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JOSEPH ROWNTREE FOUNDATION

Climate Change Impacts on the Future Cost of Living (SSC/CCC004)

Appendices

Report to the Joseph Rowntree Foundation and the Project Advisory Group

Paul Watkiss Associates

Paul Watkiss, Federica Cimato, Alistair Hunt, Bruce Morley

March 2016

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Appendix 1. CCRA Analysis and Update

The UK's 1st Climate Change Risk Assessment (CCRA) considered the impacts and opportunities from climate change on the UK, looking at the future effects in the 2020s, 2050s and 2080s across low, medium, and high climate change scenarios (using UKCP09 climate projections) for five themes: Agriculture and Forestry; Business, industries and Services; Health and Wellbeing; Natural Environment; and Buildings and Infrastructure. The analysis focused on the 100 or so risks/opportunities, considering these in quantitative and in monetary terms. In some cases direct quantification and valuation was possible: in other areas qualitative assessment was undertaken, which was then considered in terms of potential importance and potential economic costs (using expert judgement). The coverage of CCRA1 against Figure 1 is shown below.

Cost Category	**Included in CCRA1**
Direct expenditures	✓
Indirect Cost Pathways	✓
Indirect Cost International	×
Policy Costs	×
Non-market Costs	✓

The CCRA approach considered costs from the perspective of social welfare, as measured by individuals' preferences using a monetary metric- generally expressed through the willingness to pay to avoid the risk. This type of approach captures the wider costs and benefits to society as a whole, rather than considering only the financial aspects (i.e. it adopted an economic rather than a financial analysis, consistent with Government appraisal). It therefore places monetary values on all impacts, not just those directly valued by markets, so it includes the welfare aspects (at the bottom of Figure 1- main summary). However, for direct expenditures, the values excluded the cost of taxes and charges and thus are lower than the prices actually paid by households.

The valuation was undertaken using unit costs for defined physical impacts, e.g. the valuation of a unit of additional energy consumed, or the non-market valuation for an additional respiratory hospital admission. These unit costs were based on values used by Government in appraisal, i.e. as used in regulatory impact assessment. The approach did not undertake wider economic modelling, thus it did not consider the indirect effects on market prices, and the subsequent demand responses. A summary of the main risks and opportunities to the UK is presented in Figure 2. While there are some important caveats, the CCRA values provide a robust starting point to understand how important climate change risks could be for households and the major cost categories. Importantly, CCRA showed that only a small number of effects are likely to have a material impact at the UK aggregate level – and by implication on the average household, whether these directly affected household costs or welfare costs. The colour coding on Figure 2 reflects risks (in red) and opportunities (in green), ranked from low to very high in terms of economic costs. The impacts that fall into the low category (£1-10 million/year) are insignificant when expressed in terms of UK GDP or averaged costs per household and even impacts in the medium category (£10 – 100 million/year) translate into very small potential effects, given the size of the UK economy and population (there are some 26 million households in the UK). Of course, in practice a number of these national costs will fall on a much smaller number of households, thus these issues are considered later.

		2020s	2050s	2080s
FL6a	Residential properties at significant risk of flooding	-H	-H	-VH
FL7a	Non-residential properties at significant risk of flooding	-H	-H	-VH
AG1b	Changes in wheat yield (due to warmer conditions)	+H	+H	+H
BE9	Reduction in energy demand for heating	+H	+H	+VH
AG1a	Changes in sugar beet yield (due to warmer conditions)	+M	+M	+M
WA5	Public water supply-demand deficits	+M	-H	-H
BD2	Risks to species and habitats due to coastal evolution	-M	-M	-H
BD7	Risks to coastal habitats due to flooding	-M	-M	-H
BE2	Increased subsidence risk due to rainfall changes	-M	-M	-M
FL14a	Agricultural land lost due to coastal erosion	-M	-M	-M
FL4a	Agricultural land at risk of flooding	-M	-H	-H
BU8	An expansion of tourist destinations in the UK	+H?	+H?	+H?
HE6	Decline in winter morbidity due to higher temperatures	+H	+H	+VH
HE5	Decline in winter mortality due to higher temperatures	+M	+M	+H
EN3	Heat related damage/disruption to energy infrastructure	-L/M	-L/M	-L/M
FL15	Flood risk for Scheduled Ancient Monument sites	-L	-L	-M
FO1a	Forest extent affected by red band needle blight	-L	-L/M	-M
HE1	Summer mortality due to higher temperatures	-L	-M	-M
HE2	Summer morbidity due to higher temperatures	-M	-H	-H
HE4a	Mortality due to summer air pollution (ozone)	-L	-L	-M
TR1	Disruption to road traffic due to flooding	-L	-L	-M
BE3	Overheating of buildings	-M	-M	-H
EN10	Energy transmission efficiency capacity losses due to heat - over ground	-M	-M	-M
EN2	Energy demand for cooling	-M	-H	-H
FL11a/b	Power stations/sub-stations at significant risk of flooding	-M	-M	-M/H
FL12a/b	Hospitals and schools at significant risk of flooding	-M	-H	-H
HE3	Extreme weather event (flooding and storms) mortality	-M	-M	-M
HE7	Extreme weather event (flooding and storms) injuries	-M	-M	-M
WA7	Insufficient summer river flows to meet environmental targets	-H	-H	-H
BD3	Risk of pests to biodiversity	-L	-M	-M
BD4	Risk of diseases to biodiversity	-L	-M	-M
BD5	Species unable to track changing 'climate space'	-L	-M	-M
BD9	Changes in species migration patterns	-L	-M	-M
BD10	Biodiversity risks due to warmer rivers and lakes	-L	-L	-M
BD11	Generalist species more able to adapt than specialists	-L	-L	-M
BD12	Wildfires due to warmer and drier conditions	-L	-L	-M
BU1	Climate risks to investment funds	-H?	-H?	-H?
BU9	A decrease in output for businesses due to supply chain disruption	-M	-M	-M
BU10	Loss of staff hours due to high internal building temperatures	-H	-H - VH?	-H - VH?
MA3	Increased ocean acidification	-L	-M	-M
MA2a	Decline in marine water quality due to sewer overflows	-L	-M	-M
MA2b	Risks of human illness due to marine pathogens	-L	-M	-M
MA5	Opening of Arctic shipping routes due to ice melt	+L	+M	+M
MA6	Distribution of marine alien/invasive species	-M	-M	-H

Confidence

Figure 2. Range of potential magnitude (all estimates) and time of onset (medium emissions, central estimate) for those risks considered important from an economic perspective

Cost	
-L	Low (£1-9m/yr)
-M	Medium (£10-99m/yr)
-H	High (£100-999m/yr)
-VH	Very high (£1000m/yr+)
?	Uncertain

Benefit	
+L	Low (£1-9m/yr)
+M	Medium (£10-99m/yr)
+H	High (£100-999m/yr)
+VH	Very high (£1000m/yr+)
?	Uncertain

Confidence (including valuation)

- High
- Medium
- Low
- Very low

The following key risks and opportunities identified in the CCRA are shown below, using the cost categories in Figure 1. The study has initially focused on these, examining the major cost risk/opportunities identified in CCRA1. These are:

Cost Category	CCRA Metrics
Direct expenditures	Demand for heating (BE9) Demand for cooling (EN2)
Indirect Cost Pathways	Residential properties at significant likelihood of flooding (FL6) Water Supply demand deficits (WA5) Subsidence (BE2)
Indirect Cost International	Not included
Policy Costs	Not included
Non-market Costs	Heat mortality (HE1) Temperature Morbidity (HE2) Cold Mortality (HE5) Cold Morbidity (HE6)

Note that while the effects of climate change on agriculture could have a large potential effect on household costs, as food is a major household expenditure item, the CCRA coverage was partial. The issue of agriculture is therefore discussed in detail in the international evidence line.

The CCRA1 costs for these effects have been used in this study to estimate estimated how important the potential costs are for the average household. The CCRA considered costs as:

- The current costs for the historic climate baseline (generally 1961-1990 consistent with UKCIP09[1]) but with a recent socio-economic baseline (2008).
- The additional (marginal) costs or benefits due to climate change per household per year, for the three future time periods (2010-2039 (2020s), 2030-2059 (2050s) and 2070-2099 (2080s)) across different potential emission scenarios (low, medium and high) and climate model projections (across the probability distribution, i.e. 10th or 90th percentile), i.e. to capture uncertainty (see box).

For the analysis here, values are updated from the CCRA and expressed as current (2013-2014 prices). Note that for heating and cooling (BE9 and EN2) the analysis was updated using current DECC retail (market) prices for energy costs (actual 2013 values), rather than the values used in CCRA (DECC government appraisal values), as the latter are based on the long-run variable cost of energy supply rather than the costs paid by households.

In all cases, values in future years are presented in current prices to allow comparison over time (i.e. they are not discounted). When future CCRA impacts include future population projections, the household costs are adjusted for future household numbers using ONS projections consistent with the numbers used in the CCRA[2].

The same (current) unit prices are also used in all future time periods. It is highlighted that for many areas – and especially the energy demand for heating and cooling – the assumption of static prices omits some important changes. Future energy costs to households will change in

[1] This means that we have already experienced some of the climate change shown in the findings in this chapter.

[2] Some CCRA impacts are presented for the impacts of climate change only on current population, while some are presented for climate and socio-economic change together (e.g. taking account of higher future population in the future) and thus it has been important to adjust values by the appropriate current or future population.

the future, with low or high price scenarios, low or high growth scenarios, and critically on the implementation of mitigation policy. For example, even in the 2030s, the price is around 25% higher under DECC's high price scenario. This highlights that future prices (for the same unit of a good or service) may be very different to today, and that a degree of self-consistency is needed: future prices will be determined by the level of future mitigation, which in turn will affect how large the impacts of climate change are in the future (in the 2050s and beyond).

The results for the key cost categories in CCRA1 are presented in Table A1. The analysis shows that climate change impacts will be responsible for additional costs, such as from flooding and heat related mortality, but also additional benefits, such as from reduced demand for heating or reduced cold-related mortality. It is stressed that it is not appropriate to add the elements to a total (net) value, partly because these only present a sub-set of all impacts, but also because of the differential impact on different groups or locations from these effects.

Nevertheless, it is clear that two effects dominate the impacts of climate change on households in the UK: increased flooding costs (an indirect cost pathway and an impact) and reduced winter heating (a direct expenditure and a benefit).

The cost estimates do increase over time, with costs and benefits increasing through the 2050s and 2080s. However, in all periods, for each individual impact, the range across the emission scenarios and climate model uncertainty is large. Within each time period, the difference is typically a factor of three to four. This broadly reflects the difference between a future 2°C (low emissions) or 4°C (high emissions) world. At the current time (November 2015), and based on the pledges from countries as part of the INDC process (Intended Nationally Determined Contributions), it is estimated that warming would be limited to 2.7°C by 2100[i] if these commitments were delivered (noting there is actually a significant range around this, due to the sensitivity of the models). This still falls some way short of the international goal – agreed at the Conference of the Parties (UNFCCC, 2010) - to limit future warming to 2°C relative to pre-industrial levels, and to consider lowering the goal to 1.5°C in the near future.

Table A1. Marginal annual average costs to England/E&W/UK households or household welfare due to climate change, range of values (CCRA estimates in 2013-14 prices).

Positive values are benefits. Relative to CCRA baseline (1961-1990 climate; current socio-economic).

			Additional £ Cost (-) /Benefit (+) per household per year (above baseline) by climate change scenario				
		Baseline	LOWp10	LOWp50	MEDp50	HIGHp50	HIGHp90
2020s							
Demand for cooling EN2	Direct cost			*-0.4*	*-1.8*	*-3.6*	
Demand for heating- BE9 (Eng. only)	Direct cost	484		+38	+87	+135	
Flooding - FL6(Eng. & Wales only)	Indirect cost	29.7			-5.1 to -44.8		
Water deficit - WA5 (UK)	Indirect cost	2.4	+1.8	-1.7	-1.7	-1.7	-5.6
Subsidence BE2 (Eng. only)	Indirect cost	14.7		-2.9 (Mp10)	-0.9	+1.7 (Mp90)	
Heat mortality - HE1	Welfare	0.9		-0.5 (Mp10)	-1.1	-2.1 (Mp90)	
Cold mortality - HE5	Welfare	31 to 69		+5 to + 7(Mp10)	+ 8 to + 13.1	+12 to +19 (Mp90)	
2050s							
Demand for cooling EN2	Direct cost			*-3.2*	*-16.0*	*-32.0*	
Demand for heating - BE9	Direct cost		+58	+124	+135	+164	+226
Flooding - FL6	Indirect cost				-9.8 to -86.8		
Water deficit - WA5	Indirect cost		-3.0	-7.7	-8.8	-9.9	-14.0
Subsidence BE2	Indirect cost		-3.7	-1.4	-1.9	-2.0	+0.9
Heat mortality - HE1	Welfare		-1.0	-2.1	-2.7	-3.0	-5.8
Cold mortality - HE5	Welfare		+8 to +12	+12.4 to 19.4	+ 12.5 to 19.5	+15.3 to + 24.0	+ 20.7 to 32.9
2080s							
Demand for cooling EN2	Direct cost						
Demand for heating - BE9	Direct cost		+108	+180	+204	+238	+332
Flooding - FL6	Indirect cost				-23.8 to -131		
Water deficit - WA5	Indirect cost		-5.9	-10.6	-12.1	-12.7	-16.1
Subsidence BE2	Indirect cost		-3.5	-1.4	-2.1	-2.7	+0.7
Heat mortality - HE1	Welfare		-1.5	-3.2	-4.8	-7.0	-14.0
Cold mortality - HE5	Welfare		+9.9 to +15.4	+15.4 to 24.2	+15.1 to +23.8	+21.9 to +35.1	+ 27 to +47

Note that values for 2020 often only consider the medium scenario only, thus p10 and p90 (the probability distribution, i.e. 10th or 90th percentile) for this scenario reported.

Heating Update from CCRA (long-run variable cost of energy supply) using current retail prices.
Cooling. Indicative value only (no detailed quantification included).
Flooding: Climate change only, no socio economic change. medium p50, with a range. Figures only for England and Wales.
Heat and cold mortality. Uses a VOLY estimate, adjusted to 4 months of life lost/premature death. Use of a higher period of life lost would significantly increase the value, and the use of the VSL would increase by two orders of magnitude.

Since CCRA, the ASC has updated some of these impact or cost estimates, notably for flooding and heat and cold related mortality (in the report, *Climate risks to well-being and the economy*: ASC, 2014). There has also been a further update of the flooding numbers as part of CCRA2, and

CCRA2 has reviewed the literature to update all of the information in CCRA1. These updates have been considered below. CCRA2 has also extended the analysis to include international effects (see the international evidence line). However, CCRA2 has not included a systematic update of the economic costs of these effects, and primarily synthesises the literature.

It is also important to explore whether there are differences in the pattern of these costs by income or deprivation levels. A more thorough check was made to map CCRA climate risks against the UK household expenditure items contained in the Living Costs and Food Survey and to explore direct, indirect and welfare effects. These are also included in the discussion below. This looked at exposure patterns by income group, but also the effects on household costs, noting that as shown in Table 1, the poorest households spend a much higher proportion of their income on key expenditure items. It also reflects the impacts of climate change on welfare and on the poorest. In terms of the households or families in these lower income groups, the statistics show that some groups do face a greater risk of poverty than others[3].

