

**Defra Evidence and Analysis Series**

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**Paper 1**

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**Adapting to  
Climate Change:  
Analysing the Role  
of Government**

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## Chief Economist's Foreword

# Research and analysis is at the heart of the way we develop and manage policy in Defra.



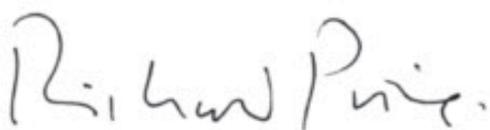
Our economists, statisticians and social and operational researchers work as an integral part of the policy process to answer some of the key questions facing our society:

- What should we be doing to prepare for climate change?
- How can we safeguard environmental resources for future generations whilst still meeting the needs of today?
- How can we manage the environment in a way which gives the best opportunities for businesses and growth?
- What will a high-productivity food sector look like in the future?
- How can we adequately value the goods and services provided by the natural environment in decision making?

Researchers and analysts in Defra create a solid platform for us to answer these questions and to shape thinking on policy issues both within the UK and internationally.

The Defra Evidence and Analysis Series will bring this research to a wider audience, creating the basis for discussion with the wider academic, business and policy-making community.

It is pertinent that this first paper, *Adapting to Climate Change: Analysing the Role of Government*, addresses an issue that is rapidly rising on the policy agenda. While there is a great deal of analysis on climate change mitigation, the evidence base on adaptation is still rather thin. The paper is designed to help provide a framework for thinking about the role of government in this area, and where policy can make the biggest difference in helping society to manage the risks we face as the climate changes. As with all of the papers in this new series, we hope it will be useful for people engaged in developing and debating public policy, and also that it will provoke others to do their own work and generate new insights which will help us all to make progress in this area. So naturally, we welcome any comments or contributions you would like to make to this debate.

A handwritten signature in black ink that reads "Richard Price". The signature is written in a cursive, slightly slanted style.

### **Richard Price**

Chief Economist and Director for Economics, Statistics,  
Operational and Social Research  
Defra

# Executive Summary

Climate change is one of the greatest challenges facing the world today. Strong international action is required to reduce greenhouse gas emissions. However, past emissions mean that we are now committed to decades of temperature rise, and to over 100 years of sea-level rise. Projected rises in global mean temperatures would result in a faster rate of climate change this century than the Earth has experienced for at least 10,000 years.

The UK Climate Projections 2009 (UKCP09) suggest that the UK is likely to experience warmer wetter winters, hotter drier summers, and more frequent extreme weather events. It will also be affected by the impacts of climate change occurring in other countries. Preparing for a changing climate – adaptation – will help the UK to reduce adverse consequences and take advantage of new opportunities. This paper provides a framework for analysing the role of Government in helping people and businesses adapt to projected changes in climate.

## Understanding adaptation

**There are two components to our response to the challenge posed by climate change: addressing the causes of climate change by reducing concentrations of greenhouse gases in the atmosphere – mitigation, and preparing for the consequences – adaptation.** Both are essential elements in our response, although there are important differences between them:

- the benefits from mitigation occur on a global scale, whereas adaptation generally results in localised benefits; and
- there is no single metric for measuring success in adaptation, in contrast to mitigation which can be measured by reductions in greenhouse gas emissions.

**In consequence of this, people and businesses will take action to adapt when it is in their interest and power to do so – that is, they will take measures where the benefits outweigh the costs to them.** Possible adaptation responses include: preventing, tolerating or sharing losses, changing use or activity, changing location and restoration. For example, farmers might increase yields by changing their crops and businesses can reduce the risk of disruption by preparing for climate risks. In some cases, the costs of trying to prevent all losses will exceed the benefits, and it will be efficient to accept some residual losses.

**There are a range of barriers that make it challenging for people and businesses to choose the right adaptation strategy:**

- **Market failures.** These include lack of information or awareness of climate impacts, misaligned incentives and the public good nature of some adaptation measures.
- **Behavioural barriers.** Adaptation decisions are complex, and involve dealing with long time horizons and uncertainty. Taking into account climate change in decisions made today – such as how and where to build new infrastructure – will have long-term benefits, but may entail additional near-term costs. There is a tendency for people to demonstrate inertia, procrastinate, and have implicitly high discount rates that place little weight on the future consequences of their decisions.
- **Adaptive capacity.** Some people lack the ability to respond to climate change because of financial or other constraints.
- **Natural capacity.** Natural systems might be unable to adapt because of the natural pace of their adaptive capacity, their resilience to frequent stresses, and the surrounding environment.

**The Government can play a role in supporting people and businesses to overcome some of these barriers and create an environment conducive to the appropriate adaptation decisions.**

Evidence on our level of adaptation to current climate and the existence of barriers to adaptation demonstrates that self-interest will not always be sufficient, particularly as climate change will be much more rapid than previously experienced. Analysing the role of Government does, however, require a sound understanding of these barriers to motivate any intervention.

**Adaptation decisions are not made in a vacuum – the options and incentives available are shaped by a range of non-climate related policies and institutional arrangements.** For example, water companies' responses to the increased risk of drought will be affected by the regulator's decisions on how much they can charge for water, planning decisions about where and what they can build and the legal framework governing abstractions and water use. By ensuring that these institutional frameworks support adaptation, the Government can help to manage the UK's exposure to climate risk.

**The Government's own actions will be critical to successful adaptation.** Public procurement, the operation of the Government estate and involvement in the provision of important adaptation public goods (such as flood defence) will all affect the UK's resilience to climate impacts. Incorporating adaptation throughout the Government's actions will also have wider benefits such as expanding the market for climate resilient products and services.

**This framework for thinking about the costs and benefits of adaptation, and the barriers to adaptation can help to inform policy design. Interventions to overcome barriers to adaptation can be assessed against three criteria:**

- effectiveness – the policy should reduce vulnerability to climate change;
- efficiency – the benefits should outweigh the costs; and
- equity – distributional consequences should be taken into account.

Given the long-term nature of climate change and inherent uncertainty, it is vital that policies are designed with the flexibility to respond to changing circumstances and better information.

## The economic framework applied

**Insurance is a key mechanism for sharing risks and encouraging adaptation.** Premiums based on risk should provide people with the right incentives to adapt, while enabling them to spread the losses resulting from climate hazards across time, over large geographical areas, and among different social and commercial communities. The UK markets are well developed for dealing with flooding, which is one of the main climate risks. The challenge for future development is to ensure that the regulatory framework remains flexible to encourage the development of innovative approaches while ensuring the financial resilience of the sector.

**Decisions about public infrastructure will have significant, long-term consequences for the UK's resilience to climate change.** Infrastructure is essential for UK competitiveness and economic growth. The Government plays a crucial, but diverse role in this area through funding, regulating and in some cases directly providing public services. It is essential that the regulatory and institutional framework helps to ensure that climate risks are managed and provides the right incentives for investment in adaptation.

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**There is a clear need to improve our understanding of the long-term fiscal implications of climate change.** For example, in the Long-Term Investment Strategy for flooding and coastal erosion, the Environment Agency estimated that around £1bn per year would be required to maintain our current levels of flood protection by 2035, an increase of around 80 per cent on 2010-2011 levels. Further research should also examine the extent of any implicit liabilities borne by the Government as a result of climate change.

**The built environment will need to be adapted in order to reduce the risks associated with rising temperatures and more frequent extreme events.** More frequent extreme events will damage the buildings themselves, and higher temperatures during the summer are likely to make the inhabitants less comfortable. Decisions about the location and characteristics of new buildings will have long-term consequences. However, the future occupants of these buildings will have very little say about how and where they are built. Building standards and planning policy will play a key role in addressing climate risks. Retrofitting will be an essential adaptation response, as most of the building stock we expect to use in 2050 has already been built. In social and rented accommodation, the existence of split incentives may lead to an inefficiently low level of retrofitting in the future.

**The natural environment will adapt, but the rapid pace of climate change risks disruption and losses of biodiversity and ecosystem services.** Moreover, climate change will add to already existing pressures. Analysis suggests that addressing existing inefficiencies, which additionally risk exacerbating the vulnerability of ecosystems, will yield net benefits regardless of uncertainty over future climate change.

## Next steps

**There is a need to define and measure whether the UK is adapting enough and in the right ways.** Adaptation decisions can be assessed against the criteria of effectiveness, efficiency and equity, based on current knowledge. It is also possible to assess whether the processes and institutional framework underpinning adaptation are appropriate and provide the right incentives for decision makers. However, further work is needed to assess whether the cumulative result of these decisions is a 'well-adapting' UK.

**Adaptation will need to be undertaken at all levels of decision making.** Businesses, the wider public sector and households play a key role in ensuring the UK adapts to climate change. Action will be required at local, regional and national levels, and the Government can play a coordinating role by providing an environment conducive to adaptation which is effective, efficient and equitable. This should present individuals and businesses with consistent and predictable signals to drive changes in behaviour.

