Present Value over 2011-2030 (2010 prices); [2] Accumulated population and work-years over 2011-2030 without discounting; [3] Dependents are defined as members of the population outside working age (mostly those surviving into retirement).

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.

Figure 1: Annual discounted GDP of individual scenarios - effects on GDP of the health co-benefits in the three scenarios[1]



[1] Note: the plots in Figure 1 are on different scales. The economic impact attributable to health effects in the housing intervention are not directly comparable with the scenarios for the other sectors because the underlying assumptions are so different, especially in relation to the time course of implementation. The irregular shape of the insulation plot is due to the common mental disorder health effects described in the paper. The health effects are phased to correspond with a program of investment in home insulation/ventilation (which is not modelled in this paper). The relatively small health benefits for this scenario combined with the conservative assumption that the CMD impact was assumed to apply for only the first season following exposure makes the irregular shape more pronounced.

Appendix A: detailed description of scenarios modelled

Active travel scenario

The objective of the 'active travel' scenario is primarily to calculate the health-related economic benefits that would result from increased walking and cycling in urban England and Wales. Our previous studies reported in The Lancet suggested that 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 this paper we focus on the economic impact of the health co-benefits of increased active travel and do not consider the overall costs of policies to reduce greenhouse gas emissions.

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 two main sources, including positive health effects 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 (see Appendix B). The resulting dynamic patterns of health effects, including Years of healthy Life lost due to Disability (YLD) and Years of Life Lost (YLL), see Appendix C for specific values, 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 in the companion paper[2]. 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.

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[1] http://www.dft.gov.uk/pgr/statistics/datatablespublications/roads/traffic, accessed 19/01/12

[2] Travel in Urban and Rural areas, Personal Travel Factsheet – March 2010 http://webarchive.nationalarchives.gov.uk/+/http://www.dft.gov.uk/pgr/statistics/datatablespublications/personal/ntsfactsheets/NTSTravelinUrbanRuralareas.pdf, accessed 19/01/12

Housing insulation/ventilation scenario

As for the active travel scenario, the health co-benefits from housing insulation were based on a GHG reduction strategy but only the health effects are modelled. The health effects modelled 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 (see Appendix C for all YLL and YLD values). It was decided that, although no YLDs had been estimated in Wilkinson et al[4] for diseases for which YLLs had been calculated, that YLDs should be included for these conditions to bring the analysis in line with those in the other sectors. We used the ratio of YLLs to YLDs from the WHO Global Burden of Disease to estimate YLDs corresponding to the YLLs. 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). 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 and are presented in Appendix C. As for the housing insulation scenario, 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

As outlined above, and in the main article, 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 are tabulated in Appendix C and were primarily the original Lancet articles 2009[10-15] or were adjusted from the relative burden of YLLs vs YLDs as outlined in WHO Global Burden of Disease. However, to illustrate the effect of this adjustment the raw (adjusted) YLL and YLD values are tabulated in Table A and compared with the age and duration adjusted values.

Table A: Comparison of raw YLDs and YLLs with those adjusted for life expectancy and duration.

	YLD	YLL	YLD (Adjusted*)	YLL (Adjusted *)
Healthy Diet Related Diseases				
Ischaemic Heart Disease (saturated fat)	9,994	167,466	11,595	182,136
Stroke (cholesterol)	9,994	2,264	420	2,533
Active Travel Related Diseases				
Diabetes (Activity)	15,323	7,006	17,136	7,265
Alzheimer (Activity)	27,987	7,212	29,481	7,474
Hypertensive Heart Disease (Activity)	657	4,697	820	5,501
Ischaemic Heart Disease (Activity)	18,835	138,451	21,850	150,578
Cerebrovascular Disease (Activity)	19,958	65,329	23,451	73,133
Breast Cancer (Activity)	3,089	21,457	3,203	18,198
Colorectal Cancer (Activity)	857	5,526	891	5,404
Depression (Activity)	14,746	36	18,672	24
Long-term Intracranial Injuries (Traffic Related)	1,655	6,849	-949	-3,762
Short-term Intracranial Injuries (Traffic Related)	4,027	16,665	-4,341	-8,865
Spinal Cord Injuries (Traffic Related)	827	3,424	-600	-1,907
House Insulation/ventilation Related Diseases				
Cerebrovascular Disease (ETS)	-903	-5,723	-491	-2,960
Ischaemic Heart Disease (ETS)	-745	-7,903	-403	-4,006
Cardiopulmonary Disease (PM2.5)	5,267	55,860	2,848	28,309
Lung Cancer (PM2.5)	120	7,980	15	921
Cardiovascular Disease (cold)	520	4,480	282	2,283
Lung Cancer (Radon)	-40	-2,676	-5	-309
Asthma (Mould)	-933		-523	
Depression (Cold)			7,144	