One point to note is that it is usually assumed in such studies that future economic growth will increase income, reduce poverty, increase adaptive capacity and thus reduce the potential impacts of climate change. In the numbers above, we assume current impact levels remain, and do not explicitly try to assess how income profiles (or poverty levels) might increase in the future. It is noted that the IFS (2014) study forecasts an increase in poverty in the UK, with one in three children and nearly one in four working-age adults in relative income poverty (after housing costs) by 2020, and recent policies are likely to exacerbate these figures.

Direct Expenditures

Discussion and Updates

The main effect of climate change on direct expenditures is on household energy costs, notably energy for heating and cooling. There is a large direct benefit from warmer winters in reducing the costs of heating (a private autonomous adaptation), and this benefit is large due to the reduction in heating demand anticipated by the 2030s (a central value of around 15-20%, but with a considerable range, with benefits increasing in future years) combined with the high current cost of heating and the importance in household energy bills.

Because the UK is a temperate country, there are low levels of cooling (air conditioning) today, and even under future scenarios, the likely increase in demand (cooling degree days and energy for cooling) is likely to be more modest than the reduction in winter heating. However, more recent estimates (compiled as part of the CCRA2 review, Kovats and Osborn, 2015) indicate higher levels of cooling demand are likely, driven by rising temperatures and heat-extremes, and the low cost/marketing of air conditioning. The UK housing stock has not been designed with higher temperatures in mind, and already around 20% of households in the UK experience overheating during relatively cool summers. This is likely to be a growing issue with warmer temperatures and heat extremes, especially for some properties (e.g. high level flats), and in some locations (notably London) due to the urban heat island effect. It is also worth highlighting that the costs of cooling (generally met by air conditioning) is more expensive because it uses

[3] Those at high risk of poverty include workless households, those where no one works full time, single parents (more likely to be women) and single pensioners, working-age people with a disability and some ethnic minority groups. Families with children are the biggest group in poverty. Belfield et al, 2014: Living Standards Poverty and Inequality in the UK, IFS, 2014), though this depends on the definition used.

electricity (which is more expensive per unit delivered) and involves the incremental purchase of air conditioning units / cooling systems (which are not currently in place, unlike heating systems). Indeed, in some extreme scenarios (such as the extreme high level scenario in the DECC 2050 energy projections), where cooling is adopted by all houses, the costs of cooling could be a similar order of magnitude to the reduction in winter warming by the 2050s.

Distributional effects

A discussion of how changes in energy costs affect different households is included in the next evidence stream, but in summary, electricity and gas are a major household item (5%) and a much higher proportion of low income households (e.g. 10% of the lowest income decile). Further-more, heating demand is quite inelastic (i.e. demand does not change much with higher prices), although increasing energy prices can result in lower income households reducing their energy consumption. This means that the reduction in winter heating will benefit low income groups the most, because they spend a higher proportion of their available income on fuel, and as the demand for heating reduces with climate change, this will increase available income.

For cooling, the picture is more complex, because the ownership of air conditioning is strongly income dependent (there is a strong correlation between income and AC appliances, Isaac and van Vuuren, 2008), and demand for electricity for cooling is likely to be more elastic. The take up of AC is likely to be extremely low amongst low-income groups, but instead they will experience higher temperatures and impacts on welfare (lower comfort levels, and potentially higher health impacts). There are also some types of housing, which are poorly designed and subject to over-heating, thus there is also a distributional impact from exposure. These heating and cooling patterns will also have a strong geographical pattern across the UK: winter heating demand (and thus benefits) will be greatest in Scotland and the North, while summer cooling demand will be greatest in the South.

Indirect Costs

Discussion and Updates

The main impact in this category was the impact on flooding, as this directly affects households (as well as having other indirect effects). In practice, most of the flooding cost will be borne by insurance companies (though this will feed through to insurance costs, and thus in turn, to insurance premiums). The CCRA estimated that 75% of the cost of flooding would be borne by household insurance companies, and one quarter of the total was attributed to provision of emergency and hospital services. There is, however, a large economic cost from flooding on non-residential buildings though also on other sectors (energy, transport, agriculture, business, etc.). The impact on non-residential properties in particular is large, i.e. of the same order of magnitude as the residential costs. These will pass through to higher costs for goods and services, and thus will affect households, but the transmission mechanisms are complex. However, it is clear that they will increase the cost estimates in the table.

The flood damage estimates in CCRA were updated in the ASC (2015) report and most recently for CCRA2 (Sayers et al, 2016). The latter considers a 2°, 4°C and High ++ scenario by 2050 (with current population). The economic values (equivalent annual damage), expressed as household costs, is shown below. These lead to similar estimates to CCRA1 – but with a very high increase for the high ++ scenario. The values are shown below.

Additional Cost per household (£/hh/year) – residential flooding – current households

	Expected Annual Damages (Economic) for UK			Increase in expected Annual Damages (Economic) for UK		
Present	£340m					
Epoch	2°C	4°C	H++	2°C	4°C	H++
2020s	£360m	£460m	£580m	£20m	£120m	£240m
2050s	£430m	£620m	£1300m	£90m	£280m	£960m

Source Sayers et al, 2016

There is also a smaller cost on households from the increase in subsidence. The impact on households for this impact will be similar to floods (via insurance), but the overall impact is much more modest.

The other major cost area in this category in CCRA was from the effects on water supply (and demand) and the household costs of water, which is around 2% of average household expenditure. However, the regulated nature of the UK's water sector means that impacts are indirect. The CCRA looked at estimates on the amount of water available for abstraction – and compared with demand forecasts to estimate when resources zones might fall into deficit. The resulting water deficits were values using supply-side cost data, as a proxy for the welfare value of water. Assuming the current structure of the sector, there would likely be increases in supply side costs from measures taken by the water companies (under most scenarios), which would be passed on in the form of water charges to customers. However, for households with water meters, there would be the potential for changes in demand as a result. The costs above would then translate to additional direct costs to households. Note that this was one area where the uncertainty is large, and under some of the low scenarios, there could even be benefits. There are also geographical patterns of risk across the UK, with the south more potentially at risk. As with flooding, the impacts on water (and water prices) would have impacts across the economy, which would also feed through to the prices of goods and services, so the cost estimates in the table are likely to be an underestimate.

These values have been updated as part of CCRA2. Under the upper bound scenario (high population growth and a high climate change projection) for the 2050s, under a 'no additional action' adaptation scenario, there is a pattern of large deficits in the provision of public water supplies; particularly in the south-east of England and the north of England. Such deficits are projected to become more acute and widespread in the 2080s and would present significant challenges in most parts of the UK but particularly across England. All countries are projected to be in deficit when considered at a national scale. Under this scenario, the projected total deficits across the UK equate to over 3,200 and over 6,000 Ml/d by the 2050s and 2080s respectively, equivalent to shortfalls of 16% and 29% of the required demand for water at that time. There are also some local scale deficits identified, including for London. These have been valued using the same valuation approach as CCRA1. It is noted that the pattern of projected supply-demand deficits is approximately the same between the original CCRA analysis and CCRA2, the greatest deficits are shown to be in England, particularly the London area and the north east. The differences are in the volumes of deficit calculated. In general, CCRA2 projects slightly less severe deficits than the first CCRA analysis. Adaptation also appears to have a larger influence than it did in the CCRA1 analysis, however, it should be noted that the 'Current objectives+' per capita consumption values in CCRA2 are more than 30 l/h/d lower than those used in the CCRA analysis.

There are some additional categories that could add to these costs. One of the most important is the effects on agriculture. CCRA found potential benefits on yields of some major crops, but negative impacts on others, as well as a range of other effects (flooding, changes in pests and disease). There were also potential impacts on the diary sector. This issue is explored more in the international section.

There are also potential impacts on transport and business, primarily from disruption, that could affect households indirectly, though the impacts on household expenditure are anticipated to be modest. A major gap in the knowledge base relates to how climate change risks affect biodiversity and ecosystem services, and in turn how this could indirectly affect household costs.

Distributional effects

There are a number of distributional aspects with respect to flooding. First, there are differential patterns of exposure, from risk patterns or differences in protection (as found in CCRA1). These appear clearly for coastal flooding, where there is a high correlation with socio-economic profile and the index of multiple deprivation (i.e. poorer communities are at higher risk). There is not the same correlation for river flooding, due to the higher proportion of higher income households in these locations. At the national level, the CCRA1 found that some of the areas that are at particularly risk of flooding, in Yorkshire and the Humber and the East Midlands, are areas that have (relatively) high levels of deprivation/lower average incomes. There are also differentiated patterns of protection in place. As highlighted by the CCRA1, London has a higher standard of protection than elsewhere in the UK (annual probability of flooding of 0.1%, or 1 in 1000 years). It is also likely that low income groups may be more adversely affected by flooding in relation to the post-flooding events and responses (see CCRA2).

The CCRA1 reported the number of properties in the top 20% of deprived areas at significant likelihood of river or tidal flooding could range from about 100,000 to 200,000 in the 2020s (compared with a baseline figure of about 70,000), rising to 170,000 to 300,000 by the 2080s for the range of climate change scenarios selected.

Subsequent work by the University of Manchester has created a national index of social vulnerability to flooding based on a range of factors including considering low income and also other issues of personal sensitivity, enhanced exposure and adaptive capacity. They have mapped the areas of greatest vulnerability and overlaid this with maps of flood exposure to identify areas of greatest flood disadvantage across England (see Lindley et al 2011 and www.climatejust.org.uk)

The CCRA2 analysis (Sayers et al, 2016) estimates there are currently 320,000 people in deprived areas at a 1 in 75 (year) risk of flooding, relative to the UK total risk of 1,800,000 people. While the increase in flood risks from climate change is similar for this group to the national average, it does mean that a larger number of additional people in deprived areas will be flooded under climate change.

There is also the issue of how the costs that arise affect low income households, notably around insurance cost. The LCF shows that insurance represents less than 1% of total expenditure for the lowest decile group (0.8%) as well as for the highest (0.9%). However, ABI (2010) reports that almost 40% of people in the lowest income decile did not have insurance at all in 2010, compared to 2% in the highest decile group. Such houses are also unlikely to invest in the costs of household measures to reduce flood impacts, as while the benefits of these are high, they involve high up-front costs (Grant et al. (2011). This is especially important given the high individual costs of a flood event on a household. In the event of flooding, the impact of an event on an uninsured individual household will be extremely large, both in terms of direct costs and welfare (well-being). The cost of a flood event depends on height, length and velocity of the flood as well as property type. The average insurance claim per domestic property reported in early floods was between £23k and £30k[4]. More recent ABI estimates cite a value of £50000 per claim[5]. These factors are critical given the high individual costs of a flood event on a household, although there are differences between building (structural) insurance and home contents insurance and the level of cover by tenure. There is some information on insurance take-up (Flood Re, 2016): mortgage lenders in the UK require their customers to have buildings protection which includes cover for flooding, thus take-up of insurance is as high as 98% for homeowners and coverage of households at-risk of flooding is similar to that of those not in risk areas. Take-up for renters is lower, with around 50% of these households having insurance, but take-up in at risk areas is higher at 55% (compared to 46% in non-flood risk areas). In the event of flooding, the impact of an event on an uninsured individual household (owner occupier) will be extremely large, both in terms of direct costs and economic welfare (well-being).

The implications of these effects will be determined by how the UK household insurance market evolves, and the policies introduced by Government. Currently, the proposed Flood Re scheme (a collaboration between the insurance industry and the Government) will cap the cost of insurance to households in flood prone areas with a banded system with premiums increasing with council tax band to provide affordable cover (though note houses built since 2009 are excluded to prevent building in high flood risk areas). However, as this may support a transition to market prices which reflect risk, this could have very important implications for future cover. There are also issues with the nature of the insurance agreement and the planned level of Government investment in flood protection, which could alter the future landscape. Although the eligibility for Government flood finance takes account of the Index of Multiple Deprivation, it is seeking to leverage other source of funds (partnerships funds) to meet the necessary flood protection investment levels. Analysis in a recent JRF report (England and Knox 2015) highlights that in practice, there is not such a strong link for funds being directed to areas with higher IMD and higher flood risk.

There will be similar insurance related issues with subsidence. The unit values in the CCRA for a

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[4] Information from the 2007 Floods (EEA) synthesizes information, highlighting the considerable uncertainties. Early estimates by RMS (2007) and Carpenter (2007) made shortly after the floods, based on ABI sources, suggest that the average domestic claim was some £30,000 for the June event and £40,000 for the July event (the latter in the more affluent south of the country). More recent estimates obtained in June 2009 from ABI show that 132,000 insurance claims had been lodged for damage to domestic property associated with the summer flood events at a total value of £1.72 billion, equivalent to about £13,000 per claim (though there were multiple claims made per household). A review of 18,000 aggregated claims submitted by households for the summer flood events derived from the Weathernet insurance validation database shows an average claim of £24,303 for residential properties, but the estimate is highly skewed by a small number of very large claims.

[5] https://www.abi.org.uk/News/News-releases/2016/01/New-figures-reveal-scale-of-insurance-response-after-recent-floods

case of subsidence used a value of £10,000[6], though ABI reports the average cost of dealing with subsidence is running at £6,900.

There are also distributional effects for water costs. The lowest income decile of household spends 2.9% of their budget in water supply services compared to 1.2% of the highest decile, and 1.7% of the average UK household. The increases in costs associated with additional supply side measures would therefore impact more strongly on these low income households. In cases where the structure of the industry changed, or even if there was more water metering, this might have stronger distributional impacts.

Non-market Costs

Discussion and Updates

The major welfare costs in the CCRA arose from the impacts on health (although this reflects the ease of valuation for this non-market category compared to others). These costs are estimated from the perspective of social welfare, and capture the wider costs and benefits to society as a whole. They consider three components which capture different components of this cost. These are the resource costs i.e. medical treatment costs; the opportunity costs, in terms of lost productivity; and dis-utility i.e. pain or suffering, concern and inconvenience to family and others. However, as health care costs are largely covered by service providers (e.g. NHS and health facilities), these do not feed through to changes in household expenditure.

The CCRA found a large direct benefit from warmer winters in reducing cold related mortality and morbidity, but also an impact for the same end-points from increased temperatures and heat extremes. The CCRA reported that the cold-related costs outweigh the heat related costs by some margin, though the difference narrows in later years. A number of other health impacts were quantified and valued in CCRA. These included flood related deaths (which equated to a further £0.9, 1.9 and 2.7 as a welfare cost per average household in the 2020s, 2050s and 2080s), flood related injuries (which was of a similar order), ozone related deaths (which were an order of magnitude lower), skin cancer cases and mental stress from flooding (which were also low compared to temperature related mortality). When these additional impacts are added, the gap between costs and benefits narrows significantly.

The temperature related mortality health estimates were updated as part of the ASC (2014) report, and these health impacts – when monetised using the same values as the CCRA analysis – indicate the differential is lower. The changes to heat and cold related mortality are shown below, and these show a large increase in projected heat mortality. When the other health costs (from CCRA1) are added, this effectively closes the gap, and there are net health costs (in economic terms) from climate change.

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[6] A unit value of £10,000 was used by Graves & Phillipson (2000) and Driscoll & Crilly (2000). These estimates are derived from the typical costs of undertaking specific remedial work for property subsidence. Aggregate historical data on subsidence claims supplied by the ABI for Great Britain can also be used to derive unit values. Using a regression analysis, Metroeconomica (2005) derived a central unit cost of £5,650, with a lower-bound of £1,500 and an upper bound of £12,000. ABI (https://www.abi.org.uk/News/News-releases/2015/01/Cost-of-home-insurance-falls-average-price-paid-for-buildings-cover-down-6-contents-insurance-down-5) reports a value of £6900. However, there are other welfare cost components such as the disruption endured as the repair work is undertaken, hence CCRA used a unit value of £10,000.