**There is a need to develop and apply tools for making decisions with incomplete information in the presence of uncertainty.** The evidence base is improving rapidly, but dealing with incomplete information and uncertainty is an inherent feature of adaptation. The recent Government appraisal guidance on adaptation emphasises the importance of designing flexibility into decisions.

# Introduction

The Earth's climate is changing. Past emissions mean we are committed to several decades of rising global mean temperatures regardless of future mitigation efforts. For the UK, this will imply changes in weather patterns, rising sea levels and increasing frequent and severe extreme weather.

People and ecosystems have always responded to changes in climate. For example, farmers have grown different crops, and species have migrated to more hospitable environments. However, this has occurred in the context of slower rates of climate change than expected in future. Past emissions mean that we are now committed to decades of temperature rise, and to over 100 years of sea-level rise. Global average temperatures are likely to rise by between 1.1 and 6.4°C by 2100 (compared to the 1980-99 average) depending on which emissions pathway the world follows for the rest of the century (IPCC WG1, 2007). Projected rises in global mean temperatures could result in a faster rate of climate change this century than the Earth has experienced for at least 10,000 years (Met Office, 2008).

The purpose of this paper is to provide a framework for analysing the role of Government in helping people and businesses adapt to projected changes in climate. The paper does not develop new policy; rather it is designed to help facilitate and inform discussion of the appropriate role for Government and policy design in adaptation.

The paper is timely as the 2008 Climate Change Act introduced a new framework for building the UK's ability to adapt to climate change. Moreover, while there is a substantial body of research concerning climate change mitigation to aid policy makers, there has been relatively less research on adaptation. The Stern Review (2006) stated that although some adaptation will occur autonomously, there is a role for Government to play in providing policy guidelines, and economic and institutional support to help the private sector and civil society adapt. The Organisation for Economic Cooperation and Development (OECD) (2008) reviewed regional and country-specific studies on the costs and benefits of adaptation, and considered the role of economic and policy instruments in facilitating adaptation.

This analysis builds on previous work by examining the incentives and barriers to future autonomous adaptation in the UK and building a framework within which to consider the role of Government in the context of adaptation.

The economic framework has been applied to four cross-cutting themes:

1. Insurance
2. Built private assets
3. Public infrastructure and public utility services
4. Natural environment and biodiversity

These are necessarily brief discussions, not designed to be comprehensive but rather to illustrate key issues and indicate areas for further research. For each theme, barriers to adaptation have been identified, along with some options for addressing those barriers.

The focus of the paper is adaptation in the UK. The international aspects of adaptation are largely outside the scope of this paper, although critical for future work.

The paper is structured as follows:

- to begin, the impact of climate change globally and for the UK in particular is overviewed;
- Part I explains the economic framework for adaptation and the implications for the role of Government; and
- Part II provides an analysis of market and other barriers to adaptation by theme, while presenting some options to address those barriers.

# How the climate is changing

The global average temperature has increased by nearly 0.8°C since the late 19th century (IPCC WG1, 2007). However, there is considerable geographic variation in temperature rises around the globe: the temperature in central England has increased by about 1°C since the 1970s.

Nine out of the fifteen warmest years on record for England have been in the last 15 years (Jenkins *et al.*, 2007). This does not mean that next year will necessarily be warmer than last year, but the long-term trend is for rising temperatures.

Inertia of the climate system means that global temperatures lag behind emissions of greenhouse gases (GHGs): as a result, actions to cut emissions now would not slow the rate of rise of global temperature until at least 2040 (IPCC WG1, 2007). After this time, our success at mitigation now and in the future will have an increasingly significant effect on the amount of climate change we have to adapt to.

The latest scientific evidence suggests that there are a range of possible climate outcomes for given emissions trajectories<sup>1</sup>. These ranges are wide and may change in future as the science develops further. The latest UK Climate Projections (UKCP09) make this explicit by providing a range of projections of the future climate with associated probabilities, based on the strength of evidence provided by current knowledge, climate modelling capability and using expert judgement.

These projections suggest that the UK is likely to experience an increase in seasonal temperatures, more so in summer than in winter. For example, the projections give a range of summer average temperature increases for the south-east of England of between 2 and 6.4°C<sup>2</sup> by the 2080s (2070-2099) under a medium emissions scenario<sup>3</sup>. In contrast, increases in winter mean temperature are given as +3 (1.6-4.7)°C (Murphy *et al.*, 2009). Sea levels are projected to rise across the UK and central estimates for sea level rise (taking into account land movement) show that the sea level is projected to rise around London by 36cm<sup>4</sup> in 2080 under a medium emissions scenario (Lowe *et al.*, 2009).

As well as rising temperatures, climate change is likely to lead to changes in the number of extreme events: specifically, increases in hot days (nationwide and particularly in south east England) and decreases in frost days (greatest where frost days are currently more frequent) (UK Climate Projections: Briefing Report). Box 1 provides a summary of projected climate change for the UK in the 21st century and changes in mean summer temperatures respectively.

<sup>1</sup> UKCP09 provides three future scenarios of greenhouse gas emissions chosen from scenarios developed by the IPCC. These scenarios show how a range of factors such as population, economic growth and energy use may change over time.

<sup>2</sup> 10-90% confidence interval.

<sup>3</sup> The values given are the central estimate (50% probability level) followed by the 10%-90% probability levels. Changes are in relation to a 1961-1990 baseline.

<sup>4</sup> The figure given is the central estimate (50th percentile). The 5th-95th percentile range under a medium emissions scenario for London is 21-68cm. The results for sea level rise in UKCP09 provide model frequency distributions rather than probabilities which are given for the atmospheric variables.

## Box 1. Summary of climate change for the UK in the 21st Century

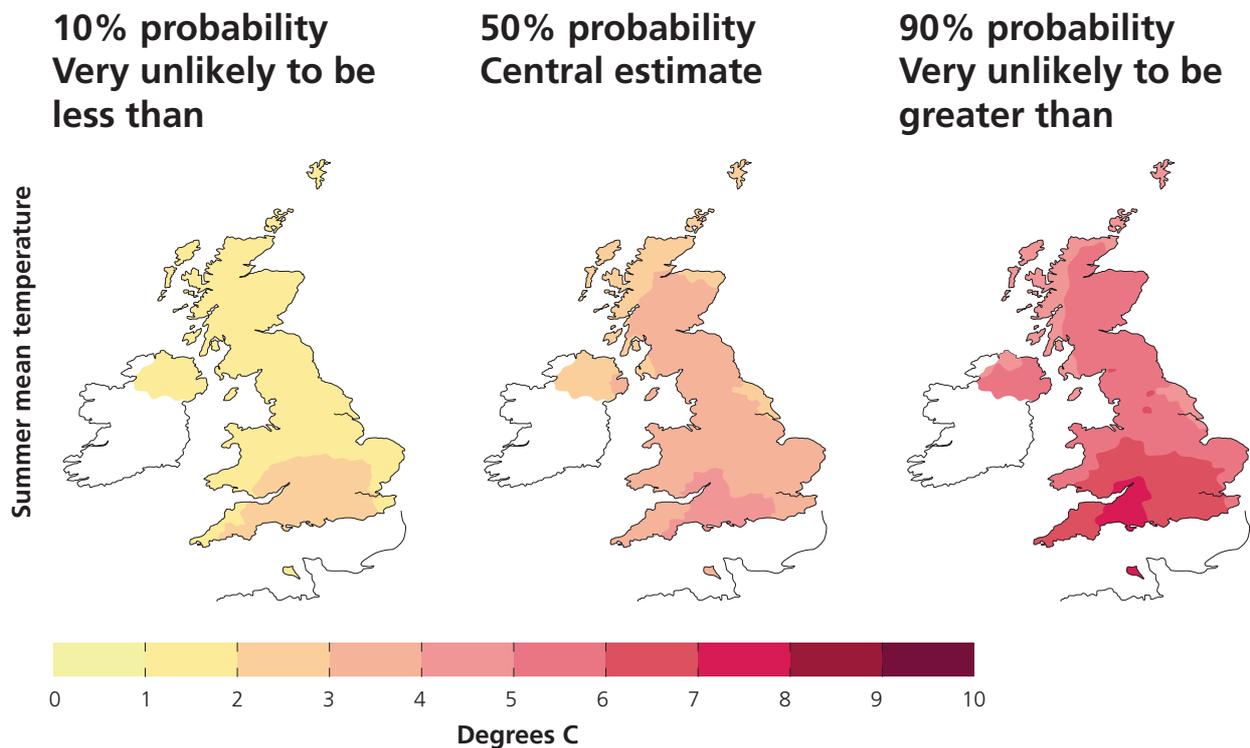
### Long-term / seasonal averages:

- Warmer, drier summers
- Milder, wetter winters
- Rising sea levels

### Extremes:

- More very hot days – extremes of temperature increase as well as frequency
- An increase in the frequency of dry spells in summer
- A decrease in days with frost in winter

The maps below show some projections of how the UK climate may change for the 30-year period from 2070–2099 (called the 2080s) at a resolution of 25 km. These maps give a range of climate that we might expect, together with the likelihood of different outcomes. The central estimate is given by the centre map. The changes are very unlikely to be less than the left hand map, and very unlikely to be more than the right hand map.