* 'Adjusted figures are those effects which are estimated to occur within the 20 year time period of the model and are calculated from the duration value for YLDs and life expectancy for YLLs

Appendix B: detailed health impact analysis

Health effects
Health effects in the model (benefits and harms) were captured in three ways.

1. 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.
2. 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.
3. 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)

Immediate vs. staged implementation
YLL and YLD estimates from GHG reduction policies have been previously reported[2,3,4]. These estimates assume an immediate intervention and calculate reductions in disease burdens due to changes in exposure to various factors (outlined in the scenario specific descriptions and Appendix A). As a result, we assume immediate implementation of a healthy diet and active transport intervention to accomplish the necessary changes in consumption and transportation use and so assume that the health benefits presented in the previous Lancet papers would be realised. 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.

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 presented in the assumptions table (Appendix C). A more comprehensive modelling approach for phasing the co-benefits would require re-calculation of the co-benefits using time-varying disease risk profiles within multi-state life tables[5]. However, we used the co-benefits as calculated from the previous studies.[2,3,4] 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[6] 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.

CRA Adjustment

Since the standard comparative risk assessment method (that we used in the previous Lancet studies) is a static tool for estimating health effects it 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[45] 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. The rates used are tabulated in table B1.

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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

[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

Table B1: Percentage changes in health effects over time					
	2008 (un-discounted DALYs)	**2015 (un-discounted DALYs)**	**2030 (un-discounted DALYs)**	**Growth Rate '08-'15**	**Growth Rate '15-'30**
All Healthy Diet Related Diseases					
Ischaemic Heart Disease (saturated fat)	18,432,764	20,635,108	27,095,621	1•6%	1•8%
Stroke (cholesterol)	10,478,600	12,044,720	16,750,335	2•0%	2•2%
All Active Travel Related Diseases					
Diabetes (Activity)	2,969,258	3,730,546	5,643,687	3•3%	2•8%
Alzheimer (Activity)	3,699,256	4,960,683	9,075,682	4•3%	4•1%
Hypertensive Heart Disease (Activity)	1,215,580	1,419,836	2,167,223	2•2%	2•9%
Ischaemic Heart Disease (Activity)	18,432,764	20,635,108	27,095,621	1•6%	1•8%
Cerebrovascular Disease (Activity)	10,478,600	12,044,720	16,750,335	2•0%	2•2%
Breast Cancer (Activity)	1,934,588	2,404,857	3,553,682	3•2%	2•6%
Colorectal Cancer (Activity)	2,126,074	2,629,208	4,016,609	3•1%	2•9%
Depression (Activity)	9,432,559	11,531,693	18,073,759	2•9%	3•0%
Long-term Intracranial Injuries (Traffic Related)	3,833,261	4,122,512	4,956,999	1•0%	1•2%
Short-term Intracranial Injuries (Traffic Related)	3,833,261	4,122,512	4,956,999	1•0%	1•2%
Spinal Cord Injuries (Traffic Related)	3,833,261	4,122,512	4,956,999	1•0%	1•2%
All House Insulation/Ventilation Related Diseases					
Cerebrovascular Disease (ETS)	10,478,600	12,044,720	16,750,335	2•0%	2•2%
Ischaemic Heart Disease (ETS)	18,432,764	20,635,108	27,095,621	1•6%	1•8%
Cardiopulmonary Disease (PM2•5)	18,432,764	20,635,108	27,095,621	1•6%	1•8%
Lung Cancer (PM2•5)	3,613,493	4,430,858	6,472,929	3•0%	2•6%
Cardiovascular Disease (cold)	37,444,528	42,134,289	56,174,901	1•7%	1•9%
Lung Cancer (Radon)	3,613,493	4,430,858	6,472,929	3•0%	2•6%
Asthma (Mould)	1,456,336	1,730,207	2,514,172	2•5%	2•5%
Depression (Cold)	9,432,559	11,531,693	17,029,223	2•9%	2•6%