Social welfare cost per household	2020s	2050s	2080s
Increase heat mortality	+0.4	+1.4	+2.7
Decreased cold mortality	-1.2	-3.6	-5.8

As well as the health effects there are number of other non-market costs that could have potentially important effects on households. The most important is in relation to the effects on biodiversity and ecosystem services, and in turn how this could affect household welfare, but this remains a major gap in the knowledge base.

Distributional effects

Direct health costs are not a large direct expenditure item, and indeed high income households spend more on health than low income deciles (presumably due to private health care). Indeed this might mean that some of the additional health impacts might affect high income households more (in the form of higher taxes, or higher health insurance).

The health impacts do, however, have distributional impacts with some larger impacts on low income households, though these will include beneficial as well as detrimental effects. First, vulnerability to health impacts, particularly heat and cold-related mortality, is higher for certain population groups, notably the elderly, those with existing health conditions and those with access to low levels of social care. There are strong correlations with these groups and income levels. However, while there will be greater impacts from heat related mortality on low income households, there will be greater benefits for similar groups from reduced cold-related mortality. Nonetheless, where costs arise, such as the lost time at work, it may have greater impacts on low income households due to temporary work contracts.

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Appendix 2: UK Climate Change Mitigation costs

This task has reviewed the literature and evidence on the impact of UK climate mitigation policies on consumer prices, primarily focusing on energy bills, though also with a consideration of policies targeting other areas. It has also looked at the evidence of how these costs vary across different income groups (distributional analysis) and the reasons behind this.

While these costs do not arise as a direct result of climate change, their inclusion recognises the UK's international commitment to tackling climate change, noting also that the level of future impacts in the UK (and thus the impact of climate change on the cost of living) are determined by the amount of international mitigation.

The first area – and the one that has been most comprehensively covered in existing studies – relates to the increase in existing and near-term energy costs for households (primarily for heating) from climate mitigation policy.

The UK currently has several climate change mitigation policies. The electricity generation sector is subject to a number of carbon pricing policies: the European Union Emission Trading System (EU ETS) and the Carbon Price Floor (CPF), as well as the Renewables Obligation (RO), which supports generation from renewable sources. From 2014, a number of additional policies were introduced as part of the UK Electricity Market Reform. In addition, the UK business sector is subject to policies that apply, directly or indirectly, a price on carbon. These various policies have the potential to increase electricity and energy costs.

At the same time, UK households have been directly targeted by policies to encourage improvements in energy efficiency, to reduce energy demand and to lower household energy costs. This includes the Green Deal[7] and the Energy Company Obligation (ECO), as well as small-scale low-carbon generation (FITs)[8]. The most vulnerable households can also benefit from policies that provide energy bill abatement such as the Winter Fuel Payment (WFP), Warm Home Discount (WHD) and Cold Weather Payment (CWP).

DECC (DECC, 2014) estimated that these various (mitigation) policy measures together would cost an average dual-fuel household £188 extra a year, while helping save £276 in 2020, leading to an overall saving of £92 in 2020 in a scenario with climate change policies compared to a scenario with no policies (2014 real prices). However, in the same year, the Committee of Climate Change (CCC, 2014) reported that meeting the carbon budgets would add policy costs to a standard dual-fuel bill (representing 87% of UK households) worth £160 in 2020 (in 2013 prices) or £45 more than in 2013. Climate change mitigation policies would lower wholesale costs to £940 (a decrease of £85 pounds from 2013), and generate potential savings of £80. This

[7] The Green Deal is a market led framework that allows individuals (home owners and tenants) and businesses to make energy efficiency improvements to their buildings. Central to the Green Deal is a finance mechanism that will allow access to the finance needed for these improvements with repayment made by installments attached to the electricity bill instead of upfront payments. However, in budget 2015, it was announced that funding for Green Deal will cease to be funded, to be replaced by a new value for money approach. The budget also announced the abolition of the new zero carbon home standard for 2016: this will affect the potential efficiency of new stock, although this is a low proportion of the overall housing stock

[8] FITs support organisations, businesses, communities and individuals to generate low-carbon electricity using small-scale (5 megawatts (MW) or less total installed capacity) systems.

is significantly lower than the DECC's estimate – although the two studies used slightly different approaches). Overall, CCC estimates that by including energy savings, the typical dual-fuel energy bill will decrease by up to £120 between 2013 and 2020.

There are, however, a number of issues on how these costs and savings vary with income group.

First, the studies above have implicit assumptions about the level of uptake of energy efficiency, i.e. from households (such as the Green Deal) or the effectiveness of industry obligations (from the ECO), which in turn predicate the reduction in household energy costs reported above. The uptake of options would ordinarily be expected to be lower among low-income or vulnerable groups, e.g. due to access to finance or their preference towards finance orientated measures such as the Green Deal. However, this has been partly addressed with policies aimed at regulating the efficiency standards of the social housing stock; and low-income pensioners are the largest recipient group of support bill policies, such as the winter fuel payment (WFP), the cold weather payment (CWP), and the warm home discount (WHD) (IFS, 2013b).

Second, the costs above relate to average households, which in the UK are primarily fuelled by gas (central heating). The costs of mitigation policies on homes that heat their homes using electricity (7% of UK households) are considerably higher. Electrically heated homes consume three to four times as much electricity as the average dual-fuel home (CCC, 2012), and CCC (2014) estimated the policy costs for these households could increase by £210 by 2020 (out of a total bill of £1,025) and to £360 by 2030 (out of a total bill of £1,255). Increases could be higher in certain regions, such as Northern Scotland, where the costs of low-carbon policies for the electrically heated could reach £390 by 2030. Critically, a large percentage of the fuel poor in England use electricity as their main source of energy. They include off-gas households with older occupants (338,000 households), and households in small, urban flats, living in predominantly electrically-heated rented dwellings (almost 400,000 households) (CSE, 2014). The CCC (2014) reports that if the energy efficiency measures foreseen by the fourth carbon budget are not targeted to the fuel poor[9], then numbers in fuel poverty will sharply increase, from 5.6 million in 2013 to an estimated 8 million in 2030.

Third, it is clear that on average, any changes in energy costs will affect households differently. Lower income households spend a higher proportion of their total expenditure on energy relative to the wealthiest households: 9.6% of the total expenditure for the former compared to 3.6% for the latter[10]. Indeed, JRF (2013) estimated that climate change policies would benefit high-income households the most: the highest income decile group would see a greater

[9] Here we use the '10% definition' whereby a household is said to be in fuel poverty if it needs to spend more than 10 per cent of its income (including housing benefit) on fuel to maintain an adequate level of warmth. Fuel poverty in England is measured using the Low Income High Costs (LIHC) indicator. Under the Low Income High Costs definition, a household is considered to be fuel poor if: they have required fuel costs that are above average (the national median level), and were they to spend that amount, they would be left with a residual income below the official poverty line. Fuel poverty is a partially devolved matter and currently the Low Income High Cost (LIHC) measure is only used in England. Therefore at the UK level fuel poverty is measured under the 10 per cent definition.

[10] Living Cost and Food Survey (2014). Detailed household expenditure as a percentage of total expenditure by equivalised disposable income decile group, 2013. Equivalised income is household income that has been recalculated to take into account the fact that households with many members are likely to need a higher income to achieve the same standard of living as households with fewer members.

reduction of their bills, both in absolute terms (of £182 or more than double that of the lowest decile group of £69) and as a percentage of their bill compared to a scenario with no policies (a reduction of 12%, or 5 percentage points higher than that of the lowest decile).

Increasing energy prices can result in lower income households reducing their energy consumption, depending on the price elasticity of demand. Empirical evidence shows that energy is a necessity with price elasticity close to zero (i.e. demand does not change very much with price). However, price sensitivity decreases with income, such that at lower income levels, demand contraction due to increases in prices is higher (Jamasb and Meier, 2010; IFS, 2013). Low-income households are less responsive to gas price increases than high-income households, likely reflecting that low-income households maintain a certain level of warmth in their homes even when prices increase. However, households with no access to gas also tend to pay more for electricity and might therefore have to settle for less comfort resulting in lower total energy spending (Jamasb and Meier, 2010). These issues are also relevant for cooling demand (see CCRA analysis stream), which is primarily met through electricity.

Low-income households are less able to benefit from lower energy unit charges or discounts due to the payment methods they typically use. In the poorest decile group, 43% of households use prepayment for electricity (the most expensive payment option) whilst 28% use direct debit (the least expensive one). In the richest decile, the trend is the opposite with only 2% of households using prepayment and 77% using direct debit (IFS, 2013b).

Alongside the changes on household energy costs, other areas of policy have been reviewed.

CCC (2012, 2014) estimated that energy costs will also rise significantly for commercial and industrial users due to low-carbon policies (an increase of around 20-25% from 2011 to 2020), which could feed through to the costs of goods for household. However, average energy costs are only a small component of total costs for these sectors (i.e. less than 0.5% of costs in the commercial sector and around 3% of costs in the industrial sector), and are expected to have a negligible impact on retail prices.

Low-income households are less likely to be affected by policies targeting the transport sector – as they are less likely to have a car and more likely to travel less. However, although fiscal measures such as petrol taxes and congestion charges are progressive in aggregate, they are regressive among motorists (Blow and Crawford 1997; Crawford, 2010 in IFS). So for example, increases in fuel duty could have a stronger negative effect on poor motorists in rural areas.

There are not currently major climate mitigation policies that will impact food prices. The Greenhouse Gas Action Plan (GHGAP) published by the Industry Partnership in 2011 is a voluntary led approach with an ambition to reduce our greenhouse gas emissions by three million tonnes of CO_2 equivalent per year from 2018-2022. However the impacts on retail prices have not been estimated.

Finally, looking forward, the costs of policies above only relate to modest reductions in greenhouse gas emissions, through to 2020 or the period of the third carbon budget.

The fourth carbon budget requires emissions reduction of 50% on 1990 levels by 2025 on the overall path to reduce emissions by 80% on 1990 levels by 2050 (the 2050 target). These post 2020 emissions targets will involve much ambitious policies, and have the potential to influence household costs much more strongly, depending on the assumptions made, although under some scenarios reported by the CCC, the costs of low-carbon generation could be lower than conventional.

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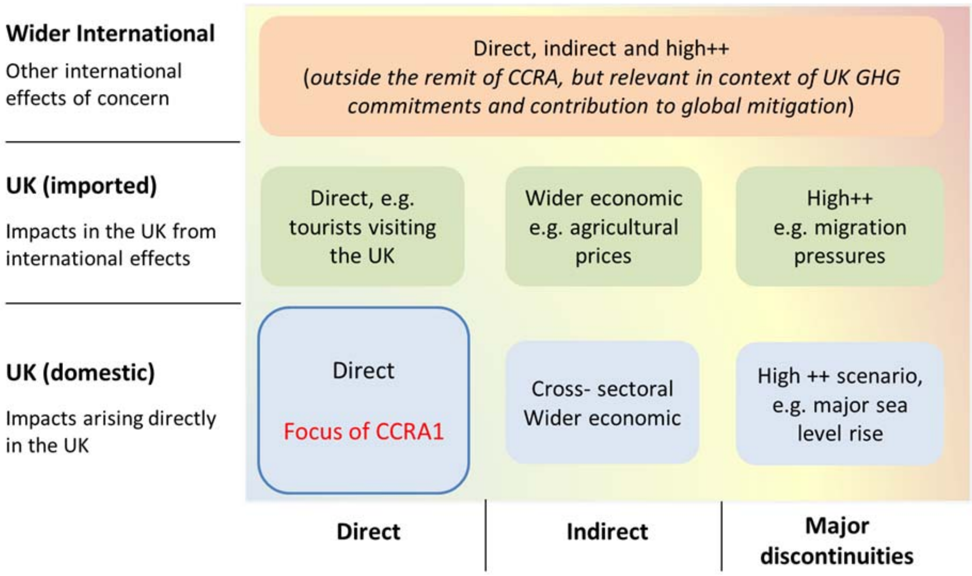
Appendix 3: International Effects

As highlighted earlier, CCRA1 focused on the domestic impacts of climate change in the UK, and thus omitted the potential effects that could happen internationally from climate change, and their subsequent impact on the UK. It did, however, recognise that these impacts existed and that they could be as large as direct UK impacts.

This evidence line has therefore investigated the potential distributional effects on UK households from climate change impacts occurring outside the UK. This has used a literature review to investigate the possible international economic costs of climate change and the impact on prices of international goods, notably food, and their subsequent effect in the UK. The framework for the chapter is shown below, based on a report for the ASC. Of particular relevance for this evidence line is the centre row, showing the potential impacts in the UK that might arise from international climate change.



Framing matrix of the CCRA in the context of examples of other direct, indirect and global risks from climate variability and change. Updated from Watkiss and Hunt, 2012.

One of the earlier UK studies to investigate these potential effects was the Foresight study (Foresight, 2011). This examined - in some depth - how international climate change could affect the UK through its global dependencies and networks. The study reported that the impacts of climate change overseas could be as important to the UK as the direct impacts within UK. A subsequent study by PwC (PwC, 2013), further disaggregated the UK effects of international impacts into risks and opportunities and evaluated their importance relative to direct domestic climate change impacts. This study confirmed the finding that international climate change impacts are likely to be at least as important to the UK as domestic impacts.

Using these reviews as a starting point, this study has provided a list of the most important potential international effects, shown in the Table. The effects on the UK are grouped in three broad categories: International Trade & Business; Health and Wellbeing, and; UK in the World & Foreign Policy. The list is not comprehensive but does indicate the major international indirect cost pathways. The table also considers how these effects might affect households, described in terms of changes in household income/employment and expenditures. Finally, the table outlines the possible transmission mechanisms for these household impacts.

The analysis then reviews the empirical evidence and literature, and considers the indicative significance for UK households. This focuses on agricultural production, partly because of the importance of food in relation to household expenditure, but also because of the larger evidence base in this area.