Source: Jenkins et al (2009); UK Climate Projections: Briefing Report

UKCP09 provides the best available evidence on the UK's future climate. However, it is subject to the uncertainty that is inherent in climate modelling. The future climate we experience will depend partly on which emissions trajectory we will be on in the future, but it will also be influenced by other aspects of the climate system. Some of these are very challenging to model (e.g. tipping points and wind patterns).

# Part I: The Economic Framework

The IPPC (2007) refers to adaptation as “the adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities”. Some adaptation is expected to occur autonomously: faced with a changing environment, individuals and the natural environment will adapt when it is their interest and power to do so. However, the level of adaptation of the UK will be determined by all the decisions taken by multiple actors, and in some instances market failures and other barriers can prevent society from achieving the appropriate level of adaptation for the UK.

Part I explains the economic principles underpinning adaptation. It proposes an economic framework for thinking about adaptation, and explains the barriers that might prevent adaptation from being undertaken autonomously to the efficient level. The framework is then used to clarify the rationale for government intervention on supporting adaptation.

Section 2.1 explains the economics of adaptation. Section 2.2 presents a range of strategies that can be undertaken to adapt to the impacts of climate change; section 2.3 explains the market failures and other barriers that can justify Government intervention on adapting to climate change. Section 2.4 proposes some criteria for selecting adaptation instruments, and finally section 2.5 proposes three strands to the Government’s approach to supporting adaptation.

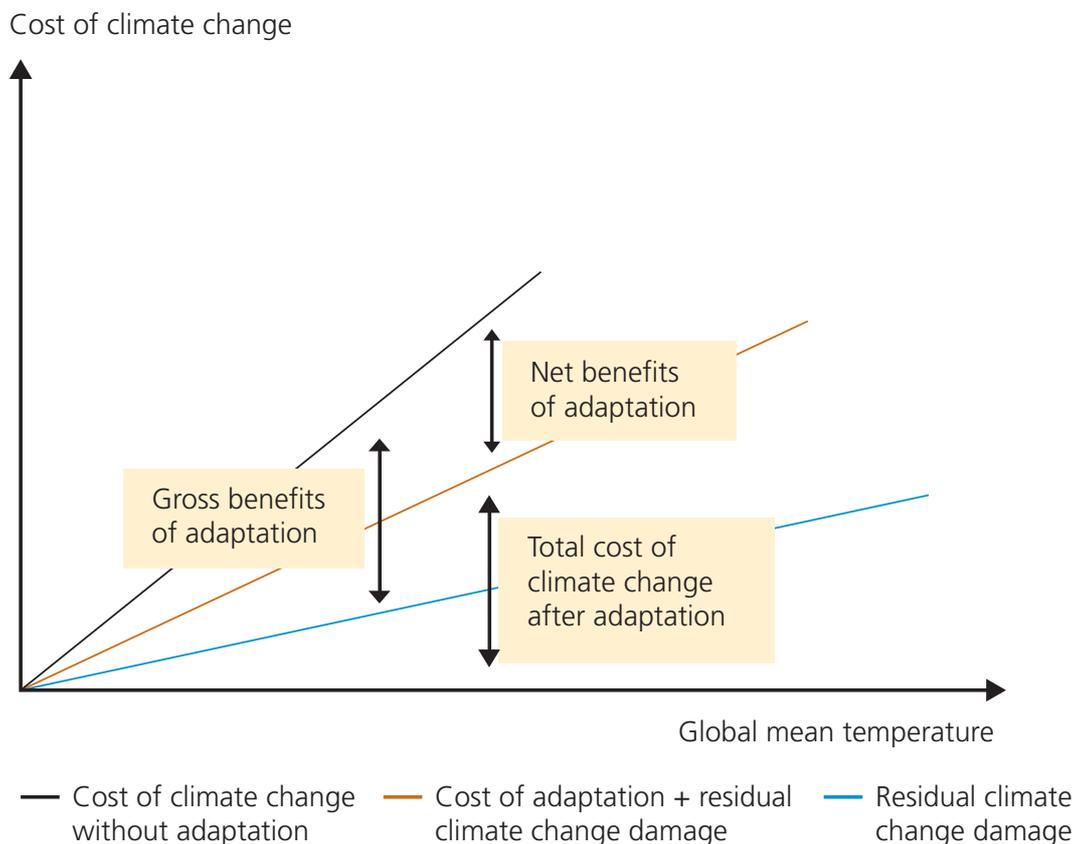
## 2.1 Understanding adaptation

There are two components to our response to the challenge posed by climate change: addressing the causes of climate change by reducing concentrations of greenhouse gases in the atmosphere (“mitigation”), and preparing for the consequences (“adaptation”). Although these are both essential elements of our response, there are important differences between them:

- the benefits from mitigation occur on a global scale, whereas adaptation generally results in localised benefits; and
- there is no single metric for measuring success in adaptation, in the same way that mitigation can be measured by a decrease in emissions of greenhouse gases.

Figure 1 shows the total costs of climate change without adaptation (top black line) in contrast to reduced costs through adaptation (orange line). Adaptation incurs costs but results in benefits, i.e. it reduces the residual damages from climate change. In this framework, the efficient adaptation strategy is to minimise the combined total of residual damages and costs of adaptation. Efficient adaptation strategies may include accepting some residual damage, if the costs of offsetting all the impacts of climate change are greater than the benefits of doing so. As well as minimising costs, efficient strategies will also seek to take advantage of opportunities from climate change (e.g. the potential to grow new crops). Again, the underlying principle is that this should occur when the benefits of exploiting these opportunities outweigh the costs.

**Figure 1 – Adaptation and the costs of climate change**



Source: Stern (2006)

Although conceptually intuitive, adaptation has complex practical implications. In particular, whether or not individuals' adaptation lead to net social (not only private) benefits<sup>5</sup> depends on a number of factors. These include the types of incentives people are faced with and the extent to which actions are coordinated within a society. In addition, the impacts of climate change are likely to be unevenly distributed between and within regions, communities and social groups. Adaptation will reduce the vulnerability of different individuals and the environment to different levels, depending on local and context specific needs and capacity. There can be short-term benefits from becoming better adapted to the current climate and long-term benefits from being better adapted to the future climate.

Several studies have estimated aggregated figures of the costs of adaptation, mainly for developing countries<sup>6</sup>. The results of these studies along with their limitations are explained in Box 2.

## Box 2. Costs of adaptation

A range of studies have attempted to estimate the aggregate costs of adapting to climate change. Most studies have estimated these costs by adding a mark-up to climate-sensitive investment flows, but they have increasingly tried to incorporate additional costs.

Estimates of adaptation costs for developing countries (\$billion p.a.)<sup>7</sup>

World Bank (2006)	9-41	Cost of climate-proofing FDI, GDI and ODA flows
Stern (2006)	4-37	Update, with slight modification of World Bank (2006)
Oxfam (2007)	>50	Based on World Bank, plus extrapolation of costs from NAPAs and NGO projects
UNDP (2007)	86-109	World Bank, plus costing of PRS targets, better disaster response
UNFCCC (2007)	27-66	Mark-up assumptions based on various sectoral studies. Global estimates are 49-171 \$billion p.a.

Source: adapted from OECD (2008). Note: FDI = foreign direct investment, GDI = gross domestic investment, ODA = official development assistance, NAPA = National Adaptation Programme of Action, PRS = poverty reduction strategy, NGO = non-government organisation.

These estimates should be treated with care. A recent review by the International Institute for Environment and Development (IIED) (2009) identified a number of shortcomings with these studies, and concluded that the actual costs were likely to be 2-3 times higher than the United Nations Framework Convention on Climate Change (UNFCCC) had estimated. One of the main issues is that these estimates do not consider the benefits of spending on adaptation, which would be required to estimate how much adaptation is cost-effective. Instead, they examine the costs of achieving some pre-determined adaptive actions.

The Government has commissioned a Climate Change Risk Assessment and Economic Analysis to provide more detailed estimates of both the costs and benefits for adaptation in the UK. The World Bank is undertaking more detailed analysis for developing country case studies<sup>8</sup>.