Healthcare Savings

Estimation of scenario and disease specific changes in healthcare savings are documented in the accompanying paper[19]. 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 (see Appendix C). Changes in pension payments were calculated as changes in YLLs for those of retirement age (over 65) multiplied by the yearly pension payment estimate (see Appendix C).

Table B2 demonstrates the contributions to the economic benefits of each of the health outcomes. Reductions in disease burden from Ischaemic Heart Disease (IHD), Dementia and 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.

Table B2 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), ˇIHD 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

Appendix C: Assumptions Table

Assumption	**Value**	**source**
UK population (by age)	Mid-year population estimates 2004 to 2008, and 2008-based population projections 2009 to 2030, by single year of age and sex in the United Kingdom	http://www.statistics.gov.uk/ populationestimates/ flash_pyramid/default.htm
	Health Assumptions: General	
Health effect implementation	**Agriculture and transport:** immediate exposure change, sigmoid curve or linear distribution as outlined below **Insulation:** as above but time distributed health effects are divided by 20 and introduced linearly over time (benefits/harms beyond 2030 are not included)	
Time effects distributed as sigmoid curve (cumulative distribution function of a normal distribution) with parameters 2 years (mean) and 0·9 years (standard distribution)	Ischaemic heart disease Stroke Alzheimers disease Hypertensive heart disease Cerebrovascular disease Depression Trachea, bronchus, lung cancers Lower respiratory infections Upper respiratory infections Inflammatory heart diseases Chronic obstructive pulmonary disease Asthma Other respiratory diseases	
Time effects distributed as sigmoid -curve with parameters 3·2 years and 1·2 years, respectively	Diabetes	
Time effects distributed as sigmoid curve with parameters 17 years and 1 year, respectively	Breast cancer Colorectal cancer Lung Cancer	
Linear (constant) distribution of health effects	All road traffic crashes	

Pension payment	£5312 per year	http://www.direct.gov.uk/en/ Pensionsandretirementplanning/ StatePension/DG_188551
Benefit payment	£ 3146 per year	http://www.timesonline.co.uk/ tol/money/reader_guides/ article5572594.ece
Life expectancy (for YLL adjustment)	See source	Murray CJL, Lopez AD (1996) The global burden of disease
Disease duration (for YLD adjustment)	See source	Murray JL & Lopez AD (1996) Global health statistics. WHO.
Prevalence (for YLL and YLD distribution by age)	See source	Murray JL & Lopez AD (1996) Global health statistics. WHO.
	Health Assumptions: Agriculture (Exposure: Response)	
YLL	167466 (Saturated fat: IHD) 2264 (Cholesterol: stroke)	Friel S, Dangour AD, et. al. Lancet 2009 *Scaled by ONS UK population model underlying CGE model*
YLD	9994 (Saturated fat to IHD)	Friel S, Dangour AD, et. al. Lancet 2009 *Scaled by ONS UK population model underlying CGE model*
YLD	9994 (Cholesterol: stroke)	Calculated relative to YLLs for Cholesterol: stroke using cerebrovascular disease ratio of YLLs to YLDs from WHO Global Burden of Disease
	Health Assumptions: Transport (Exposure: Response)	
YLL	7,006 (Physical activity: Diabetes) 7,212 (Physical activity: Alzheimer) 4,697 (Physical activity: Hypertensive heart disease) 138,451 (Physical activity: Ischaemic Heart disease) 65,329 (Physical activity: Cerebrovascular disease) 21,457 (Physical activity: Breast cancer) 5,526 (Physical activity: Colorectal cancer) -22829 (Urban road accidents broken into: 6,849 Fractured skull or intracranial injury (30%)	Woodcock et. al. Lancet ,2009.. *Scaled by England and Wales urban population model from Jarrett, et. al, of 45,431,777 (settlements of 20,000 residents or more, representing approximately 82% of the population of England and Wales)*