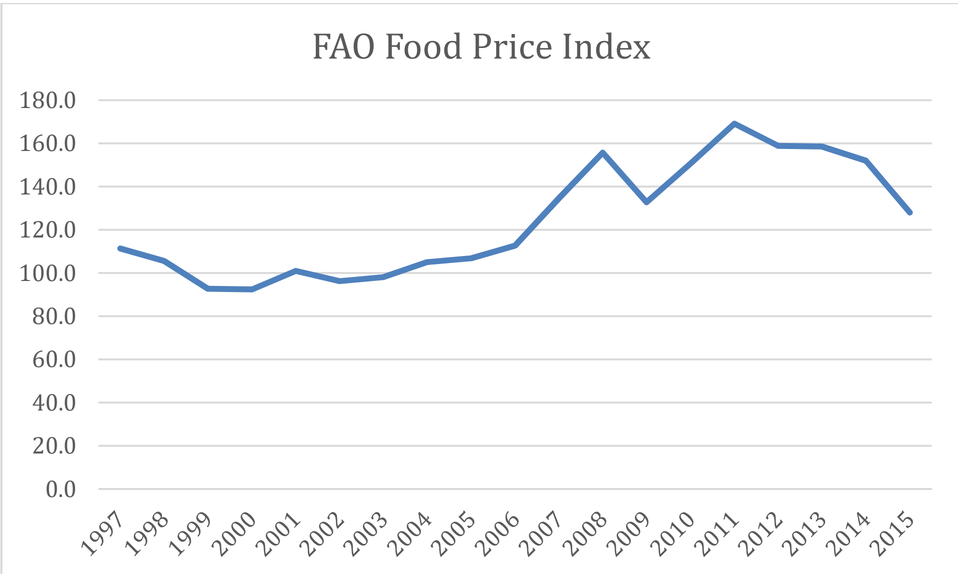
International Climate Change and UK Households – examples of linkages

Climate Change Impact	Effect on UK Households	Potential transmission mechanisms
International Trade & Business		
Production	Changes to food prices affecting household consumption	Temperature increases reduce aggregate cereal production, resulting in higher world prices which are reflected in higher consumer food prices in UK. Embodied water costs passed on in import prices, and therefore UK consumer prices.
Supply chain disruption	Changes to food & raw material prices – including energy - affecting household consumption	Damage to transport infrastructure in exporting country disrupts supply of raw materials to UK & other markets, resulting in higher intermediate good prices, then passed on to consumer prices.
Foreign demand for UK exports	Changes in sectoral employment patterns affecting household incomes	Demand for UK technical expertise, e.g. in design of flood resistant buildings, results in more employment in construction engineering, etc.
UK overseas business interests	Changes in incomes to those with shares in businesses affected by climate risks	UK businesses with assets & operations increasingly vulnerable to international climate risks lose value, resulting in falling incomes to their owners.
Finance	Changes in household insurance costs	Insurers adversely affected by increased pay-outs & damage to their asset investment portfolio as a result of increases in extreme events, pass on resulting higher costs to UK customers.
Tourism	Changes in employment patterns affecting household incomes	Patterns of European tourism change as Mediterranean region heats further so that more people holiday in UK, increasing associated industries.
Health and Wellbeing		
Effects on UK citizens abroad	Changes in health risks from e.g. vector-borne diseases, affecting welfare and income	Increased incidence of contagious diseases in UK from international travellers leads to lengthy recovery time resulting in un-paid leave from employment, or loss of income from self-employment.
Humanitarian assistance to e.g. drought areas	Individual donations and changes to public expenditure, affecting tax rates	Increased humanitarian assistance from climate change induced extreme events results in higher UK income taxes, and lower disposable incomes.
UK in the World & Foreign Policy		
International development	Individual donations and changes to public expenditure, affecting tax rates	Similar to humanitarian assistance, more investment in international development to counteract climate change impacts may result in higher tax rates and lower disposable incomes.
Migration	Changes to public expenditure, affecting tax rates, and employment patterns	Similar to humanitarian assistance. Also, increased migration to UK may have supply-side and demand-side effects on regional economies with resulting employment impacts.
Conflict	Changes to public expenditure, affecting tax rates, and employment patterns	May have supply-side and demand-side effects on regional economies with resulting employment impacts.

Effects on agriculture and food

Agriculture is a highly climate sensitive sector, and the potential magnitude of future climate change has led to a considerable body of analysis, though major differences remain on the likely effects. A key issue for this study relates to how changes in agricultural production ultimately feed through to prices, and the affordability of household expenditure on food. To answer this question, the analysis has focused on recent research, which has investigated how food prices may vary depending on how agricultural production is affected by climate change.

The figure below shows the trend from 1997 to 2015 in the UN Food and Agriculture (FAO) international food price index.[11] It shows that there has been an upward trend since 2000 that has included two significant spikes in 2006-2008 and 2010-11. In the case of the first price spike, of 40%, weather shocks have been identified as a major factor, such as drought in Australia (2005–07) that reduced wheat production and trade. However, other contributory factors included policies to promote the use of biofuels, which increased demand for maize and vegetable oils. There were also contributory factors from the depreciation of the US dollar, upward pressure on prices for petroleum and fertilizer (because of the resource-intensive nature of their economic growth and increased demand for meat, and hence animal feed (FAO, 2011). The second price spike – also of 40% - is also attributed to many of the same factors, though the strongest determinant is thought to have been the effects of drought and wild-fires in Russia and Ukraine that reduced production of barley and wheat by 30% (Wegren 2011).



Global Food Price Index Trend – Real Prices (2002-2004 = 100)

Both of these recent spikes can therefore be attributed, in part, to extreme weather events, though there are a series of other demographic and resource constraint factors that contribute to a longer term upward trend.

[11] The FAO Food Price Index is a measure of the monthly change in international prices of a basket of food commodities. It consists of the average of five commodity group price indices. See: http://www.fao.org/worldfoodsituation/foodpricesindex/en/

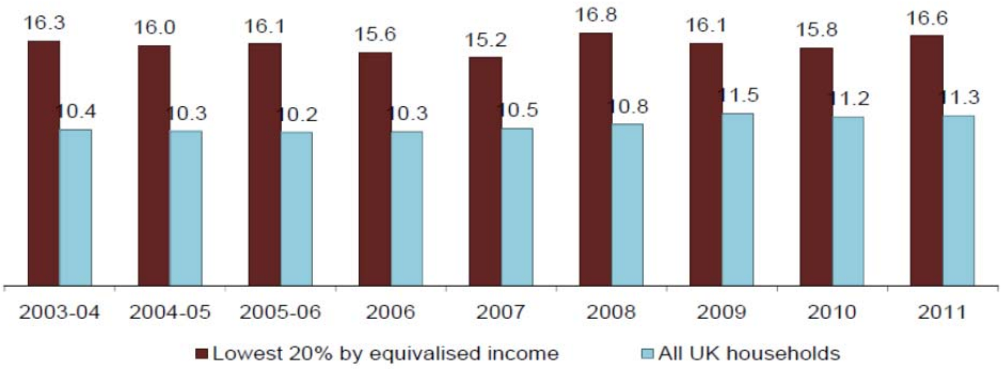
This observed pattern highlights the link between climate change and international food prices. This can be extended to consider the link with UK household expenditures, as reflected by changes in UK food prices – shown in the table. The table shows that whilst food prices rose at the same rate as overall consumer prices between 2001 and 2007, the increase in food prices between 2007 and 2011 was twice as high as that in all prices (26% compared to 14%). It is also interesting to note that although individual food products that are directly based on the cereals affected by the extreme weather events - such as bread, cereals and biscuits & cakes – increase at a similar rate (125%-133%), the meat and dairy are at least as high, (122% - 159%), reflecting the fact that cereals are used as an input for livestock. Those food products that have little relation to cereals – fruit, vegetables and alcohol – are fractionally lower (118% - 126%). These data suggest, implicitly, albeit weakly, that a global price – UK consumer price relationship may exist.

Recent Food Price Index Trends in the UK (2007 = 100)

	2001-02	2007	2011	% change since 2010
All Items Consumer Price Index	90	100	114	4.5
CPI food items	90	100	126	5
Bread	79	100	125	5.1
Cereals	94	100	130	5.6
Biscuits and cakes	93	100	133	11.2
Beef	94	100	129	4.1
Lamb	85	100	155	21
Pork	91	100	135	5.2
Fish	88	100	131	9.2
Butter	88	100	159	15.3
Cheese	98	100	129	5.7
Eggs	78	100	137	1
Milk	91	100	122	0.9
Potatoes	97	100	125	5.6
Vegetables	85	100	121	2.2
Fruit	98	100	126	3.9
Alcoholic drinks	100	100	118	5.8

Source: Defra, 2012

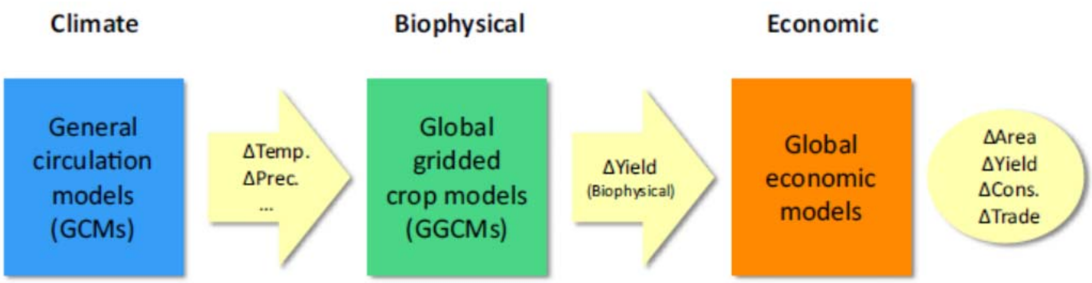
As highlighted earlier, the percentage of total household expenditure on food purchases is highest for those in the lowest income quintile. What is also interesting, shown in the figure below, is that this percentage has increased over the period 2007-2011 when the two global food price spikes occurred. This means that the food bill for an average family rose and was 12% more in 2011 than 2007, and the poorest spent 17% more in 2011 compared to 2007. Defra (2012) also reports that "low income households bought less food in 2011 than in 2007…. the lowest ten per cent of households by income purchased 9.8 per cent less food by weight between 2007 and 2011."



Percentage of spend going on food and non-alcoholic drinks

Source: Defra, 2012

While the analysis above indicates a potential link from global agricultural production to prices and UK household expenditure, it is more challenging to estimate how these effects will arise under climate change. A number of different approaches have been adopted to model these effects, though the majority of studies use a standard impact-assessment framework, which links the results of global climate projections with crop model to estimate changes in yield for major international crops. These are then incorporated as an input into the economic modelling, using global trade, partial equilibrium or general equilibrium models.



The impact assessment modelling chain. Source: Nelson et al. 2013

However, this modelling framework involves certain key factors and assumptions that can have a major influence on the outcomes of the analysis.

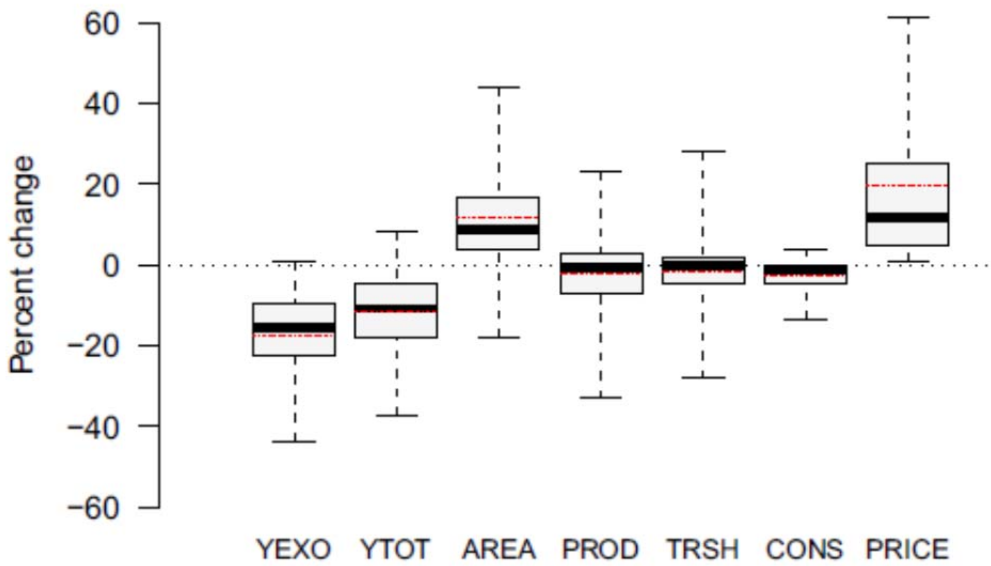
In terms of the biophysical results (and yields), this arises from the GCMs used, and notably whether uncertainty is considered. It also varies according to whether CO_2 fertilisation effects (which have a positive effect on yield) are considered. Nonetheless, there is some consensus from the crop models that negative impacts are projected for most crops in tropical and temperate regions above 2°C. The problem is that in earlier periods, the patterns are uncertain, and include potential gains as well as losses in yields, with strong variations between crops and across regions (Porter et al., 2014).

Similarly, a large range of outcomes can arise when these crop yields are fed into the economic models, and results are significantly affected by the extent and ease with which international trade is assumed to allow production patterns to shift as regional climatic conditions change.

The most recent comprehensive review and synthesis of the literature on the global impacts of climate change on agriculture has been undertaken in the Agricultural Model Inter-comparison and Improvement Project, (AGMIP), and the main results are reported in Nelson et. al. (2013). This study compares the outputs of seven economic models – three economy-wide (general equilibrium) models and four agricultural market-specific (partial equilibrium) models – from simulations that use the yield output to 2050 for a common climate scenario (RCP8.5) and a common reference socio-economic scenario for population and GDP (SSP2). The inter-comparison also used seven scenarios of biophysical crop yield changes under climate change – based on a combination of five different crop models and two general circulation models. Yields of four crop aggregates—coarse grains, oil seeds, wheat, and rice— were modelled.

The Figure below provides the main summary of the results. The percentage changes given are relative to the reference socio-economic scenario (the absence of climate change). The figure provides an overview of how the initial shock at the crop and the regional level propagates through the response options in the economic modelling. The economic models transfer the shock effect to the response variables. Producers respond to the price increase associated with the shock both by intensifying management practices [the final yield change (YTOT) is a mean decline of 11%] and by altering the area devoted to these crops (AREA), resulting in a mean area increase of 11%. The combined yield decline and area increase result in a mean decline in production of only 2%. Consumption (CONS) also declines only slightly (mean decline of 3%) as a result of the higher prices. Changes in trade shares cancel out across regions but the share of global trade in world production increases by 1% on average. Finally, average producer prices (PRICE) increase by 20%.

The direction of responses described above are common to all the models, though the magnitude of responses varies significantly across models, crops, and regions. Consequently, the ranges defined for each economic variable are substantial. For instance, the price results show a range of 0% to 60%.



Variability of key crop and economic model results across crop aggregates: 2050.
Source: Nelson et al. 2013.
YEXO = mean biophysical effects of the exogenous climate change shock on yields; YTOT = Final yields; AREA = crop area; PROD = production; TRSH = net imports relative to production in the reference scenario ; CONS = consumption; PRICE = market price effects. The boxes represent first and third quartiles, and the whiskers

show 5–95% intervals of results. The thick black line represents the median, and the thin red dotted line, the mean value.

In the current study we are interested in whether, and how, these price effects may impact on UK households, and low income households more specifically.

As a first approximation, it is possible to simply impose the estimated 20% (mean) price rise from climate change, (range 0 to 60%), on to households. If we assume that they react in the same way as they did to the 2007-2011 food price increases, this would mean that the food bill for an average family would be 9% (0%-28%) more in 2050 than without climate change, but the poorest decile would spend 13% (0%-39%) more.

The average weekly household expenditure in the UK in 2014 was £517.30, with the amount spent on food and non-alcoholic drinks being £58.80 (11%). This increase therefore equates to an impact of- £275/year (with a range of 0 to -£856), and thus major to substantial potential increase in household expenditures.