<sup>5</sup> The total increase in the welfare of society from an economic action, i.e. the sum of the benefit to the agent performing the action plus the benefit accruing to society as a result of the action (HM Treasury, 2003).

<sup>6</sup> The UNFCCC (2007) study is the only one that provides global estimates of \$49-171 billion per year, with costs for developed countries estimated to be between \$22-105 billion per year. For consistency reasons, in box 2 we report the estimates by UNFCCC (2007) for developing countries only.

<sup>7</sup> Estimates of additional annual investment and financial flow needed for the period 2010-2015. The UNFCCC (2007) estimates are for additional annual investment and financial flow needed by 2030.

<sup>8</sup> See <http://beta.worldbank.org/climatechange/content/economics-adaptation-climate-change-study-homepage>

## 2.2 Adaptation options

In general, people might be expected to take autonomous action to adapt when it is in their interest and power to do so; that is, they will take measures where the private benefits outweigh the costs to them<sup>9</sup>.

Adaptive strategies may include actions taken after and before the realisation of a climatic event. Autonomous adaptation can include reactive adaptations to recover after climate impacts have occurred including recovery and actions to prevent similar impacts in the future; and anticipatory adaptations, or actions taken in advance to prepare for, and minimise, the risks of potential impacts. The type and extent of autonomous adaptation that occurs will be affected by the characteristics of the climate risk, the decision-maker and the institutional framework within which adaptation decisions are made.

Burton (1996) classified possible adaptation strategies into several categories. These include preventing, tolerating or sharing losses, changing use or activity, changing location and restoration. Table 1 provides a typology of adaptation strategies and examples of actions for each type of strategy.

In the case of natural systems, climate change is expected to affect the characteristics of habitats and trigger the migration of species. The overall impact is not clear-cut, as adaptive responses will vary depending on the location and natural capacity of different species. Some species are likely to gain climate space<sup>10</sup>, while others might lose it. Some habitats might be more exposed to climate stresses (for example, coastal habitats will be more exposed to sea level rises and coastal erosion); others might be more exposed to more frequent shocks (for example, those exposed to more frequent gales and storms<sup>11</sup>); and others might become more habitable. In some circumstances, the adaptation strategies described in Table 1 will also apply to the natural environment: for example, tolerating losses and migrating.

**Table 1 – Adaptation strategies and actions**

Adaptation strategies	Description	Examples of adaptive actions
<b>Preventing losses</b>	Take action to reduce the exposure to climate impacts	Building sea walls
<b>Tolerating losses</b>	Accept losses where it is not possible or cost-effective to avoid them	Accept reduced crop yield
<b>Spreading or sharing losses</b>	Distribute the burden of impacts over a larger region or population beyond those directly affected by the climate event	Insurance of assets
<b>Changing use or activity</b>	Switch of activity or resource use to one better suited to the changed climate	New business opportunities (e.g. tourism, agriculture, insurance)
<b>Changing location</b>	Migrate to an area which is more suitable under the changed climate	Assets moved away from areas at risk of flooding
<b>Restoration</b>	Restore assets to their original condition following damage or modification due to climate	Re-building or replacement of damaged assets

Source: adapted from Burton's (1996) classification of adaptation options.

<sup>9</sup> Autonomous adaptations are widely interpreted as initiatives by private actors rather than by governments, usually triggered by market or welfare changes induced by actual or anticipated climate change (Leary, 1999 in IPCC WGII, 2007).

<sup>10</sup> Climate space is the geographic area that is projected to have climatic conditions similar to the climate of those areas currently occupied by the species and likely to be climatically suitable for their survival.

<sup>11</sup> There is uncertainty about storm patterns, and it is currently not possible to produce probabilistic projections of changes in frequency, strength and location of future storms. The IPCC AR4 assessment concluded that the majority of current climate models show a poleward shift of the storm tracks, with some indication of fewer, but deeper, depressions. This can only be concluded when looking at the hemispheric scale; the UK is much smaller than this scale and any climate change signal is swamped by natural variability and sampling uncertainty resulting in a lack of any robust signal of changes for the UK (UK Climate Projections. Annex 6, at <http://ukclimateprojections.defra.gov.uk/content/view/2091/517/>).

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## 2.3 The role of Government

The UK Government is committed to ensuring that society is adapting to the effects of climate change. The Government may take action either to achieve a more efficient outcome than would otherwise occur, or on distributional grounds, as is the standard approach to policy making (HM Treasury, 2003). This also means that in designing and implementing policies, programmes and investments, the Government should account for the impacts of climate change.

In some cases, private incentives to adapt should be a sufficient trigger for changing behaviour, and when the market operates efficiently the price mechanism should lead to the most efficient adaptation outcome. In practice, however, the sum of autonomous adaptation responses may not lead to a socially efficient outcome because of:

- **Market failures.** Existing market distortions can affect people's incentives to adapt. These include imperfect information about climate impacts and misaligned incentives in the management of physical assets. In addition, individuals will generally base their adaptation decisions on private costs and benefits. However, some adaptive actions might have the nature of public or quasi-public goods, or result in social costs and benefits (i.e. externalities) that if not accounted for might not lead to the best outcome for society as a whole. Annex A describes these in more detail.
- **Policies and institutional arrangements.** The options and incentives available to individuals and businesses are shaped by a range of non-climate related policies and institutional arrangements. This is particularly the case for some of the most climate sensitive sectors, such as agriculture and the natural environment.
- **Behavioural barriers.** Adaptation decisions can be complex, and involve dealing with long time horizons and uncertainty. Evidence from behavioural economics suggests that people struggle to make rational decisions in these circumstances. Instead, there is a tendency for people to demonstrate inertia, procrastinate and have implicitly high discount rates, i.e. to place very little weight on the future consequences of their decisions. This can be explained by short-sightedness or impatience. Consequences of this may include adapting too little or adapting in the wrong ways. These are also described in more detail in Annex A.
- **Adaptive capacity.** Some people lack the ability to respond to climate change because of financial or other constraints. The result can be a less than efficient level of adaptation. For example, people living in rented accommodation may have limited control over how well their houses are adapted to a changing climate.
- **Natural capacity.** The ability of natural systems to adapt may be hampered by the rate of climate change exceeding the system's ability to respond, the existence of other stresses and the effects of human activity. There is the risk that multiple pressures on the natural environment could lead to irreversible damage or extinction.

In addition to the barriers explained above, there are also distributional issues to consider:

- **Uneven distribution of impacts.** Climate change will have different impacts across sectors, regions, and social groups. Some communities are likely to be more exposed to climatic hazards because of where they are located: for example, people in southern England are more likely to be exposed to heat waves than those living in northern England.

- **Different adaptive capacity.** Within sectors, regions and social groups there are variations in people's ability to adapt to impacts, and these can exacerbate existing inequalities. Economic well-being, age, education and the strength of social networks can affect individuals' adaptive capacity by affecting their access to technology, insurance, capital, transportation, communication, social support systems and other assets. For example, older people and children are considered highly vulnerable to the effects of heatstroke.

As noted above, the rationale for Government intervention is generally based on the existence of market failures or where there are clear Government distributional objectives that need to be met<sup>12</sup>. These are not, however, sufficient reasons to justify intervention: it is also necessary that the social benefits of any intervention outweigh the costs.

Climate change will also have macroeconomic impacts, e.g. by affecting productivity, growth, migration and potentially the fiscal position of Governments (see Box 3). It is outside the scope of this paper to analyse the macro-economic impacts of climate change and adaptation. However, this is a critical area for future research work.

### Box 3. Macroeconomic impacts of adaptation

There is a complex relationship between economic growth and climate change: climate change can affect growth by increasing the depreciation of capital (such as buildings), or by affecting productivity and output. In turn, these can affect the rate of investment and the investment available for Research & Development (R&D) and new technologies. By reducing the impacts and exploiting the opportunities posed by climate change adaptation might ultimately boost growth.

Economic growth (along with demographic change) may also lead to higher concentrations of assets and people in areas exposed to climate change risk, as well as greater stress on natural resources. This could ultimately increase the exposure and vulnerability of individuals and the natural environment to climate change, which would drive up the value of climate change losses. Finally, the growth path we are on will determine the types of adaptation strategies that can be adopted by individuals, businesses and Government.

Climate change is also likely to have fiscal implications. For example, a study by the European Central Bank (2009) found that the budgetary impact of extreme events ranges between 0.23% and 1.1% of GDP depending on the country group, although the effects are most pronounced in developing countries. The extent of the fiscal impacts will depend upon the extent to which the economy is diversified, and the proportion of climate risk that is ultimately borne by the Government.