	16,665 Extremity injuries, Abdominal injury, Pelvic injuries & Thoracic injury (73%) 3,424 Spinal cord injury (15%))	
YLD	15,323 (Physical activity: Diabetes) 27,987 (Physical activity: Alzheimer) 657 (Physical activity: Hypertensive heart disease) 18,835 (Physical activity: Ischaemic Heart disease) 19,958 (Physical activity: Cerebrovascular disease) 3,089 (Physical activity: Breast cancer) 857 (Physical activity: Colorectal cancer) -6,509 (Urban road accidents broken into: 1,655 Fractured skull or intracranial injury (30%) 4,027 Extremity injuries, Abdominal injury, Pelvic injuries & Thoracic injury (73%) 827 Spinal cord injury (15%))	Woodcock et. al.,Lancet 2009 *Scaled by England and Wales urban population model from Jarrett, et. al, of 45,431,777(settlements of 20,000 residents or more, representing approximately 82% of the population of England and Wales)*
	Health Assumptions: Insulation/ Ventilation (Exposure: Response)	
YLL	-5723 (ETS: Cerebrovasular disease) -7903 (ETS : Ischaemic Heart disease) 55,860 (PM2.5: Cardiopulmonary disease) 7980 (PM2.5: Lung Cancer) 4480 (Cold: Cardiovascular disease) -2676 (Radon: Lung Cancer)	Wilkinson et. al. 2009 *Scaled by ONS UK population model underlying CGE model*
YLD	-933 (Mould: Asthma)	Wilkinson et. al. 2009 *Scaled by ONS UK population model underlying CGE model*
YLD	-903 (ETS: Cerebrovasular disease) -745 (ETS : Ischaemic Heart disease) 5267 (PM2.5: Cardiopulmonary disease) 120 (PM2.5: Lung Cancer) 520 (Cold: Cardiovascular disease) -40 (Radon: Lung Cancer)	Calculated relative to YLLs cerebrobascular disease and ischaemic heart disease (both IHD and cardiopulmonary disease) ratio of YLLs to YLDs from WHO Global Burden of Disease
	Other Assumptions	
GDP growth and inflation (for pre-simulation)	See source	World Economic Outlook Database (accessed online 18/7-2011)
All Healthcare Costs/Savings		Jarrett et. al. (accompanying paper)

Appendix D: Detailed description of CGE model

The scenarios were implemented using an economy-wide dynamically-recursive Computable General Equilibrium (CGE) model. The model was constructed on the basis of the 'IFPRI Standard Model'[20]– a well known and widely applied static model framework which has recently been used in health applications by some of the authors[16]. The standard model is a static multi-sector simulation model with multiple production sectors and goods markets for individual sectors such as agriculture, manufacturing and services, including health. 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.

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.[9] The original data-set contained 57 sectors, including 14 agricultural sectors, 28 primary extraction and manufacturing sectors, and 15 service sectors. This data-set was, subsequently, extended to account, separately, for household demand and production of private transportation services (three sectors) and private heating services (two sectors). Finally, the data-set was aggregated to 22 sectors including three agricultural accounts ('crops', 'livestock', and 'forestry and fishery'), seven primary extraction and manufacturing sectors (including 'processed meat and dairy products' and 'fossil fuels'), seven service accounts (including 'energy', land transportation', and 'Public administration, defence, education, health'), and five sectors relating to private transportation and heating services. The level of aggregation was chosen as a trade-off between retaining sufficient detail for meaningful analysis of the different scenarios and minimizing the complexity of the model.