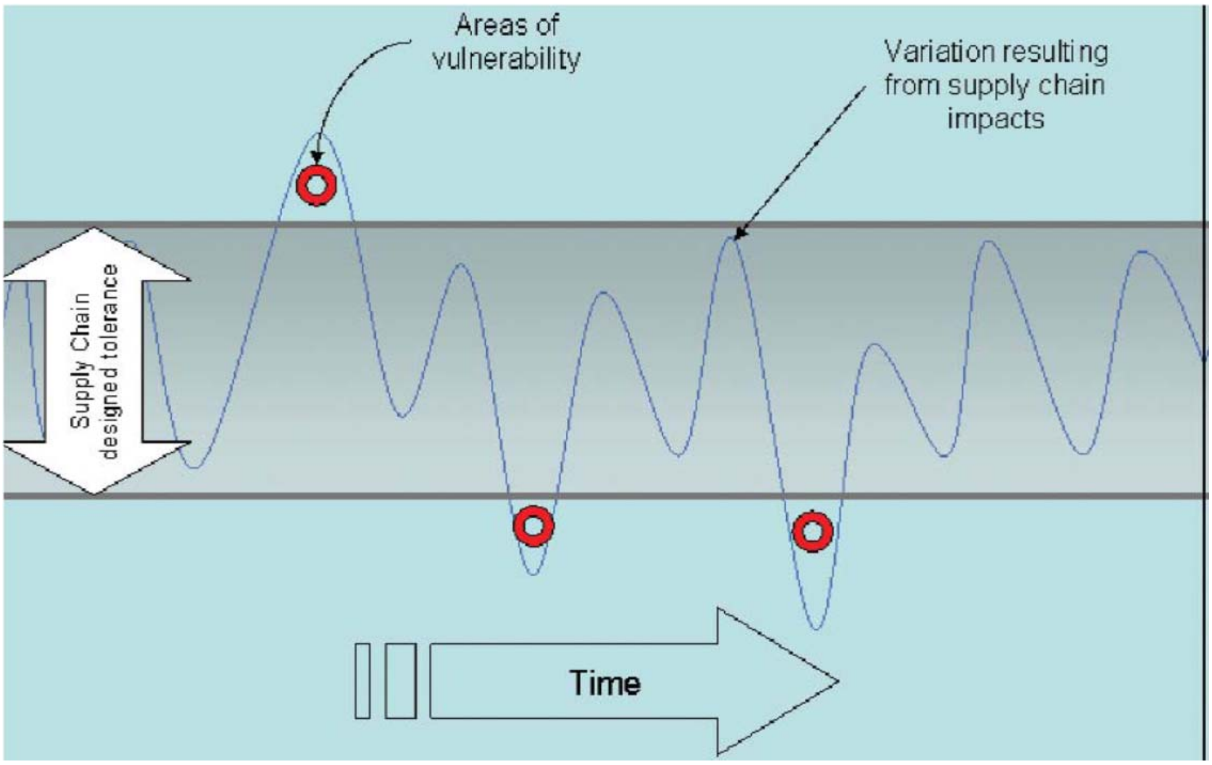
However, this simple transfer is inappropriate for a number of reasons. Perhaps the most important reason is the fact that the model results are for 2050 and one would expect that UK household income would be significantly different by then. Indeed, there is a degree of self-consistency with the modelling analysis, which uses the SSP2 socio-economic scenario that assumes that GDP per capita in the UK will be 2.5 times higher than in 2010. This would mean absolute levels of household income – both mean and lowest deciles – would be significantly higher.

There are also other reasons for treating the simple analysis with caution: there will be changes in household consumption baskets to 2050; there is a strong possibility of a non-linear household response; and the analysis involves crude extrapolation of price effects for four global crops to all household food purchases. It is also highlighted that the modelling analysis in Nelsen et al. is based on one climate and socio-economic scenario, does not consider extreme weather events comprehensively, and has limited applicability of price- and income-elasticity transfers from current to future time periods.

Nonetheless, Nelson et. al. report that their results indicate that "the price increases caused by the inelastic nature of global demand are likely to significantly increase food costs for the poor, with especially negative effects for the poor in rural areas who will also see reduced income from production side effects".

International impacts on UK supply chains from climate change

Supply chain vulnerability is a point of weakness and/or possible threat to the supply chain network of a business organisation (CIPS, 2006). Recent growth in globalisation has created more complex supply chains and with that greater risks. These complex networks may increase the number of potential weaknesses in the security of supply. The figure below illustrates that the business objective is to maintain performance within the upper and lower tolerance limits and to recognise and correct these points of vulnerability quickly before they create a significant risk (CIPS, 2006).



Vulnerability of an individual supply chain

Source: CIPS, 2006

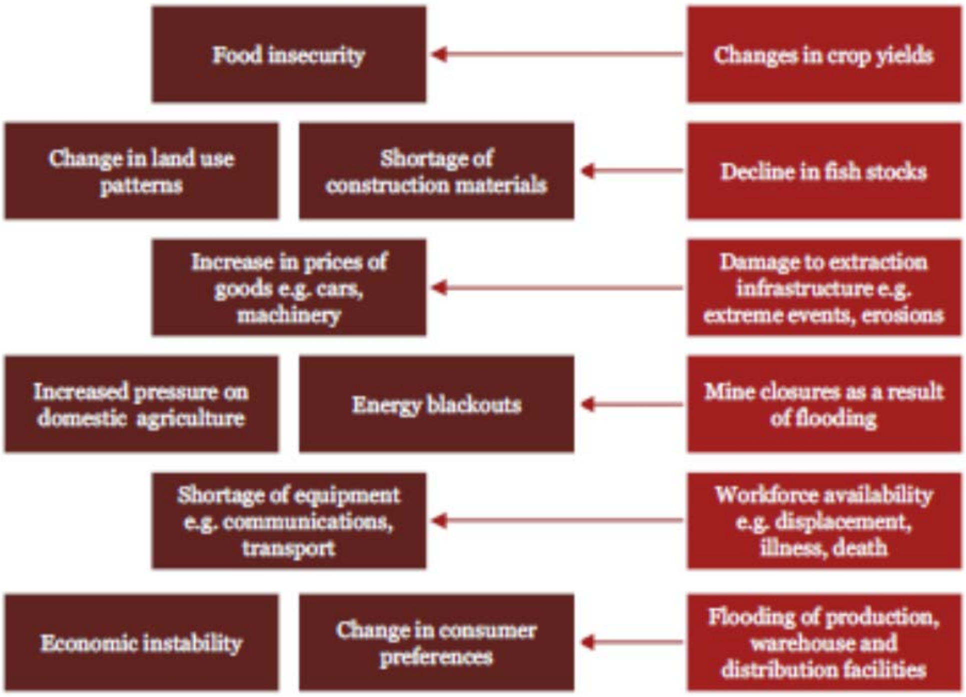
Climate Change Risks and Supply Chain Management

Extreme weather events, as well as changes in the means of climatic variables, are understood to have impacts on supply chains in which UK businesses and customers are a part. These impacts include, inter alia:

- Changing conditions affecting the extraction and/or production of raw materials to be used in food and manufacturing processes;
- Disruption to the transportation of raw materials, labour, capital or finished goods and services;
- Impacts on the international demand for UK-produced goods if, e.g. climate change impacts on incomes in importing countries, as well as on the production of UK exports – both forms affecting the value of trade flows to and from the UK.

An example given below, taken from PwC (2013), indicates - in generic terms - a number of potential impacts of trade disruptions to the economy. These occurrences are likely to have associated financial and economic costs that may be only partially mitigated by hedging and other risk management tools.

Examples of knock-on impacts from trade disruptions to the rest of the UK economy



Source: PwC (2013)

Relationship of Climate risks in International Supply Chains to UK households

Other things being equal, one would expect climate change-induced supply chain risks to result in higher market prices faced by households. This will be the case where there is some constraint in the supply of goods to market resulting from a climate risk. It is notable that – as indicated by the range of examples presented above – the extent of possible markets that may be impacted is very broad. However, perhaps as a result of this breadth, the size of price impact has not been investigated in quantitative terms for the UK.

Nevertheless, in principle, macro-economic models now exist that are able to trace the effects of global climate risks and associated trade disruption on UK domestic markets, and - by extension – on households. An example is the GTAP Multi-Regional Input-Output (MRIO) model developed by Owen and Barrett (2013), which offers a comprehensive study into trade dependences associated with UK consumption.

An additional source of data is historical analogues on this type of price effect. For example, the floods that affected Thailand extensively in October and November, 2010 resulted in global disruption in manufacturing components – particularly in the automotive and high-tech sectors – and price increases of 20-40 percent. Furthermore, many of the factories that make hard disk drives were flooded, leading to worldwide shortages of hard disk drives in the short-term. In all sectors, these type of price impacts lasted less than a year.

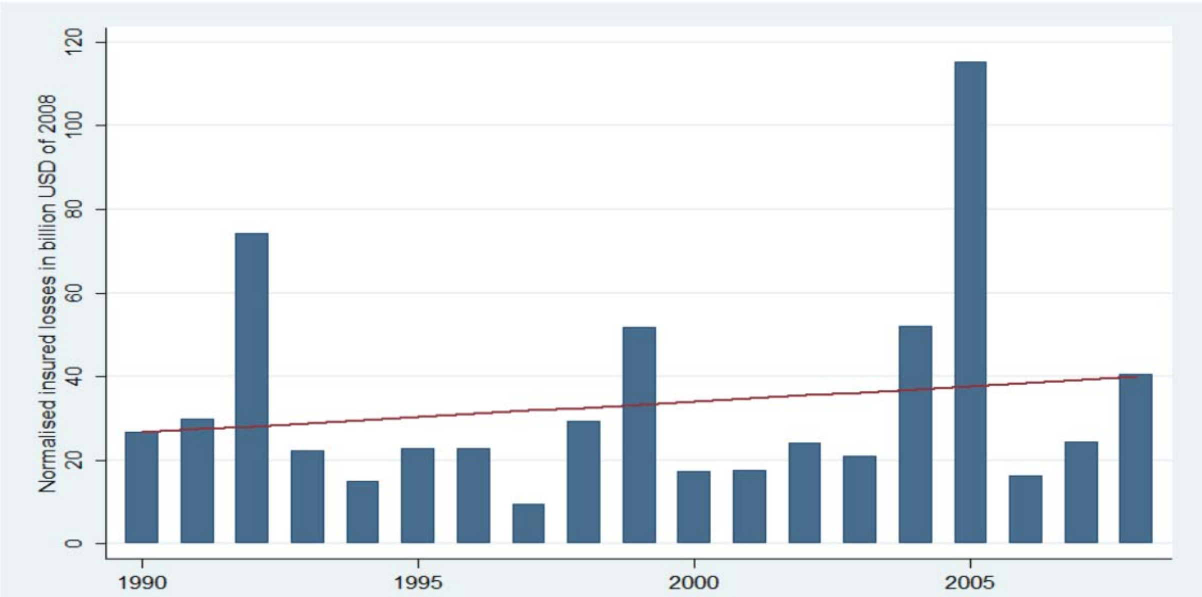
International impacts on UK financial services

The UK Financial Services sector primarily includes insurance services and banking and investment, associated with financial risk and capital management. The five main functions of the sector are:

i. transfer and pooling of risk;
ii. provision of access to capital;
iii. asset management;
iv. intermediary services, and;
v. advisory services.

The sector as a whole contributed £129 billion to the UK economy in 2010, equivalent to just under 9% of GDP (Office of National Statistics, 2011). In economic terms, functions i)-iii) are by far the most important, comprising approximately 90% of the total sectoral value.

The UK Financial Services sector has been identified as having significant potential exposure to international climate change impacts. Two elements of the financial sector in the UK are thought to be particularly vulnerable to climate change impacts projected internationally (Hunt et. al. 2009). First, the insurance and re-insurance function (i) above - is exposed to the projected increase in frequency of extreme weather events globally to the extent that it provides cover to health and property that is vulnerable to such events and whose cost is not internalised in the premiums asked for such cover. Extreme events such as Hurricanes Mitch and Katrina are illustrations of the types of risk that may need to be covered. The figure shows recent trends in insured losses associated with extreme weather events in developed countries.



Insured Losses from Non-Geophysical Disasters in Developed Countries.
Source: Barthel and Neumayer (2010)

Second, and aligning with (ii) and (iii), above, the banking and insurance sectors are exposed as they hold physical assets that may be vulnerable to changing climate – either through extreme events or through changes in mean values. For example, a bank lending to a company that owns a port in a country whose coastal geography makes it particularly susceptible to sea level rise and associated storm surges will have a liability that grows in size over time. Again, the financial sector exposure will be determined by the extent to which the increased risk is captured within the contract agreed between the parties.

Direct overseas exposure to UK financial services is dictated by the degree to which these functions are offered to those in non-UK markets and the degree to which non-UK financial services are offered in the UK.

For (i), total UK overseas insured risk equated to £65 billion in 2008, equivalent to about 25% of the total UK insured risk. Long term insured risk comprises 65% of the UK total. The overseas insured risk is dominated by exposure in mature economies; of long term overseas insured risk, 50% is in the EU whilst 37% was in North America.

For (ii), banking service export earnings from overseas lending equated to £31billion, or 35% of total UK banking lending earnings in 2008 (Office of National Statistics, 2010). Of the overseas lending, approximately 60% was to mature economies – the largest single economy borrower being the US – whilst about 40% was to emerging markets, the five largest being China, South Africa, Brazil, India and United Arab Emirates (TheCityUK, 2011).

For (iii), £1.11 trillion of overseas assets were managed by UK financial services, equivalent to 30% of total UK asset holdings. Around two-thirds of these assets are located in the EU, whilst 16% is in the Americas (IFSL, 2009). These assets can be regarded as similar to those resulting from UK foreign direct investments, (FDIs), where the overseas physical assets are owned by UK companies. In turn, these are related to overseas portfolio investments which comprise of UK ownership of stocks in overseas companies. Income to the UK from FDI and overseas portfolio investments were £82 billion and £47 billion, respectively. In the subsequent assessment, these assets are considered as being equivalent and so are not distinguished from each other.

Additionally, the UK financial service sector hosts a significant number of organisations that are foreign-owned (Silver et. al. (2010). For example, of UK Banking sector assets, around 50% are foreign owned. Of this 50%, one-half are owned by EU companies whilst one-third are US-owned.

Climate Change Risks and the Financial Services sector

Silver et. al. (2010) carried out an assessment of the potential impacts of overseas climate change on the UK financial sector. The authors undertake a qualitative analysis of the sector's vulnerability to international climate change impacts on the basis of the three functions most important to the UK, highlighted above. The impacts are primary, secondary and tertiary impacts, and are classified according to four sectoral groupings – Agriculture, Food and Ecosystems; Water Resources; Human Health, and; Industry, Settlement and Society. The impacts are further disaggregated according to scenarios differentiated on the basis of a pro-active or reactive response by the sector, as well as the health of the economy, i.e. robust or fragile. The findings are summarised in the table below.

International Climate Change Vulnerability mapping of UK Financial Sector

	REACTIVE ROBUST		REACTIVE FRAGILE		PROACTIVE ROBUST		PROACTIVE FRAGILE	
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
			Primary: Transfer and pooling of risk					
AFE								
WR								
HH								
ISS								
			Primary: Access to capital					
AFE								
WR								
HH								
ISS								
			Primary: Asset management					
AFE								
WR								
HH								
ISS								
			Secondary: Transfer and pooling of risk					
AFE	•	•	•	•	•	•	•	•
WR	•	•	•	•	•	•	•	•
HH								
ISS								
			Secondary: Access to capital					
AFE	•	•	•	•	•	•	•	•
WR	•	•	•	•	•	•	•	•
HH								
ISS								
			Secondary: Asset management					
AFE	•	•	•	•	•	•	•	•
WR	•	•	•	•	•	•	•	•
HH								
ISS								
			Tertiary: UK and Global Economy					
	•	•	•	•				

Legend: green (low vulnerability), yellow (low to medium vulnerability), orange (medium to high vulnerability) and red (high vulnerability), grey (negligible effect); Black dots indicate the potential for low probability high impact events to occur; AFE = Agriculture, Food and Ecosystems; WR = Water Resources; HH = Human Health; ISS = Industry, Settlement and Society.