It is outside the scope of this paper to look at the macroeconomic aspects of climate change and adaptation. Understanding links is nonetheless important when designing interventions with a view to enhancing growth in the long run. Fankhauser and Tol (2005) showed that transient effects on growth (e.g. loss of sectoral output and damage to infrastructure) can have persistent effects. The impact of climate change on output via reduced growth has been estimated to be larger than the direct impact effect. There is a need to improve understanding of the mechanisms, which cause persistency and design adaptation strategies that reduce the multiplier effects in the long run.

<sup>12</sup> Market failure refers to where the market has not and cannot of itself be expected to deliver an efficient outcome; the intervention that is contemplated will seek to redress this. Distributional objectives are self-explanatory and are based on equity considerations (HM Treasury, 2003).

## 2.4 Criteria on which to judge adaptation

Clear performance criteria can support the design of appropriate interventions to support adaptation. Three main criteria embedding the principles for good adaptation are proposed:

- **Effectiveness** – the ability of an instrument to correct for the existing market or non-market failure. This requires a good understanding (ex ante) of the level of autonomous adaptation affected by different barriers and failures; and intervening at the most appropriate level to address local, regional, national and international barriers to adaptation.
- **Economic Efficiency** – the ability of an instrument to achieve the greatest social benefits at the lowest cost, once uncertainty is appropriately incorporated in the decision making, for example with help of the updated supplementary guidance to the Green Book. In the UK, public intervention is generally assessed using cost-benefit analysis<sup>13</sup>.
- **Equity** – the distributional impacts of an instrument. Different measures will have different effects on different sections of society<sup>14</sup>. Following the supplementary Green Book guidance on adaptation, distributional issues should be considered when designing instruments. Care should be taken to avoid creating perverse or conflicting incentives.

Effectiveness, economic efficiency and equity are in principle exhaustive criteria for assessing policy instruments for adaptation. However, the high degree of uncertainty over climate change, and the lack of evidence over climate impacts create some practical challenges in applying these criteria.

### Dealing with uncertainty

There are two important aspects to any adaptation decision: what to do and when to do it. This involves comparing the adaptation costs with the short-term and long-term benefits. Given that the size of these benefits (and sometimes the costs) are uncertain, the standard economic approach to decision-making would be to use the Expected Utility theorem. In essence, this approach deals with uncertain outcomes by determining (and comparing) their expected utilities, i.e. the weighted sums obtained by adding the utility that would be gained in each outcome, multiplied by the probability of that outcome occurring. Government appraisals tend to use estimates of monetary values as a proxy for society's utility.

This approach works well for decisions where the range of possible outcomes and their associated probabilities are known: for example, participating in a lottery. The impacts of climate change do not have these characteristics. The existence of tipping points, feedback mechanisms and limitations of existing models means that there are a wide range of possible future climatic scenarios (as illustrated by UKCP09). There has been considerable progress in our understanding of the climate system, but there will always be an inherent element of uncertainty about the impact of a given climate scenario on society and the environment and the likelihood that it will occur.

A variety of approaches have been proposed to support decision-making in the presence of pervasive uncertainty. One approach recommended in the adaptation literature is to identify and implement 'no-regret' measures that would be justified under all possible future climate scenarios; and 'win-win' measures, that reduce the vulnerability to climate change while meeting other policy objectives, including climate change mitigation (Pew Center, 2009).

<sup>13</sup> In the presence of uncertainty, standard cost-benefit analysis might not be appropriate. Alternative methods (such as the Real Option Approach presented in annex C and proposed in the Green Book supplementary guidance on adaptation) may be considered to account for the type of asset under consideration, including its life span; a range of possible future scenarios and their level of confidence; and the option of incorporating new evidence as it becomes available.

<sup>14</sup> Policy instruments may have differing impacts according to income, age, gender, ethnic group, health, skill, or location etc.

However, a strategy of only implementing 'no regrets' and 'win-win' policies would be extremely restrictive and likely to lead to inadequate action being taken to adapt. For this reason, the Green Book guidance on adaptation emphasises the importance of designing flexibility into decisions. Annex C describes how using Real Options Approach alongside the standard Green Book approach is a useful tool for addressing those issues. A range of alternative models have also been proposed to support decision-making in the presence of uncertainty. An example is provided by the Robust Decision Making (RDM) framework developed by Lempert *et al.* (2003), discussed in Box 4 below.

### Box 4. 'No regrets' and 'win-win' options

'No regrets' and 'win-win' options are strategies for dealing with uncertainty. 'No regrets' options are able to deliver benefits (or net cost savings) today regardless of the extent of climate change in the future; and 'win-win' options reduce vulnerability to climate change whilst also contributing to the achievement of other social, environmental or economic outcomes.

Examples of 'no regrets' and 'win-win' adaptation may include investing in improving scientific capabilities and research to gain a better understanding of the dynamics of the impacts of climate change; adding flexibility into long-term infrastructure design; and creating incentives for the efficient use of scarce resources.

It can be challenging to identify suitable 'no regret', or 'win-win' adaptation options. Lempert and Schlesinger (2000) suggest that, under conditions of deep uncertainty, society should seek strategies that are robust, or "that will work reasonably well no matter what the future holds" (Lempert and Schlesinger, 2000). The authors explain that robust strategies perform well compared to the alternatives over a wide range of assumptions about the future. In this sense, robust strategies are "insensitive" to the resolution of the uncertainties. In general, "there can be a trade-off between optimality and robustness such that a robust strategy may sacrifice some optimal performance in order to achieve less sensitivity to violated assumptions" (Lempert and Collins (2007) in Dessai *et al.* 2009).

The Robust Decision Making (RDM) framework proposed by Lempert *et al.* (2003) uses computer simulation models to derive high regret scenarios, or states of the world where the base case strategy – i.e. the strategy which results in the lower net costs, given the current knowledge of the world – performs poorly compared to alternative strategies; and to identify the key-factors determining high regrets states (e.g. population growth, decreases in rainfall patterns). This model provides an analytical tool for selecting policy relevant scenarios, characterised by a limited number of key-vulnerabilities; and designing adaptive strategies which better address the identified key-vulnerabilities are "least-regret" or robust over a defined range of key-factors.

Despite the attractiveness of such an analytic method, some methodological and practical challenges remain. In particular, the RDM approach requires significant computer support and outcomes depend, in part, on the robustness of the proposed strategies. Nonetheless, the model provides useful insights into the relevant aspects of decision making in the presence of high levels of uncertainty.

## Adaptation in the context of other climate change policies

Adaptation interventions should be designed with an awareness of their impact on mitigation policies. Mitigation and adaptation will both be required to effectively tackle climate change and some measures can support both adaptation and mitigation (e.g., improving water efficiency). However, adaptation and mitigation are also substitutes in economic terms<sup>15</sup>. These interrelationships need to be considered when designing and implementing policy. It is only recently that studies have attempted to explore these relationships in a systematic way. Box 5 describes how Integrated Assessment Models (IAMs) have started incorporating climate change adaptation into global cost-benefit analysis of climate change.

### Box 5. Modelling the links between adaptation and mitigation

Integrated assessment models (IAMs) are used for economic analyses of climate change. They combine scientific and economic modelling to identify optimal climate change strategy; generally, this is defined as the strategy that maximises global welfare over time. Recently these models have started incorporating adaptation: either explicitly or implicitly through the shape of the climate change damage function or shifts in the structure of the economy. Models of this type are DICE/RICE (Nordhaus and Boyer, 2000), FUND (Tol, 2002, 2005), PAGE (Hope, 2006), and MERGE (Manne and Richels, 2004).

The AD-DICE model developed by de Bruin *et al.* (2007, 2009) builds on the DICE (Dynamic Integrated model of Climate and the Economy) model to include adaptation. Results from this model show that adaptation could reduce gross damages of climate change by an average of 27% (Bruin *et al.* 2009). Costs to reduce the first 15% of gross damage are extremely low after which they rise significantly, indicating that mitigation will also be needed.

Unlike the AD-DICE, the PAGE (Policy Analysis of the Greenhouse Effect) model allows a binary choice (set by the modeller) between no adaptation and adaptation. Through this model, Hope (2009)<sup>16</sup> shows that adaptation measures have a benefit:cost ratio in the range of 60 and 20 to 1; and adaptation reduces the cost of future impacts over the next two centuries by about a third (28% to 33%, mean net present value).

The different models led to a general consensus on the advantages of adaptation in reducing climate change damages in a cost-effective way; and on the benefits resulting from undertaking both mitigation and adaptation. However, these results should be treated as illustrative, rather than a precise guide to the optimal balance between adaptation and mitigation. The underlying issue is that the models and data used by IAMs need to have global coverage; both for the modelling of the climate system and for the analysis of the costs and benefits of adaptation and mitigation. In order to achieve this breadth of coverage, they necessarily need to make a range of simplifying assumptions. For example, they have incomplete coverage of non-market impacts: such as the damage to the natural environment. This means that the results do not account for the full range of costs and benefits.