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. In order to measure the future economic impact of the above scenarios, it was necessary to run a pre-simulation to target historical UK growth patterns over the period 2004-2010. Focus was on targeting of nominal demand aggregates (private and government consumption, gross fixed capital formation and stock changes, and export and import aggregates), as well as nominal and real GDP. In this way, the pre-simulation established 2010 as the base year for undertaking meaningful simulations of the GHG emission reduction scenarios over the period 2011-2030. In order to measure the simulation impact of the three scenarios, it was, furthermore, necessary to establish a counterfactual growth path over the period 2011-2030. The expected future growth path was modelled on the basis of the historical UK growth performance during 1990-2010, which included an average 5·1% nominal GDP growth rate and an average 2·1% real GDP growth rate. The targeting of nominal and real GDP growth rates were achieved by letting the GDP deflator act as price numeraire, and by allowing the model to determine the underlying expected change in Total Factor Productivity (TFP) in the UK economy over the projection horizon.

The implementation of the dynamically-recursive CGE model was based on a neo-classical model closure. This implies that prices clear all domestic markets for goods and production factors (with full employment of available factor supplies), and that balance of payments equilibrium is ensured through adjustments to the real exchange rate. General equilibrium, furthermore, requires that all institutional budget accounts are balanced, including current and capital accounts for all agents including private households, firms, and the government. Balance on current accounts is in all cases ensured through adjustments to savings, while balance on the aggregate savings-investment account is ensured through the specification of a standard savings-driven investment closure. Additional closure rules are applied to the government's current account in order (1) to ensure that the government budget remains a constant fraction of absorption in the UK economy over time, and (2) to ensure that the government budget is not expanded by the model shocks within a given year. The former target is achieved by adopting a so-called balanced macro closure where government consumption is modelled as a fixed share of absorption, while the latter target is achieved by adopting a so-called revenue-neutral government budget closure where total government revenues are fixed by allowing household tax rates to vary endogenously. The balanced macro closure is only applied in the derivation of the counterfactual growth path, while nominal government consumption is kept fixed at the counterfactual government consumption growth path (net of healthcare savings) in the simulation of the individual scenarios.

The implementation of the different scenarios involves health effects of the individual emission reduction strategies. Estimated healthcare savings are, in each case, deducted from government consumption, and this leads to a lower government current budget deficit and increased availability of domestic savings for investment purposes. Similarly, estimated social security savings (due to reduced labour market benefits) and social security costs (due to increased pension payments) are in each case deducted/added to government transfers to households. Again, this leads to a lower/higher government current budget deficit and increased availability of domestic savings for investment purposes. Finally, health benefits in the form of increases in the effective labour force (due to scenario-specific reductions in YLDs and YLLs for the working age population) are implemented through adjustments to total labour supplies, where the supplies of skilled and unskilled labour are assumed to expand proportionally. The health shocks outlined above were all introduced with a time lag and with staggered effects, to account for disease-specific differences in the dynamic pattern of the realization of the health effects (see Appendix B).

Appendix E: Sensitivity Analyses

Production Elasticities

In order to assess how the health-related labour force impact affects production differently depending on the degree of substitutability of labour for other production factors, we performed a sensitivity analysis on the elasticity of factor substitution. A high value of this elasticity causes a larger change in the ratios between different factor quantities in response to changes in relative factor prices, conversely a low value of this elasticity suggests that the ratios of factor quantities are relatively inelastic to changes in factor prices, so a change in factor prices will yield a smaller change in the relative factor quantities used in production.

In terms of specific parameter values, an elasticity of factor substitution of less than one implies that factors are complements to each other, whereas a value greater than one implies that they are substitutes. The default value for this elasticity used in the main scenarios presented in this article is 0.8. For our sensitivity analysis we have used the values 0.5, 1, 1.5 and 2 to cover a range of substitution possibilities.