Whilst the analysis does not attempt to assess the likelihood of the impacts, the findings have the following key implications:

- Opportunities for sectoral growth may arise as a response to the possibility for transferring risks associated with extreme weather events from e.g. agricultural production to insurance markets;
- Whilst human health impacts are significant as a primary impact in insurance markets, they are less likely to result in secondary and tertiary impacts. In contrast, the secondary and tertiary impacts of water resource scarcity are much more important than the primary impacts;

- In the absence of tertiary impacts, access to capital is judged to be the most vulnerable function of the financial sector, reflecting its relatively high exposure to currently emerging economies where climate change risks are projected to be more significant;
- The insurance industry is less vulnerable, due to its relatively low current level of exposure in these economies, and its greater expertise in risk management of weather events, though high levels of interdependence with the banking sector's asset access and management functions ensures continued vulnerability;
- The severity of risk to the financial sector partly depends on the extent to which the economy is robust in its ability to adapt to climate change and pro-active in its management of greenhouse mitigation. More opportunities for financial sector growth are evident within a pro-active economy;

Although the findings do not explicitly state this, it is also likely that over the next few decades, climate change risks in the principal emerging economies are likely to be significant in shaping their patterns of economic development and the consequent opportunities and risks facing the UK financial sector in these economies. Furthermore, existing markets in currently developed countries will also face more negative climate impacts in more distant future time periods, with greater risks of secondary and tertiary impacts in the UK financial sector, depending on the degree to which patterns of development are climate-resilient over the time to that period (Silver et. al. (2010)).

Relationship of Climate risks in the Financial Sector to UK households

Insurance
Currently, businesses and private individuals in the UK who have insurance cover make annual payments, known as premia, to the insurance company to pay for that cover. The cover means that those insurance companies are liable to pay compensation to the businesses and households in the event of a financial loss from, e.g., a car accident or storm damage to property. The most direct impact of climate change on UK households is therefore likely to be on the price of the premia in the instance where climate change, (e.g. higher storm frequency), results in higher insured losses in countries other than the UK, and where the insurer supplies insurance both to domestic households and international businesses and households and does not discriminate between these markets. In other words, insurance companies will increase the prices, i.e. premia, they charge for their cover in order to ensure that the increased pay-outs they would make with, e.g. higher storm frequency, are affordable. In instances where the insurance company has a range of domestic and international clients (businesses and/or individuals) and the increased pay-outs result from damages borne by those international customers, it may be the case that the insurance company recoups these international pay-outs in part by charging higher premia to domestic customers. Of course, UK households will also bear a cost as a result of businesses having to pay higher premia since these costs may be passed on to higher consumer prices.

A similar outcome would result if an extreme weather event – or series of events – led to such high pay-outs on premia that damage was done to the financial viability of an insurance company, or companies, leading to reduced competition in the insurance industry. In this case, unemployment in the insurance, and associated industries, may also result – at least in the short term – with resulting effects on the households directly affected.

A further route through which UK households may be impacted is via the lower dividends, i.e. income, that may result from negatively affected insurance/re-insurance companies. This will happen in the instance where UK households own shares in these insurance companies and the value of these shares falls as a result of storm damage overseas negatively impacting on their financial health.

The impacts on UK households that are projected to result from climate change risks overseas as a consequence of insurance coverage are described in qualitative terms above. However, it is instructive to reference the single set of quantitative estimates of effects on insurance premia that have been made in response to domestic climate change risks. These are presented in Dailey et. al. (2009), and are re-produced here. The authors first use catastrophe model runs to calculate the changes in average annual losses (AAL) that result under climate scenarios for inland flooding and wind storms in Great Britain. They then estimate the possible premia pricing impacts by examining how the changes in AAL due to climate change might change the price level of the (catastrophe portion of the) price of insurance through adopting a typical pricing formula.

Using conservative assumptions in the pricing formula, Dailey et. al. (2009), estimate that for each 1% increase in modelled AAL attributable to climate change, prices could be expected to increase by 1.47%. For inland flooding risks in Great Britain, and under alternative GDP growth and climate scenarios, they generate the results presented below.

Potential pricing changes (%) from Great Britain Inland Floods to household & business cover

GDP growth rate	0%			2.5%		
Climate scenario: Temperature increase	2^{o}C	4^{o}C	6^{o}C	2^{o}C	4^{o}C	6^{o}C
% increase in insurance pricing	12	21	37	16	27	47

Source: Dailey et. al. (2009)

For wind storms, Dailey et. al. (2009) estimate that, under alternative GDP growth scenarios, changes in AAL, in response to changes in the mean windstorm track affecting the UK, result in the pricing effects given below.

Pricing changes (%) from UK Wind Storms to household & business cover

GDP growth rate	0%	2.5%
Climate scenario: Δ in mean windstorm track in UK	37	48

Source: Dailey et. al. (2009)

This set of results suggests that – where overseas climate risks are reflected in UK insurance premia, and are of similar magnitude to the UK AALs - the effects on UK households would be significant. However, it should be noted that overseas liabilities of UK insurance companies are 25% of total liabilities, suggesting that any effects of overseas weather events are likely to have relatively small repercussions for UK households through the transmission routes described above. Moreover it may be the case that the two geographical markets, and their pricing policies, are kept separate.[12] Furthermore, the experience in the US, following Hurricane Andrew in 1992, is that whilst the insurance industry realised that the risks of losses had been underestimated and attempted to immediately increase premia, US regulatory agencies ensured that the increases were phased over time (Herweijer et. al. 2009). In the event of a similar storm in Europe, for example, it is likely that the same dampening effect on premium prices will exist as a result of the actions of regulating agencies.

This discussion is set against the broader context of UK households expenditures. In 2013, household insurance comprised 1% of the expenditure of the average income household (ONS, 2014). The bottom income decile also had household insurance costs of 1% whilst the second decile had costs of 1.6% - the highest of any decile.

Banking

Currently, businesses and private individuals pay fees – in terms of interest payments - to the banking industry to reflect the risk that the banks bare when lending to these businesses and individuals. In the instance that climate change impacts result in a change in the prospects for overseas lending activities since, e.g. international property investments become more vulnerable to flooding or wind storms, the bank fees paid by UK businesses and individuals may be expected to increase. This is as a consequence of the higher risk that these loans have, given the increased risk to the property funded by the loans.

We are not aware of any quantitative estimates of these risks, either in the UK or elsewhere. However, our expectation is that any increase in bank interest payments resulting from climate change risks would not exceed the premia price increase estimated for household insurance coverage. In any case, in 2013, household bank charges comprised 0.1% of the expenditure of the average income household (ONS, 2014).

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Appendix 4: Econometric Analysis

This part of the study involved undertaking a new econometric analysis of the links between climate and major household expenditure items in the UK.

Introduction

The aim of this study is to determine whether climate changes have had any effects on the economy as a whole, using an empirical approach and mostly UK data. As climate change has become more important to policy makers, so they have tried to assess its likely impacts on the economy and the extent to which it would affect economic growth, productivity and inflation, as well as how it may influence specific sectors, such as agriculture.

The study seeks to assess the effects of climate change on the poorer members of society. One way to do this is to analyse how climate change affects inflation, especially specific aspects of inflation, such as food inflation. Inflation is often described as the cruellest of all taxes, as it tends to affect the poorest disproportionally. Easterly and Fischer (2001) have shown that the poor are more concerned with inflation than the rich and that measures of the well-being of the poor improves as inflation falls. In terms of the emphasis on prices, especially food prices, this study follows the approach of Davidson *et al*. (2014) in determining which factors affect food prices, although with the addition of climate variables. In addition stable items such as food and clothing are more likely to impact on the poor than the rich. So to begin with we concentrate on inflation in staple products and how it is affected by the climate. In addition we have used specific data on the spending of different income quintiles, especially on basic food items such as bread.

The data used in the study is aggregate and applies to the UK as a whole. Although there is some regional climate data available, there isn't regional data on disaggregated prices, only UK wide measures. So the emphasis is on the UK as a whole. After the review of the literature there is a brief discussion on the methodology. The results are then discussed and finally some conclusions are made.

1. Background and Literature

There is an extensive body of literature on the effects of the climate on the economy, although very few time series analyses on the UK only. Most studies have used either cross section or panel data analysis, as detailed in Dell *et al*. (2014), with far fewer studies of the UK. In a similar way, there have been a number of studies which have estimated the effect of climate change on economic growth and measures of productivity, but fewer on prices. There are also a number of studies analysing the effects of temperature and precipitation on agricultural production, as well as the effects of climate change on health and energy consumption. Many of the studies regarding the effects on health further assess how the health then affects the rest of the economy and welfare of the population.

An example of the general analysis of the economy including prices, through climate effects on health can be found in Bosello *et al*.(2006) who have used a general equilibrium model, which is then shocked and the effects on the main variables simulated. The model is set up for the conditions expected to exist in 2050 and the study finds that negative health effects lead to a fall in productivity and welfare, although the effects on prices are mixed. However there are very few studies using econometric analysis that have tested the effects on prices.

The data used in most studies has been temperature and precipitation. The sources of the data are ground stations, gridded data providers and satellite data. The most basic format that the data takes is from ground stations. For more complete coverage gridded data is used and this involves interpolating station data over a grid. The satellite data is based on information obtained from satellite readings. A final type of data is reanalysis data which involves combining data sources.

Although ground station climate data has been used by many studies, often due to lack of a suitable alternative, gridded data is increasingly popular as it overcomes some of the main problems of ground station data, especially the incomplete coverage, particularly in developing countries. Gridded data provides a balanced set of data for every point on the grid, which can potentially adjust for missing station data and the urban heat island bias. The main drawback with gridded data is that it can be inconsistent across countries which may have used different interpolation methodologies.

As mentioned there are few studies specifically on the UK, although Henley and Pierson (1997) have used an econometric based approach to determine whether the demand for space heating energy is affected by the temperature outside. They have used high frequency longitudinal household data and temperature data in the UK. They find that there is a positive relationship between energy demand and the temperature, although it is non-linear, with temperatures below 10 degrees and above 20 degrees producing little impact on demand, but between 10 and 20 degrees the relationship is much stronger.

One of the main areas of study has involved the use of output as measured by GDP or industrial production. As Gates (1967) emphasises, the traditional view is that high temperatures cause lower levels of income and output. The main explanation is that higher temperatures reduce labour productivity. Many of these studies use panel data and various measures of the climate. For instance Burke and Leigh (2012) use both temperature and precipitation and find the former is a much stronger predictor of income than the latter. Other studies assess the importance of wind and wind storms on incomes, with Hsiang and Narita (2012) finding that higher wind speeds cause lower economic outputs. In terms of the agricultural outputs, the evidence suggests that higher temperatures have a negative impact on agricultural outputs. Similarly lower levels of precipitation reduce agricultural outputs. The literature on the effects of climate on health tend to find contrasting results, with both very hot and very cold climates being associated with higher mortality rates.

Data and Methodology

The data used is monthly when testing the effects on inflation (although annual in the expenditure analysis), although daily climate data is available, the economic variables are limited to monthly frequency only. The climate data has been taken from the Meteorology Office website and the data is all gridded, the first two columns in the data workbooks give the British National Grid easting and northing of the grid point. The data has been averaged across all the grids. The climate data used included the mean temperature, precipitation (mm), the maximum and minimum temperature and average wind speed.

One of the aspects of climate data is that it is not just the mean data that could potentially affect the economy, but also how volatile it is. In general the more volatile the data is, the more uncertain it is and the more unpredictable in terms of how it interacts with the economy. There are many ways of creating variability in time series data, including moving average standard deviations and conditional variance using GARCH processes. In addition the difference between the monthly maximum and minimum value could be used, although a simpler approach to the others. Although conditional variances were considered, it was difficult to find a suitable theoretical justification for this approach. Although this is a popular methodology in the economics literature, it is justified by its proxying risk or uncertainty, in terms of higher volatility clustering representing times of higher risk. This doesn't apply to climate data, so we have used the difference between the maximum and minimum values as a measure of climate volatility.

The price data is taken from the Office for National Statistics (ONS). It consists of the consumer price indexes for a number of sectors of the economy, including agricultural produce, services and health. The data is from January 1988 to December 2011 for some of the data and January 1996 to December 2011 for the other part. The Consumer Price Index was introduced into the UK in 1996 and replaced the Retail price Index. However the ONS has produced a further eight years of data for some of the indexes, based on their equivalent retail price index values. The data ends on December 2011 due to the climate data being restricted to this date.

The panel data models used expenditure on basic food items, for the 5 income quintiles. The food items included are: milk, cheese, meat, non-meat, fish, eggs, fats, sugar, potatoes, fruit, bread, cakes, biscuits, cereals, beverages, miscellaneous foods, soft drinks, confectionary and alcoholic drinks using the DEFRA database. The climate variables were taken from the same meteorological website.

There are the usual limitations to an econometric approach to modelling the climate and economy, the main one being that the modelling is all based around historic data, so it may not be able to accurately account for future effects outside of the range of temperatures recently experienced. So these effects may not be so apparent for temperatures that are 2-4 degrees C higher or a more extreme range of temperatures. It could also be that climate change may have effects from very long lags or trends, which go beyond the data range available for this study. In addition we have assumed the relationships are linear, whereas in reality they could follow a complex non-linear pattern, not readily modelled with econometric techniques.

Methodology

The econometric approach we have used is to analyse the relationship between a variety of climate variables and macroeconomic measures, including output and prices. To begin with we have done a standard Ordinary least Squares (OLS) regression with robust standard errors (Newey-West) of the following form:

$$lp_t = \alpha + \beta lc\lim ate_t + \delta X_t + u_t$$

Where p_t is a macroeconomic variable, such as a price measure and $climate_t$ is a measure of the climate such as the temperature. In addition to the bivariate study we have also added a number of control variables including income (industrial production used as the proxy), the Euro/pound exchange rate and oil prices, as noted by Davidson *et al* (2014) these are often important determinants of food price inflation. The variables are in logarithms so the beta can be treated as an elasticity. However regression analysis doesn't imply any causal link between these variables. This requires the use of Granger non-causality tests, as in Granger *et al*. (2000). The Granger non-causality tests take the following form:

$$lp_t = \alpha + \beta_i \sum_0^n lp_{t-n} + \delta_i \sum_0^n lc\lim ate_{t-n} + v_t$$

Where the number of lags (*n*) is determined by the frequency of the data. For monthly data we have included 12 lags as this removed any problems with autocorrelation. The test for non-causality is a standard F test on the joint significance of the lags of the explanatory variables. In the above case it tests for the lags on the climate variable to be jointly equal to zero, if the null hypothesis is rejected, then there is evidence of the climate Granger-causing the economy. Causality can also be tested in the reverse direction, from the economy to the climate, but as we are not assessing this, we have not conducted these tests.

There are some issues with these tests which need to be considered, including whether seasonal dummy variables need to be added to the regressions to control for seasonality in the data. We have opted to account for any seasonality and reported results including the dummy variables. A further issue is that this identifies causal relations, but not the sign of the effect, unless there is a single lag.

Results

Estimation of the determinants of inflation.

One important consideration when conducting regression analysis is whether the data is stationary or not. For the classical assumptions to apply, the data needs to be stationary. Initial tests on both the climate data and the macroeconomic data suggested it was all stationary. However to ensure stationarity, both the prices and output were differenced as well as logged, which meant the variables represented price inflation and output growth, both of which are the more popular way of expressing these effects in the literature as a whole.

Table 1 contains the results of the OLS regressions with Newey-West adjusted standard errors and covariances. To begin with we have used aggregate data across the UK, industrial production is used rather than GDP due to the availability of monthly data, whilst in Table 2 producer prices are used as they are more likely to reflect the UK economy. The data for this section of the analysis goes from January 1988 to December 2011, as producer price data only begins in 1988.

Using UK aggregate industrial production as the dependent variable, there is little evidence that the climate has had any significant effect on industrial production, with the exception of wind speed. As the wind speed increases, industrial production falls, possibly as a result of damage to buildings and infrastructure.