<sup>15</sup> An increase in the cost of mitigation would be expected to lead to an increase in the demand for adaptation and vice versa.

<sup>16</sup> The study estimated costs and benefits of the adaptation measures assumed in the Stern Review; adaptation that costs about the same as assumed in the UNFCCC study. It does that in an A2 scenario, and in 450ppm ('aggressive abatement policy') scenarios.

Domestic intervention should also be considered in the context of international and EU intervention. In 2009, the EU published a White Paper on adaptation “Adapting to climate change: towards a European framework for action”<sup>17</sup>, proposing a framework to reduce the EU’s vulnerability to the impact of climate change. EU intervention is particularly relevant when the impact of climate change transcends the boundaries of individual countries (e.g. river and sea basins and bio-geographic regions); and in those sectors that are closely integrated at EU level through the single market and common policies (e.g. agriculture, water, biodiversity, fisheries, and energy networks). This should be guided by the principle of subsidiarity and the need to ensure that action is necessary and proportional.

### Measurement

In mitigation policy there is a single, measureable, global metric of success: reducing net greenhouse gas emissions. This is not the case for adaptation where the benefits will be local, context specific and – in some cases – subject to long lead times. Individual adaptation decisions can be assessed against the criteria of effectiveness, efficiency and equity, based on current knowledge. It is also possible to assess whether the processes and institutional framework underpinning adaptation are appropriate and provide the right incentives for decision makers.

### Distribution and efficiency

In the context of adaptation, there can be trade-offs between efficiency and distributional goals, insofar as measures to correct for the distributional implications of climate change can undermine private incentives for people to adapt. In accordance with the Green Book guidance on adaptation, distributional implications should be explicitly stated and quantified where possible.

There is a substantive body of literature on distribution and climate change adaptation. This addresses not only the intra-generational aspect of equity (i.e. distribution of climate change impacts and adaptive capacity within society), but also its inter-generational (i.e. how adaptation will affect future generations’ well-being), and international aspects<sup>18</sup>.

## 2.5 The Government’s objectives

The policy response to adaptation should be driven by the characteristics of the climate risks to be addressed. One of the main aspects of this is that the appropriate adaptive response will vary depending on the location, as many of the benefits will occur locally. This favours a decentralised approach based on an efficient allocation of resources, with a strong emphasis on supporting local and regional action.

The Government can help to create an environment that is conducive to effective, efficient and equitable adaptation by:

- providing and promoting information on the future climate;
- supporting coordination at local and regional levels;
- devising a framework that embeds consistent policy targets and incentives across different levels of government, while promoting coordination; and
- directly providing or funding adaptation.

The aim is to provide decision makers with the appropriate incentives to incorporate adaptation into their strategies and processes.

<sup>17</sup> Available at <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:EN:PDF>

<sup>18</sup> See IPCC (2001) Chapter 18, Adaptation to Climate Change in the Context of Sustainable Development and Equity; Adger et. al. (2004, 2006); Muller (2002).

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With this in mind, there are three strands to the Government's approach to supporting adaptation:

***Mainstream adaptation into existing policies, regulatory frameworks and processes, while addressing existing inefficiencies***

The Government already plays a clear role in key areas affected by climate change either because of the public nature of the goods provided (e.g. natural environment and biodiversity protection), or through regulation and sometimes ownership (e.g. water, energy, and transport). Given the wide ranging nature of this involvement, it will generally be efficient to embed adaptation into the existing institutions and practice in a systematic way, and correct for any existing regulatory inefficiencies which risk being exacerbated by climate change. This will require defining how the outcomes of existing programmes and policies will be affected by climate change; and whether existing programmes, policies and regulatory frameworks either facilitate or hamper adaptation by different agents.

The integration of adaptation into existing regulatory frameworks should occur at local, regional and national level. In central government this entails ensuring that Departments incorporate adaptation in their decision-making, promoting coordination and ensuring different policies create a consistent framework for adaptation. Provided with the appropriate framework, Regional Development Agencies and local authorities can embed adaptation in their strategies.

Some policy measures have been introduced to achieve this objective. All Government departments will produce Departmental Adaptation Plans (by Spring 2010) that will identify the areas where climate change will affect their departmental objectives, programmes and policies. At the local level, 56 local authorities out of 152 across England have made adaptation a priority in their authority area through the indicator NI188 and the first round of self-assessments were submitted in June 2009.

An example of mainstreaming has been the revised planning policy guidance produced by the Department of Communities and Local Government: "PPS: Planning and Climate Change, a supplement to Planning Policy Statement 1", which sets out clear expectations on how adaptation should be integrated into planning; and "PPS 25: Development and Flood Risk", which sets out policy on development and flood risk.

***Build adaptive capacity***

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2001). This ability depends on a number of factors, including socio-economic and cultural settings, institutional and policy contexts prevalent in a specific sector or area (OECD, 2007). Enhancing adaptive capacity means providing people with the tools, information and support required to make timely and efficient adaptive decisions.

One of the main ways in which the Government is currently helping to develop the UK's adaptive capacity is through its funding of the UK Climate Impacts Programme. This programme works with organisations across the public, private and voluntary sectors to build their capacity to adapt. At the local and regional level, the Government provides funding to Regional Climate Change Partnerships. These Partnerships bring together the key stakeholders at a regional level to raise awareness, provide evidence on regional impacts and coordinate the responses of key decision-makers.

### ***Deliver adaptive actions***

Some adaptation measures are public goods, and therefore likely to be underprovided by the market. In these cases, the Government may intervene to ensure adequate provision through funding, direct provision or regulation. Examples of these include investment in certain kinds of infrastructure, or spending programmes in R&D (when these generate spillovers that cannot be fully reaped by private agents), monitoring and warning systems, and protection of ecosystems.

Different options for investing in adaptive actions will need to be investigated, with a view to ensuring resources are prioritised efficiently. This is particularly important because of the high degree of uncertainty on the timing and the scale of the impacts of climate change on the UK, and the wide range of possible interventions. Any intervention by the Government will need to focus on those areas where ultimately failure to adapt well could lead to irreversible damage or costly retrofits, expose society to imminent risks, or raise serious equity concerns.

In many cases the role of Government will be limited. The private<sup>19</sup> benefits from adapting, for example in terms of avoided losses, or economic revenues when new opportunities are exploited, will be a sufficient incentive for many people to adapt. However, recurring cases of disruption to transport services, damage to private assets, and the risk of irreversible damage to ecosystems raise the question of whether we are adequately adapted to the current climate, and make a strong case for investigating what barriers may hinder adapting to the current and future climate.

<sup>19</sup> As the benefits accruing to the decision maker only, as opposed to social benefits – the sum of the benefit to the person performing the action plus the benefit accruing to society as a result of the action.

## Part II: The Analysis Applied

The appropriate adaptation responses depend upon context. In Part II, the economic framework proposed in Part I is applied to four cross-cutting areas. For each area, this paper considers the evidence on climate change impacts, investigates the barriers that might impede adaptation, and presents the existing policies supporting adaptation. Based on this analysis, it presents some implications for future policy design.

Section 3.1 considers the role of insurance, which will be an important part of the UK's adaptation to climate change: it can help to spread the burden of unavoidable losses, and provide incentives for people and organisations to reduce their exposure to climate risks. Section 3.2 covers built private assets, including housing and commercial premises. Climate change will affect both buildings themselves, and the comfort of the people using them. Section 3.3 explores the effects of climate change on public infrastructure, and the implications for policy design. Section 3.4 investigates the Natural Environment and Biodiversity. The success of adaptation in this area is both intrinsically important and will affect the provision of the ecosystem services that people rely upon.