Table E1 shows that the overall GDP gains are smaller for low production elasticities and larger for high elasticities. For the combined scenario, the GDP gain is reduced by over £830m (3.5%) if the production elasticity is reduced to 0.5 and increased by £1.84bn (7.7%) if the elasticity is increased to 2. This shows that the ability of the economy to make productive use of the labour gains will be influential in determining the overall economic impact of the health-related labour force gains. If the economy is able to absorb the additional labour supply, the health-related labour supply gains will have a positive effect on the economic impact by increasing production, reducing the unemployment rate and reducing social security payments. Conversely, if the economy is less able to absorb the increased labour supply these gains will be reduced.

Table E1: Sensitivity of Aggregate Health Effects (NPV in 2010 prices)

		Individual Scenarios			
Production Elasticity		Healthy Diet	Active Travel	Housing Insulation	**Combined Scenario**
0•5	**ΔGDP (2011-2030)[1]**	**4,588**	**18,077**	**466**	**23,130**
	ΔGDP per capita (2015)[2]	-1•65	0•79	0•07	-0•79
	ΔGDP per capita (2020)[2]	-0•58	6•79	-0•02	6•19
	ΔGDP per capita (2030)[2]	1•58	20•84	-0•57	21•84
0•8 (Standard)	**ΔGDP (2011-2030)[1]**	**4,659**	**18,854**	**448**	**23,960**
	ΔGDP per capita (2015)[2]	-1•72	0•75	0•06	-0•90
	ΔGDP per capita (2020)[2]	-0•57	7•19	-0•04	6•58
	ΔGDP per capita (2030)[2]	1•85	22•67	-0•60	23•91
1	**ΔGDP (2011-2030)[1]**	**4,691**	**19,245**	**438**	**24,374**
	ΔGDP per capita (2015)[2]	-1•75	0•74	0•06	-0•96
	ΔGDP per capita (2020)[2]	-0•58	7•40	-0•04	6•78
	ΔGDP per capita (2030)[2]	1•97	23•51	-0•62	24•86
1•5	**ΔGDP (2011-2030)[1]**	**4,757**	**20,024**	**419**	**25,200**
	ΔGDP per capita (2015)[2]	-1•79	0•71	0•05	-1•03
	ΔGDP per capita (2020)[2]	-0•59	7•74	-0•06	7•09

	ΔGDP per capita (2030)[2]	2•20	25•10	-0•64	26•65
2	**ΔGDP (2011-2030)[1]**	**4,810**	**20,581**	**405**	**25,796**
	ΔGDP per capita (2015)[2]	-1•82	0•69	0•05	-1•07
	ΔGDP per capita (2020)[2]	-0•60	7•93	-0•07	7•26
	ΔGDP per capita (2030)[2]	2•38	26•39	-0•67	28•09

NB: [1] Net Present Value over 2011-2030 (millions £ in 2010 prices); [2] Net Present Value (£ in 2010 prices)

Half Active Travel Sensitivity

As outlined in the previous lancet paper accompanying paper[192], an additional scenario for the transport intervention has been generated which assumes half of the increase in walking and cycling estimated in the original scenario will be achieved in practice. In order to estimate the macroeconomic impact of this reduced intervention the YLL and YLD series' were halved and the reduced healthcare savings series from Jarrett et al[2] were imported.

Table E2 shows the results of this sensitivity analysis. A comparison with Table B2 (the equivalent table for the original results) reveals that the YLL and YLD values for transport are halved with the exception of road traffic crashes where the YLLs and YLDs from the full active travel scenario are multiplied by a factor of -0.86 corresponding to the relative magnitudes of the incidence estimates in Jarrett et al[2.] The healthcare savings are reduced to approximately 60-70% of their original magnitude (except for colorectal cancer where there is a smaller reduction and road traffic crashes where the -0.86 factor change in the YLLs and YLDs is mirrored). Overall, there is a reduction of 30% in the NPV GDP gains for the transport intervention and a reduction of 25% in the NPV GDP gains for the combined scenario. Therefore the reduction in health co-benefits yields an approximately proportional reduction in NPV GDP gains.