Table 1. OLS estimates (Industrial Production)

Climate Variable	Constant (t-statistic)	Coefficient (t-statistic)	R-squared
Temperature	0.001 (0.283)	-0.000 (0.264)	0.000
Min temp	0.000 (0.274)	-0.000 (0.245)	0.000
Max Temp	0.001 (0.316)	-0.000 (0.299)	0.000
Precipitation	0.002 (0.351)	-0.000 (0.326)	0.000
Wind	0.010 (1.715)*	-0.004 (1.675)*	0.006
Temp difference	0.001 (0.134)	-0.000 (0.119)	0.000

Notes: A * (**) (***) indicates significance at the 10%, 5% and 1% levels respectively.

However, when using producer prices there is more evidence of the climate affecting the economy. These are reported in Table 2 below. **There is strong evidence that increased precipitation reduces prices, whilst an increase in the difference between the minimum and maximum temperature produces a significant rise in prices[13].** However both effects are relatively small. with a 1% rise in precipitation producing a 0.002% fall in inflation. One potential explanation for this relationship is that as precipitation increases, so water for agriculture and industry is more plentiful and more able to add to productivity across the economy. Also as the temperature becomes more variable, so prices rise and it becomes more uncertain as to what the weather is likely to do and so more difficult to plan ahead, increasing prices across the economy.

Table 2. OLS Estimates (Producer prices)

Climate Variable	Constant (t-statistic)	Coefficient (t-statistic)	R-squared
Temperature	0.003 (2.429)**	-0.0003 (0.613)	0.002
Min temp	0.004 (3.866)***	-0.001 (1.772)*	0.009
Max Temp	0.002 (1.407)	0.0006 (0.109)	0.000
Precipitation	0.010 (4.326)***	-0.002 (3.377)***	0.026
Wind	0.004 (1.156)	-0.001 (0.408)	0.000
Temp difference	-0.004 (2.231)**	0.004 (3.324)***	0.026

The Granger non-causality results are contained in Table 3, this measures a short-run causal relationship, whereas the static regressions measure long-run effects, so potentially can produce different results for the same relationship. Again there is no evidence of the climate having a significant effect on industrial production, regardless of the climate measure used. However the relationship between the climate and prices is again much stronger, with all the measures of temperature Granger causing the producer price level. As a result of this initial aggregate dataset, the main area of analysis will be on the disaggregated price levels rather than industrial production.

Prices appear to be more sensitive to the climate than production, as the latter responds more slowly to changes in the environment, whereas prices can respond immediately. In addition as noted previously, inflation is a particular concern for those on lower incomes.

Table 3. Granger non-causality tests

Climate Variable	Industrial production	Producer prices
Temperature	5.707	27.696***
Min temp	5.616	24.835**
Max Temp	10.704	21.434**
Precipitation	7.171	12.151
Wind	5.723	14.283
Temp difference	8.871	18.902*

Tables A1 and A3 contain the OLS estimates of the regressions of the climate variables against the price indices, with robust standard errors. All the results include seasonal dummy variables,

[13] We have used the minimum and maximum separately here in an unrestricted form, an alternative would be to have restricted them to having equal and opposite coefficients, so being max minus min.

but although not reported we found there can be a difference between the results depending on whether these dummy variables are included or not. We have only reported results with the seasonal dummy variables as this produces a better specified model. The first specification is without the macroeconomic effects, but when the macroeconomic effects are included it has little effect on the results. When the seasonality was taken into account, there tends to be less evidence of any significant effects, with only the effect of precipitation on recreation being significant. Clearly as it rains more, so there is less demand for recreation, so there is a fall or less of an increase in price rises.

Tables A2, A4 and A5 contain the results from the shorter data span and the mainly agricultural indices and the results are a contrast to the service sector prices above. The results including the seasonal dummy variables tend to be better than those without, so that bread and cereals have a positive relationship with the temperature but negative with the extremes[14]. So **rising temperature seems to increase the price of cereals, but changes in the temperature variability seems to reduce them.**

One reason for the significant relationship between the UK climate and bread, is that about 85% of the wheat used by the millers of flour is from the UK and bread production is almost entirely based on UK produced flour. Much of the imported wheat is from other EU countries, such as Germany, which has a similar climate to the UK. This differs to some of the other food products included in this study, where in general about 40% of the UK's food is imported. From one year to the next, these numbers can vary depending on the harvest. The same phenomenon occurs with fruit, but not other produce. Without seasonal dummies, the price of fish rises with temperature, but there is no effect when seasonality is accounted for. The water supply without seasonal effects also seems to be affected by both precipitation and the minimum temperature, as there is more rain, so understandably the price of water falls, but also as the minimum temperature falls so the price of water rises. Falling temperature would suggest more freezing temperatures which could damage the infrastructure.

Tables A7 and A8 present the Granger non-causality tests and only results including the seasonal effects and macroeconomic variables are included. The macroeconomic effects include the Pound/Euro exchange rate, to account for the importance of the common agriculture policy, whereby financial support for farming is expressed in Euros. Secondly we included the growth in industrial production to determine whether it was income rather than climate that was driving prices. Finally we included the oil price, as noted by Davidson et al. (2014) as being an important driver of food prices. In table A7, only clothing is affected by the climate when seasonality is included at the 5% significance level, although food and drink as well as communication have some significant effects at the 10% level of significance. Table A8 has the Granger non-causality tests for the shorter time span and the agricultural produce. The most dominant result is for cereals and bread and the fish, both of which are affected by the temperature, whilst cereals are also affected by precipitation.

The price of fish is particularly susceptible to the climate, including its variability, whereas fruit and vegetables have no effect from the climate. This could be because there is an abundance of supply of fruit and vegetables, which is not the case with fish, although generally with fruit and vegetables it requires a large change in supply to affect prices. These results also

[14] The same tests were conducted using wheat prices and output for the UK based on data from DEFRA, however there was no evidence of any relationship so have not been included.

concur with other similar studies that have found a relationship between cereal prices and biofuels, which have created increased demand for cereals, but less so for fruit and vegetables. So as with fish, there could be a stronger relationship between the price and demand for cereals with respect to the climate. The costs of household maintenance are also affected by the temperature, which could be through the damaging effect of temperature on housing in general. Less easy to explain is the effect of wind on the price of meat.

The macroeconomic effects vary substantially across the inflation indices, with transport being adversely affected by the oil price, whilst the exchange rate not surprisingly affects recreation, partly because of the importance effect of the exchange rate on foreign holidays.

Effects of one-off shocks

Although the methodology doesn't include shocking the models and tracing out the impulse response functions, we did check on the effects of extreme climate phenomena. However with UK data this is quite limited and the most extreme events for which there is data are the floods in the summer of 2007 and the very cold December in 2010, which we have used to assess the prices in the year of the shock and the subsequent year and these are presented in Table 4. below.

The years 2007 and 2008 do appear to have seen a slightly higher inflation rate in these foodstuffs, reaching double figures in 2008, before falling back sharply in 2009. Although price changes were not much above average in 2007, it is likely that any effect would not have become apparent until 2008. So **there is some evidence the floods of 2007 could have had a slight effect on food inflation.** However the price changes in 2010 and 2011 were not substantially different to other year's price inflation suggesting that a very cold winter month has no lasting effects on UK prices, especially food.

Table 4. Inflation rates on selected foodstuffs

Items (annual % change)	Food	Bread and Cereals	Meat	Fish	Milk, Cheese and Eggs	Vegetables
2000	1.4	0.7	1.0	3.1	0.7	3.4
2001	3.6	2.0	3.3	3.2	4.0	2.4
2002	1.1	0.2	0.3	0.3	0.5	10.8
2003	3.3	3.3	2.1	1.3	3.1	4.9
2004	0.4	0.2	0.3	0.2	0.6	1.7
2005	1.5	2.1	1.2	3.6	4.2	3.5
2006	4.9	3.1	4.0	12.0	1.7	7.7
2007	6.9	8.3	2.3	3.7	15.8	6.0
2008	11.8	11.7	15.6	4.8	10.2	14.5
2009	1.7	1.8	1.8	2.2	1.4	5.2
2010	6.1	6.8	4.3	7.4	3.2	4.0
2011	3.9	4.1	5.6	3.8	2.5	0.9

Source ONS.

Results using global temperatures

This section analyses the effect on inflation of the world climate rather than the UK, although in general the two should follow similar trends in the long-run. The global climate has been measured using the 'Global temperature anomalies' monthly data. The data measures the departure of the temperature from a long-run trend, such that a positive value indicates an increase over the long-run trend. This measure has been used as we are interested in determining the impact of climate shocks or sudden movements away from the long-run on the economy and it is intended to follow the approach of section 5.2. The estimates of the long-run relationship estimates using OLS are in Table A6.

The models were the same as before, controlling for income, oil prices and the Euro/pound exchange rate. **As with the UK climate data there is very little evidence that the change in the climate has had much of an effect on UK prices.** The only exceptions are meat and recreation prices which have a negative relationship and vegetables where there is a positive relationship. With recreation, it suggests as world temperatures move above trend, so the costs of recreation fall, presumably because tourists don't need to travel so far to find warmer weather. However the effects are small overall. Again, oil prices, exchange rates and industrial production on the whole play only a minor role in price inflation, especially food price inflation, although oil prices are significant for a number of food items and especially transport not surprisingly. This result was also found in the study by Davidson et al. (2014), in their study on food prices in the EU.

Results from panel models using income quintiles

This approach has involved the estimation of five panel data models using data taken from the DEFRA database[15]. The dependent variable was expenditure on the selected food items, covering the five income groups, with explanatory variables consisting of a set of climate and macroeconomic variables. The data was annual and from 2002 to 2010. The model was estimated using standard techniques for controlling for potential econometric problem.[16]This was repeated on all five quintiles, which are presented in Table 5 below.

Table 5. Panel Estimation of Food Expenditure across Income Quintiles

Quintile	constant	Growing degree days	Exchange rate	Oil price	Real income
Quintile 1	105.373* (4.643)	-37.965* (4.389)	2.136* (4.632)	1.344* (5.376)	-13.244* (5.176)
Quintile 2	36.327 (0.859)	-12.607 (0.786)	0.684 (0.791)	0.489 (1.024)	-4.571 (0.945)
Quintile 3	19.917 (0.932)	-6.061 (0.744)	0.329 (0.761)	0.324 (1.315)	-2.990 (1.236)
Quintile 4	-82.995** (2.334)	33.378** (2.474)	-1.690** (2.346)	-0.789** (2.001)	8.376 (2.058)**
Quintile 5	-63.354** (2.641)	25.655* (2.825)	-1.320** (2.671)	-0.625** (2.378)	6.417** (2.323)

[15] The data contained a structural break in 2006, as expenditure moved from being reported for the financial year to the calendar year. The whole database was used for these results to allow sufficient observations, when the data was split into two samples at 2006 and the models re-estimated the overall differences were still evident, although the evidence was less strong, with only a limited number of observations of about 70 each.

[16] These included the conventional adjustment to the standard errors of the regression.

Notes: T-statistics in parentheses, *, **, *** indicates significance at the 1%, 5% and 10% levels. All estimation with Whites adjusted variances and covariances. Prices included in the estimation but all were insignificant. Estimation by fixed effects two stage least squares, instruments are single lags of explanatory variables and constant.

The tests were initially conducted on just a single climate measure in this section, which was growing degree days, which is basically the difference between the mean monthly temperature and a base temperature needed for growth. This measure was used as it is most likely to directly impact the costs of food production. In addition we included the main macroeconomic variables, these included real income, the Euro/pound exchange rate and the oil price.

The results suggests that for the lowest income quartile, the growing degree days has a negative effect, so as there is warmer weather increasing the days of growth, so expenditure on these food items goes down. However for the next two bands of households on the higher income quintiles, there is no evidence of any effect being significant. However for the higher quintiles, growing degree days again seems to be significant, but this time having a positive effect on expenditure. This could be a quality effect, whereby the more growing degree days, the higher quality the produce, which higher income groups can afford to purchase. Overall the results suggest climate change affects different income groups to a varying degree, having little impact on middle income households.

The negative effect for the lowest income quintile, of potentially warmer growing conditions suggests that the decreased expenditure could be partly due to increasing costs of these items, which affect the poor more as they are likely to be more dependent on these basic items. Higher income groups may possibly be able to afford costlier more luxurious items which are less affected by the climate and the macro-economy as much of their price would come from branding etc. So the transmission mechanism for the climate change to the lower income groups could be through the effects on basic food expenditure, which lower income groups are more likely to depend on than higher income groups. Another explanation could be that lower income groups tend to spend a higher proportion of their income on food than higher income households, so any outside factors like climate that affect the prices of the basic food items will impact on lower income groups and mean they need to cut back expenditure, whereas richer groups can mitigate against rises in food prices. The macroeconomic effects vary again across income quintiles, especially the oil price which confirms the findings of Davidson et al. (2014).

In the Appendix in Table A9 the above approach was used with various other measures of the climate in the models and macroeconomic effects[17]. These included heating degree days (proxying the need to heat greenhouses), cooling degree days, the extreme temperature range, the growing season days and consecutive dry days, as well as the growing degree days. The results suggest, for quintiles one to three, that the expenditure on food is fairly sensitive to the climate, in particular those elements of the climate that could affect food production in the UK. These include heating and cooling degree days, extremes of temperature and growing degree days. However none of the climate variables appear to have much of an effect on food expenditure for the top two income quintiles. Expenditure rises with heating degree days and falls with an increase in the cooling degree days, in addition a rise in extreme or volatile temperatures has a negative effect on expenditure. This could indicate that poorer households

[17] In Table 5 we have excluded price effects from the models, to allow for the effect of changes in expenditure to also come through a price effect, although this could be potentially at the expense of some bias in the results.

will be more affected by climate change than wealthier ones, possibly because wealthier people have a fairly inelastic demand for basic foodstuff.

Conclusion

Overall, the results offer some tentative evidence that changes in the climate could affect the wider economy in terms of expenditure and inflation, which in turn could affect the lower income households more than the higher income ones. This is because the climate has a significant effect on inflation, especially the inflation of food items, such as bread and as noted earlier, inflation has a stronger adverse effect on the poor than the wealthier parts of society. In addition estimating expenditure on basic food items in a panel format appears to show that the climate has more significant effects on the poorer members of society, especially the climatic effects relevant to food production.

These results provide a starting point for developing a future study into how climate change influences the expenditure of different income groups. One way would be to use a similar approach to Davidson *et* al. (2014) and follow the transmission of prices from the farming sector, through the intermediary sector and through to the shop prices, with a particular emphasis on how it affects a typical set of goods bought by low and high income groups. A further way of examining this relationship would be a micro-econometric based study using disaggregated data on a household or firm basis and disaggregated climate data applicable to the specific regions. However both approaches would require a major study over a prolonged period of time.

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Table A1. OLS Estimates (CPI inflation with seasonal dummy variables)

1988M1-2011M12 with monthly dummy variables								
	Food non-alcoholic beverages		**Clothing footwear**		**health**		**Transport**	
	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics
c	0.0254	1.116	0.007	0.267	-0.000	-0.010	0.025	0.886
Mean temp	0.016	0.511	0.038	0.891	-0.035	-0.977	0.022	0.594
precipitation	-0.001	-0.793	-0.001	-0.537	-0.000	-0.026	0.000	0.006
Max temp.	-0.013	-0.553	-0.026	-0.842	0.019	0.641	-0.010	-0.337
Min temp.	-0.009	-0.651	-0.015	-0.796	0.018	1.167	-0.016	-0.978
Wind speed	-0.000	-0.043	0.002	0.379	-0.004	-0.550	-0.004	-0.714
F-statistics	4.756*		52.490*		2.819*		7.227*	
Adj. R-square	0.220		0.843		0.017		0.326	

Notes: Model are estimated with OLS where standard errors have been Newey-West corrected. *, ** and *** denote significance at 1%, 5% and 10% levels, respectively. F-statistic show joint significance of the dummy variables.