### 3.1 Insurance

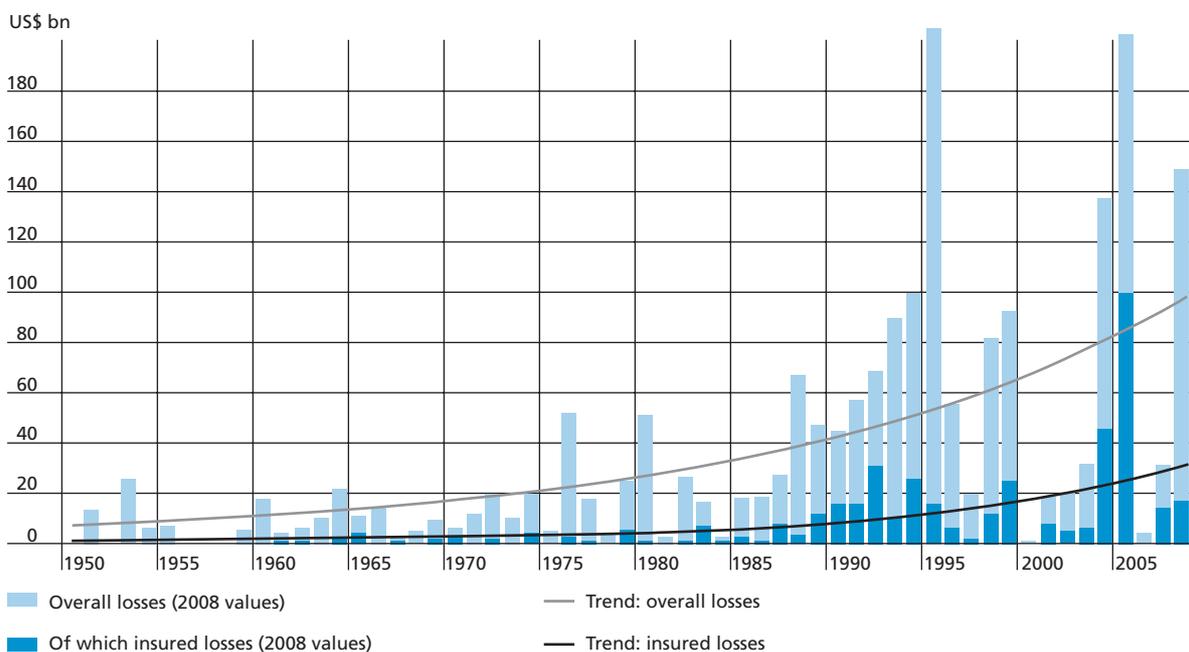
Climate change will expose individuals and businesses to new risks, and affect their exposure to existing ones. Insurance is important in this context for two main reasons: first, it enables agents to spread the losses resulting from climate hazards across time, over large geographical areas, and among different social and commercial communities; and second, premiums can provide incentives to adapt and drive behaviour change.

Climate change will exacerbate some of the pervasive issues affecting the private provision of insurance, such as asymmetric and imperfect information. From a policy perspective, it is important to support the development of an efficient insurance sector, which continues to ensure that coverage is widely available.

#### 3.1.1 Climate change impacts

The insurance industry reported that global economic losses due to natural catastrophes have increased seven-fold in real terms during the last 40 years, and the long-term analysis of large-scale natural catastrophes follows a rising long-term trend, as shown in Figure 2 (Munich Re, 2008). This is driven by a combination of increased extreme weather and rising values of insured assets.

**Figure 2 – Overall losses and insured losses from great natural catastrophes, 1950 – 2008**

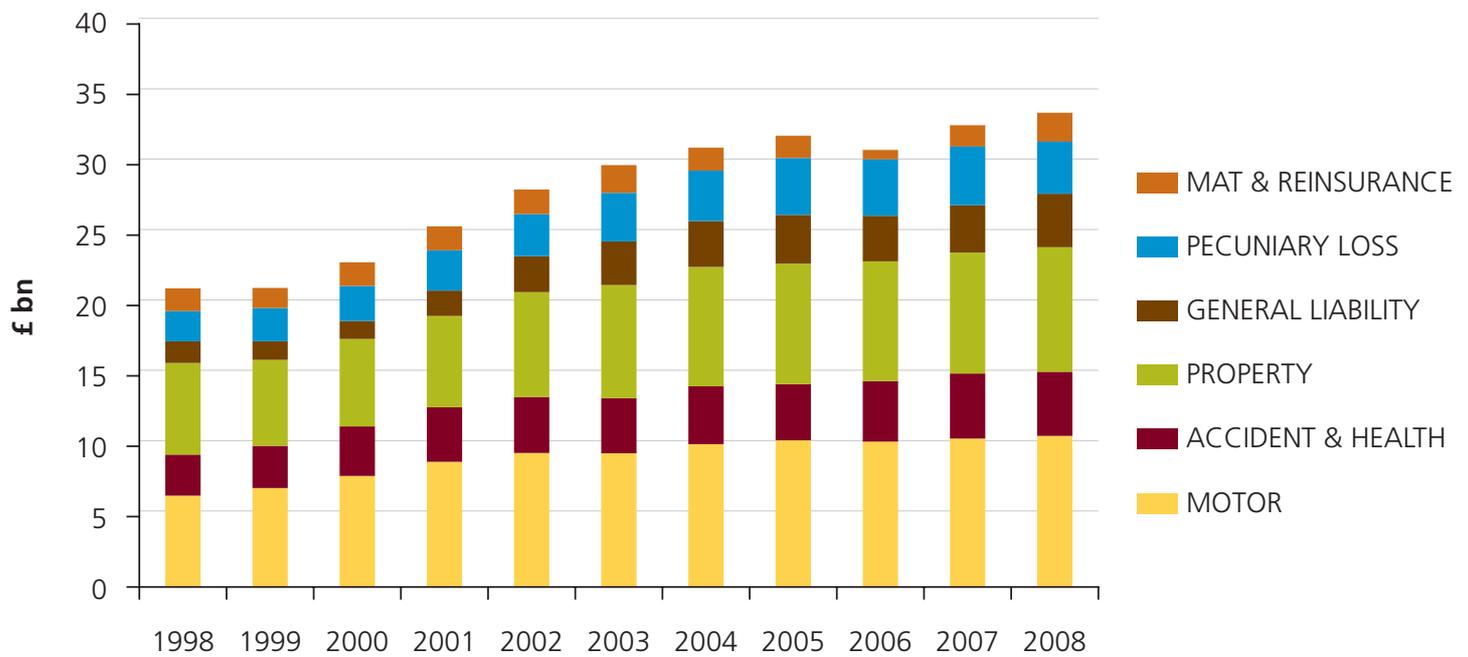


Source: Munich Re (2008)

In the UK alone, more frequent and severe extreme events have increased climate-related risks faced by individuals, communities and organisations. These risks include damage to built private assets, disruption to businesses and public services, changes in the profitability of economic activities (e.g. agriculture, tourism), and health risks. During the last decade, insurance premiums have increased, along with the number of claims (Figures 3 and 4).

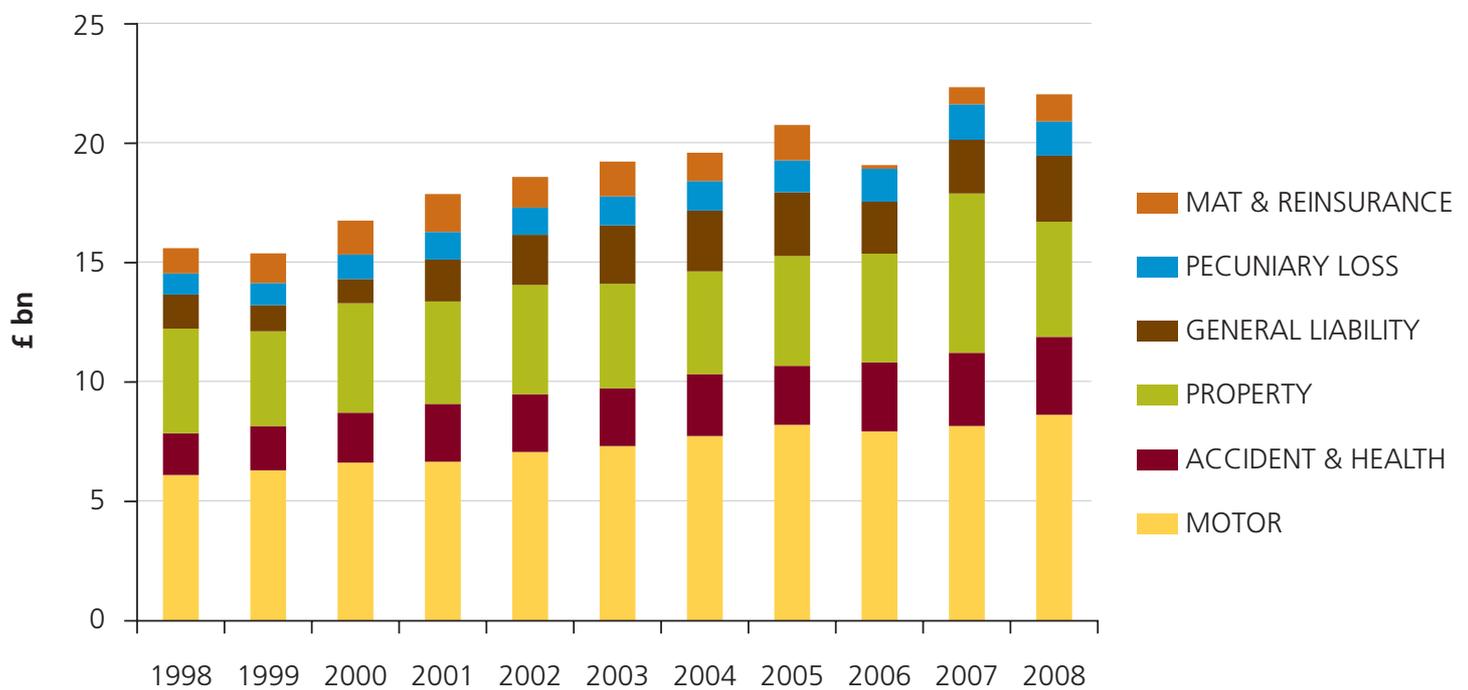
Historical data show that more frequent flooding, subsidence and storm events have resulted in increasing damages to properties. The Association of British Insurers (ABI) reported that storm and flood losses in the period 1998-2003 totalled £6.2 billion, twice that of the previous period (ABI, 2005). The heat wave in the summer of 2003 has been estimated to have caused 22,000 extra-cases of subsidence above business as usual (Metroeconomica, 2006), and in that year alone costs in subsidence claims to insurers have been estimated to be approximately £400 million. Following the more recent flooding in 2007, the insurance industry has paid out approximately £3 billion, equivalent to four years normal claims experience (ABI, 2007).