Table E2 Disease-specific Health - Related Macroeconomic Effects- Half Active Travel

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**	**82,589**	**352,455**	**118,460**	**271,539**	**1,047•6**	**-13,929•5**	**-0•30**	**5•10**	**17•18**	**18026•3**
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**	**61,707**	**143,549**	**59,138**	**123,412**	**383•4**	**-10,734•7**	**1•35**	**5•70**	**15•94**	**12919•9**
	Diabetes (Active travel)	8,568	3,632	4,595	5,840	-0•6	-4,791•4	0•46	2•32	8•46	4454•1
	Alzheimer (Active travel)	14,740	3,737	3,490	13,604	5•4	-181•2	0•00	0•00	0•60	210•5
	Hypertensive Heart Disease (Active travel)	410	2,750	794	2,071	8•7	0•0	-0•03	-0•04	-0•05	24•9
	Ischaemic Heart Disease (Active travel)	10,925	75,289	21,652	56,499	238•4	-2,808•5	-0•18	1•02	3•24	3675•0
	Cerebrovascular Disease (Active travel)	11,726	36,567	11,176	32,786	116•2	-901•0	-0•07	0•33	0•79	1397•7
	Breast Cancer (Active travel)	1,602	9,099	3,421	5,756	22•3	-162•5	0•00	0•00	-0•10	202•4
	Colorectal Cancer (Active travel)	446	2,702	752	2,109	8•4	-24•1	0•00	0•00	-0•14	39•4
	Depression (Active travel)	9,336	12	5,953	990	-17•5	-1,304•4	0•81	1•47	2•24	1877•3
	Long-term Intracranial Injuries (Traffic)	637	2,526	1,640	930	1•4	-53•3	0•03	0•06	0•08	137•6
	Short-term Intracranial Injuries (Traffic)	2,915	5,953	4,633	2,546	0•5	-227•4	0•15	0•26	0•39	491•5
	Spinal Cord Injuries (Traffic)	403	1,281	1,031	280	0•2	-280•8	0•18	0•29	0•43	409•7
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), ˜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

Discount Rate Sensitivity

In addition to the two sensitivity analyses outlined above, we have also applied various discount rates in the model to illustrate the sensitivity of our results to the future value of the benefits. The standard scenarios use a discount rate of 3.5%, we therefore applied values of 3.0%, 4.0%, 4.5%, 5.0% to test sensitivity, a discount rate of 3% or above was selected for all scenarios to enable the real interest rate to remain positive under the model's assumed inflation rate of 2.9%.

The results of this sensitivity analysis are presented in Table E3. This sensitivity analysis shows that, because of the 20 year duration of our modelling scenarios the overall macroeconomic gains vary considerably from £25.7bn for a discount rate of 3% to £19.5bn for a discount rate of 5% so the smaller discounting rate yields economic gains 24% larger than the largest discount rate. Whilst it is important to highlight this sensitivity, we would also emphasise that this preliminary study was not intended to estimate precise magnitudes of economic gains from health co-benefits of greenhouse gas reductions, but rather to demonstrate that those economic gains were worthy of consideration as a means to partially compensate the cost of greenhouse gas reduction strategies. This conclusion remains invariant to the changes in economic gains presented in this sensitivity analysis.

Table E3 Discount Rate Sensitivity of Aggregate Health Impact on GDP (NPV in 2010 prices) (£m)

		Individual Scenarios			
Discount Rate		Healthy Diet	Active Travel	Housing Insulation	**Combined Scenario**
3•0%	ΔGDP (2011-2030)	4,982	20,233	476	**25,691**
3•5% (Standard)	ΔGDP (2011-2030)	4,659	18,854	448	**23,960**
4•0%	ΔGDP (2011-2030)	4,360	17,583	422	**22,365**
4•5%	ΔGDP (2011-2030)	4,085	16,411	397	**20,893**
5•0%	ΔGDP (2011-2030)	3,829	15,329	375	**19,534**