1988M1-2011M12 with monthly dummy variables						
	Communications		**Recreation and culture**		**Education**	
	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics
c	-0.001	-0.052	0.011	1.068	0.017	0.683
Mean temp	-0.014	-0.318	0.006	0.386	0.024	0.727
precipitation	-0.000	-1.491	-0.000	-2.488*	0.003	1.520
Max temp.	0.006	0.200	-0.008	-0.669	-0.013	-0.464
Min temp.	0.007	0.370	-0.003	-0.348	-0.011	-0.799
Wind speed	0.003	0.598	0.003	1.318	-0.010	-1.408
F-statistics	1.561		7.322*		22.469*	
Adj. R-square	-0.008		0.229		0.589	

Table A2. OLS Estimates (CPI inflation with seasonal dummy variables)

1996M1-2011M12 with dummy variables										
	Food		**Goods and services**		**Bread and cereals**		**Meat**		**Fish**	
	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics
c	0.040	1.438	0.051	1.469	0.0511	1.855***	0.041	1.058	-0.070	-1.418
Mean temp	0.023	0.636	0.060	1.531	0.068	1.825***	0.023	0.423	-0.087	-1.196
precipitation	-0.001	-0.482	0.003	1.588	-0.002	-1.374	0.000	0.298	0.005	1.324
Max temp.	-0.019	-0.668	-0.047	-1.477	-0.053	-1.781***	-0.016	-0.383	0.0658	1.132
Min temp.	-0.012	-0.738	-0.025	-1.461	-0.031	-1.943**	-0.012	-0.520	0.039	1.194
Wind speed	-0.005	-0.813	-0.012	-2.240**	0.003	0.796	-0.011	-1.676***	-0.001	-0.110
F-statistics	3.248*		1.986**		2.266*		2.156**		0.818	
Adj. R-square	0.182		0.035		0.0819		0.042		-0.011	

Table A3. OLS Estimates with Macroeconomic Effects (CPI inflation with seasonal dummy variables)

1988M1-2011M12 with monthly dummy variables								
	Food non-alcoholic beverages		**Clothing footwear**		**health**		**Transport**	
	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics
c	0.023	1.106	0.010	0.389	-0.000	-0.004	0.027	1.127
Mean temp	0.016	0.505	0.045	1.042	-0.034	-0.954	0.025	0.780
precipitation	-0.001	-0.741	-0.001	-0.585	-0.000	-0.077	0.001	0.368
Max temp.	-0.013	-0.552	-0.032	-1.018	0.019	0.641	-0.017	-0.656
Min temp.	-0.009	-0.640	-0.018	-0.949	0.018	1.126	-0.016	-1.138
Wind speed	-0.000	-0.070	0.003	0.675	-0.003	-0.482	-0.001	-0.204
Exchange rate	-0.007	-0.300	0.059	1.817***	0.017	0.858	0.001	0.038
Oil price	0.000	0.306	0.000	1.043	0.000	-0.471	0.000	5.516*
Industrial prod.	-0.003	-0.342	0.003	0.138	0.010	0.623	0.015	1.132
F-statistics	4.331*		59.281*		2.514*		6.637*	
Adj. R-square	0.212		0.845		0.009		0.425	

Table A4. OLS Estimates with Macroeconomic Effects (CPI inflation with seasonal dummy variables)

Table 11.1996M1-2011M12 with monthly dummy variables										
	Food		**Goods and services**		**Bread and cereals**		**Meat**		**Fish**	
	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics
c	0.039	1.427	0.050	1.489	0.049	1.732***	0.040	1.015	-0.068	-1.299
Mean temp	0.022	0.612	0.058	1.535	0.066	1.722***	0.021	0.391	-0.087	-1.154
precipitation	-0.001	-0.423	0.003	1.628	-0.002	-1.191	0.000	0.218	0.004	1.100
Max temp.	-0.018	-0.638	-0.044	-1.464	-0.052	-1.672***	-0.016	-0.376	0.067	1.120
Min temp.	-0.011	-0.722	-0.024	-1.470	-0.030	-1.844***	-0.011	-0.470	0.038	1.143
Wind speed	-0.006	-0.916	-0.013	-2.389**	0.003	0.636	-0.010	-1.489	-0.001	-0.077
Exchange rate	-0.005	-0.195	-0.007	-0.411	-0.025	-1.003	-0.028	-0.891	0.041	1.071
Oil price	-0.002	-0.394	-0.006	-1.248	0.004	0.532	0.007	0.889	-0.018	-1.684***
Industrial prod.	-0.010	-0.830	-0.010	-0.839	-0.018	-1.504	0.018	1.200	0.036	1.093
F-statistics	2.637*		1.925**		2.183*		2.405*		0.823	
Adj. R-square	0.171		0.0291		0.081		0.040		-0.003	

Table A5. OLS Estimates with macroeconomic effects (CPI inflation with seasonal dummy variables)

1996M1-2011M12 with monthly dummy variables								
	Milk, cheese and eggs		**Fruit**		**Vegetables**		**Water supply**	
	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics
c	0.0174	0.508	0.200	2.428**	0.016	0.154	-0.042	-1.344
Mean temp	0.0432	0.965	0.313	2.791*	-0.178	-1.254	-0.051	-1.221
precipitation	-0.000	-0.304	0.003	0.541	-0.004	-0.561	-0.004	-0.815
Max temp.	-0.022	-0.567	-0.251	-2.774*	0.137	1.265	0.039	1.118
Min temp.	-0.025	-1.317	-0.144	-2.942*	0.080	1.266	0.023	1.249
Wind speed	0.000	0.021	0.005	0.253	-0.039	-1.599	0.014	1.231
Exchange rate	-0.043	-1.574	0.176	2.410**	-0.021	-0.254	-0.030	-1.106
Oil price	0.006	0.613	-0.014	-0.805	-0.028	-1.268	0.013	1.023
Industrial prod.	-0.030	-1.875***	-0.002	-0.038	-0.063	-1.106	0.035	1.069
F-statistics	2.685**		17.310*		2.479*		7.773982*	
Adj. R-square	0.0411		0.5810		0.163		0.533	

Table A6. OLS Estimates with Global Temperature Anomalies.

Inflation Variable	constant	World temperature	Euro/£ exchange rate	Oil Price	Industrial production	R^2
Bread	-0.005 (0.648)	0.002 (0.934)	-0.032 (1.256)	-0.000 (0.080)	-0.019 (2.258)**	0.017
Fish	0.012 (0.830)	0.003 (1.104)	0.052 (1.203)	0.018 (1.741)*	0.008 (0.441)	0.004
Food	-0.008 (0.885)	0.002 (1.161)	-0.015 (0.560)	-0.005 (0.676)	-0.008 (1.002)	0.00
Fruit	0.008 (0.203)	-0.001 (0.127)	0.105 (1.013)	-0.051 (1.761)*	0.003 (0.081)	0.00
Housing	-0.000 (0.046)	0.001 (0.425)	-0.001 (0.090)	-0.004 (0.825)	-0.001 (0.090)	0.00
Meat	0.018 (1.802)*	-0.004 (1.687)*	-0.036 (1.104)	0.010 (1.325)	-0.007 (0.534)	0.008
Milk	-0.002 (0.195)	0.000 (0.402)	-0.054 (2.106)**	0.005 (0.711)	-0.001 (0.830)	0.005
Vegetables	-0.077 (2.063)**	0.018 (2.130)**	-0.026 (0.295)	-0.018 (0.817)	-0.031 (0.884)	0.018
Water	-0.003 (0.278)	0.001 (0.542)	-0.002 (0.052)	0.022 (1.819)*	-0.067 (2.948)**	0.072
Clothes	0.007 (1.078)	-0.002 (1.428)	-0.073 (1.114)	0.008 (0.653)	0.094 (5.681)***	0.059
Communications	-0.001 (0.171)	0.000 (0.116)	0.037 (1.597)	0.007 (1.460)	-0.005 (0.857)	0.008
Education	0.020 (2.388)**	-0.003 (1.646)	-0.019 (0.559)	-0.003 (0.215)	0.081 (5.265)***	0.143
Food/drink	-0.002 (0.417)	0.001 (1.140)	-0.020 (0.907)	-0.001 (0.127)	-0.002 (0.849)	0.000
Recreation/Culture	0.007 (3.439)***	-0.001 (2.934)**	0.013 (1.517)	0.002 (1.181)	-0.011 (3.094)***	0.058
Transport	0.004 (1.114)	-0.000 (0.357)	0.005 (0.155)	0.042 (5.519)***	-0.043 (5.202)***	0.201

Notes: A * (**) (***) indicates significance at the 10%, 5% and 1% levels respectively.

Table A7 Granger non-causality tests for CPI inflation with macroeconomic effects 1988m1-2011m12			
Food and non-alcoholic beverages	Chi-sq	P-values	Causality at 5% (10%)
Mean temp	19.168	0.085	Yes (10%)
Precipitation	10.797	0.546	No
Maximum temperature	17.010	0.149	No
Minimum temperature	18.808	0.093	Yes (10%)
Wind speed	13.218	0.353	No
Max-min	11.437	0.492	No
Exchange rate	3.993	0.136	No
Oil price	23.225	0.026	Yes
Industrial production	19.725	0.073	no
Clothing and footwear			
Mean temp	23.147	0.027	Yes
Precipitation	12.763	0.387	No
Maximum temperature	16.842	0.170	No
Minimum temperature	21.756	0.040	Yes
Wind speed	14.145	0.292	No
Max-min	16.440	0.172	No
Exchange rate	10.116	0.606	N0
Oil price	18.094	0.112	No
Industrial production	9.571	0.654	no
Communications			
Mean temp	19.081	0.087	Yes (10%)
Precipitation	15.452	0.218	No
Maximum temperature	19.286	0.082	Yes (10%)
Minimum temperature	17.382	0.136	No
Wind speed	14.112	0.294	No
Max-min	14.099	0.294	No
Exchange rate	11.574	0.481	No
Oil price	19.084	0.087	Yes (10%)
Industrial production	16.550	0.167	no

Table A8 Granger non-causality tests for CPI inflation with macroeconomic effects 1996m1-2011m12			
Goods and Services for Household Maintenance	Chi-sq	P-values	Causality at 5% (10%)
Mean temp	24.493	0.017	Yes
Precipitation	7.471	0.825	No
Maximum temperature	12.371	0.416	No
Minimum temperature	33.085	0.000	Yes
Wind speed	6.218	0.905	No
Max-min	7.853	0.797	No
Exchange rate	20.769	0.054	Yes (10%)
Oil price	21.960	0.058	Yes (10%)
Industrial production	10.133	0.604	no
Bread and Cereals			
Mean temp	42.467	0.000	Yes
Precipitation	22.938	0.028	Yes
Maximum temperature	14.748	0.256	No
Minimum temperature	55.084	0.000	Yes
Wind speed	16.203	0.182	No
Max-min	12.884	0.378	No
Exchange rate	12.285	0.423	No
Oil price	6.419	0.894	No
Industrial production	9.172	0.688	no
Fish			
Mean temp	30.220	0.003	Yes
Precipitation	11.943	0.450	No
Maximum temperature	25.507	0.013	Yes
Minimum temperature	27.780	0.006	Yes
Wind speed	16.839	0.156	No
Max-min	16.185	0.183	No
Exchange rate	13.680	0.322	No
Oil price	10.059	0.611	No
Industrial production	8.646	0.733	no

Table A9. Panel Estimation of Food Expenditure across Income Quintiles.

Quintile	heating degree days	cooling degree days	growing degree days	extreme temperature range	growing season days	consecutive dry days	R-squared
Quintile 1	5.714* (3.147)	-0.276* (3.111)	4.450** (2.708)	-0.328 (0.704)	0.048 (0.118)	-0.036 (0.975)	0.994
Quintile 2	5.145** (2.512)	-0.188** (1.998)	4.582** (2.588)	-1.100** (2.305)	-0.648 (1.665)	0.049 (1.294)	0.994
Quintile 3	5.721* (2.807)	-0.214** (2.299)	4.816** (2.692)	-1.060*** (1.955)	-0.631 (1.517)	0.0216 (0.512)	0.994
Quintile 4	0.516 (1.138)	1.714 (0.774)	-0.116 (1.116)	-0.543 (1.036)	-0.563 (1.170)	-0.002 (0.040)	0.994
Quintile 5	1.472 (0.685)	-0.076 (0.762)	1.746 (0.907)	-0.155 (0.310)	-0.256 (0.595)	0.025 (0.568)	0.996

Notes: T-statistics in parentheses, *, **, *** indicates significance at the 1%, 5% and 10% levels. All estimation with Whites adjusted variances and covariances. Prices included in the estimation but all were insignificant. Estimation by fixed effects two stage least squares, instruments are single lags of explanatory variables and constant.

Hypothesised Relationships between the climate and economy		
Hypothetical relationship	**Economic Data: Variable; Source**	**Climate Data**
UK industrial production - temperature	Industrial production index, IMF IFS. Mean temperature, UK Met Office UKCP09	Monthly
UK industrial production – heating days	Industrial production index, IMF IFS.	Monthly
UK industrial production – cooling days	Industrial production index, IMF IFS.	Annual
UK consumer prices - temperature	Consumer price index, IMF, IFS	Monthly
UK wholesale prices - temperature	Wholesale price index, IMF, IFS	Monthly
All the above – temperature volatility	Max - Min	Monthly
All the above - precipitation	As above (mm monthly) Met Office UKCP09	As above
Consumer prices (food and non-alcholic drinks) - temperature	CPI ONS	monthly
Consumer prices (clothing and footwear) - temperature	CPI ONS	Monthly
Consumer prices (education) - temperature	CPI ONS	Monthly
Consumer prices (transport) - temperature	CPI ONS	Monthly
Consumer prices (communications) - temperature	CPI ONS	Monthly 1988
Consumer prices (recreation and culture) - temperature	CPI ONS	Monthly 1988
Consumer prices (health) - temperature	CPI ONS	Monthly 1988
Consumer prices (food) - temperature	CPI ONS	Monthly 1996
Consumer prices (housing maintenance) -temperature	CPI ONS	Monthly 1996
Consumer prices (bread and cereals) - temperature	CPI ONS	Monthly 1996
Consumer prices (meat) - temperature	CPI ONS	Monthly 1996
Consumer prices (fish) - temperature	CPI ONS	Monthly 1996
Consumer prices (milk, cheese and eggs) - temperature	CPI ONS	Monthly 1996
Consumer prices (fruits) - temperature	CPiIONS	Monthly 1996
Consumer prices (vegetables) - temperature	CPI ONS	Monthly 1996
Consumer prices (water supply) - temperature	CPI ONS	Monthly 1996
Wheat prices/output - temperature	ONS	Weekly 1994
Barley prices/ output	ONS	Weekly 1994
All the above – precipitation	As above (mm monthly, Met office UKCP09)	As above
All the above – mean daily max/min temperature	As above	As above
All the above - snow	As above (Days of snow lying on ground)	As above
All the above mean wind speed	As above (knots)	As above

[i] http://unfccc.int/resource/docs/2015/cop21/eng/07.pdf