Figure 3 – Total premium<sup>20</sup> by type of insurance, 1997 – 2007



Source: ABI (2008)  
 Note: MAT = Marine, Aviation and Transport.

Figure 4 – Claims by insurance type, and underwriting results, 1997 – 2007



Source: ABI (2008)  
 Note: MAT = Marine, Aviation and Transport.

<sup>20</sup> Total net premium (written premium less reinsurance premiums paid by the insurer).

These data should be interpreted carefully. Increases in insured losses are the result of both climate and societal factors. Changes in population and economic growth might contribute to drive up the value of economic losses. For example, increased standard of living might increase the take up of cover and the value of insured assets; and population growth might explain the location of human developments in areas exposed to climate risks (e.g. river basins). In addition, some elements of urban design (e.g. green spaces, hard surfaces, and drainage and sewage systems) affect the resilience of the built environment to climatic events, and contribute to reducing or increasing the impacts of climate change.

The UK also has risks and opportunities resulting from the impacts of climate change overseas because of London's role as a global financial centre. The UK insurance sector is the second largest in the world, accounting for 11% of total worldwide premium income. It manages assets worth £1,478 billion, equivalent to a quarter of the UK's total net worth, including assets that make up 15% of the investment in the London stock market (ABI, 2008)<sup>21</sup>. In 2008, insurance contribution to net exports was £8 billion, or 16% of UK financial net exports. This indicates a broad exposure and opportunities of the insurance industry to the effects that climate change has on global economic activities and assets.

### 3.1.2 Market failures and other barriers to autonomous adaptation

There are a number of factors that determine the ability of the market to supply insurance. Barr (1993) summarises them as follows:

1. The insured event for any individual is independent of that of anyone else.
2. The probability of the event occurring has to be less than one (or less than certain).
3. The probability of the event must be known and estimable.
4. There is no asymmetric information between the insurer and the insured (no adverse selection<sup>22</sup> and/or moral hazard<sup>23</sup>).

Climate change is likely to affect the risks individuals are faced with, and therefore the conditions under which the market can offer cover against those risks. When extreme events occur they usually result in covariate risks (e.g. extreme events affect entire communities) and knock-on effects (damage to properties, cars, health are correlated or occur in rapid successions), violating factor 1 above. In addition, climate change impacts are still not fully understood and difficult to estimate (affecting factor 3); and moral hazard issues might arise in the context of climate change adaptation (factor 4). Box 6 discusses the challenges faced by the industry in more detail.

<sup>21</sup> This compares to 13% held by company pension funds, 3% by banks, 2% by unit trusts, and 10% by other financial institutions.

<sup>22</sup> Adverse selection occurs when the insured has better information on the risks they face than insurers do; and people who know that they face large risks are more likely to buy insurance than people who face small risks.

<sup>23</sup> Moral hazard occurs when one party, e.g. an insurer, is unable to observe the action of the other party, e.g. the insured; and the party whose actions are hidden, either through acts or omissions, increases the probability of a 'bad' outcome.

## Box 6. Climate change and challenges to the insurance industry

The increasing severity and frequency of climate change hazards is likely to exacerbate some of the challenges insurers are faced with, and affect the conditions under which insurance can be provided. These challenges can be categorised as follows:

**Uncertainty and information failure.** Uncertainty over climate change, along with the lack of information over the vulnerability and the impacts of climate hazards, will make the estimation of risks particularly difficult for insurers.

**Covariate risks.** Risks related to climatic events are generally covariate (e.g. extreme events affect entire communities), and the effects of increased losses due to weather-related events may lead to more frequent spikes of payouts following extreme events, and increased insolvencies.

**Fat tails and tails dependence.** Climate change is likely to increase the likelihood of extreme events, or those in the upper tails of loss distributions (i.e. it generates 'fat' tails); importantly, a changing climate also seems to increase the dependencies between tails across multiple loss distributions (i.e. it generates 'tail dependence'). For example, due to more severe and frequent storms, high levels of claims for property damage have occurred more frequently (fat tails); and property insurance claims and car insurance claims, for example, have shown to be correlated (tail dependence), or occur in close succession (showing 'clustering').

**Asymmetric information and moral hazard.** These are well-known issues affecting the provision of insurance. In the context of climate change, insurers are likely to incur moral hazard problems when individuals behave in a way which increases the climate risks they are exposed to, and there are no incentives for them to behave differently. For example, farmers may plant climate sensitive crops, or households might decide not to protect their properties from flooding if they think they will be helped to recover from losses regardless of their investment decisions to prevent or reduce the damage.

Source: Kousky and Cooke (2009), European Central Bank (2009).

These factors might have several implications for the industry and the insured. Insurance premiums are generally set on an annual basis, so insurers need to account for how climate change – and the frequency and severity of extreme events in particular – may affect their exposure to losses in the following year. There will be an increasing need to improve the accuracy of climate data and modelling, as historical data will be less useful as an indicator of future trends.

In most cases insurance premiums serve as a signal of exposure to current climate risk, rather than vulnerability to future climate change. For example, the availability of flood insurance for a property today does not guarantee that it will continue to be available at an affordable price in the future. This can lead individuals to underestimate their true exposure to future climate risk.

More severe and extreme events will lead to higher premiums for certain categories of risks. Risk-based premiums would be efficient on the ground that they would signal risks in an appropriate way, thus providing incentives to adapt. However, there might be implications for equity, particularly if those who are already vulnerable to climate change cannot afford insurance cover, or will be left with uninsurable (and, hence, less valuable) assets.

As with non climate-related policies, the industry can consider mechanisms to partially alleviate asymmetric information issues. These could include deductibles, co-payments and other forms of policies, which will generally result in higher risk burden for the insured party. For example, insurers might use techniques such as signalling and screening (e.g. using historical records and demographic characteristics) to reduce adverse selection; and impose deductibles (whereby the person buying insurance has to pay the initial damages up to some set limit) and co-payments (under which the policyholder picks up some percentage of the bill for damages when there is a claim) to discourage moral hazard.

Other mechanisms include index-based insurance, whereby the insured party receives a pay-out independent of the losses experienced, and indemnifications are triggered by pre-specified patterns of an independently verifiable index<sup>24</sup>. Such mechanisms have been used in agriculture insurance schemes in low- and middle-income countries to reduce moral hazard, adverse selection, and the administrative costs associated with traditional insurance contracts in these countries<sup>25</sup>. However, as the OECD (2008) points out, “the inherent disadvantage of index-insurance is the lack of relation between the predetermined payout and actual damage. This ‘basis risk’ results in a potential lack of correlation between premium and payout that is difficult to correct due to the increasing unpredictability of the climate”.

To summarise, climate change will exacerbate a number of challenges already inherent in insurance provision, potentially affecting the ability of premiums to appropriately signal risk, and leading to liquidity issues for the industry at the time of extreme events. This could also have distributional implications if it leads to higher premiums for insurance cover. Climate change could, however, also present the insurance industry with new opportunities, such as the development of new services and products.

On the demand side, barriers to the uptake of insurance cover might stem from inertia and behavioural barriers, or lack of information. For example, the Environment Agency (EA) estimates that 45% of people living in floodplains do not understand the risk affecting their property<sup>26</sup>, and the ABI reports that homeowners and small and medium-sized enterprises (SMEs) have difficulty identifying risks outside flood prone areas (where Government, the EA, and insurers have focussed their guidance and support the most)<sup>27</sup>.

ABI (2007b) reports that many businesses, particularly SMEs, did not have adequate flooding or business interruption insurance in place prior to the floods of summer 2007. In addition, the ABI estimates that around 78% of households nationwide have contents insurance, but that in some of the areas affected by the summer 2007 floods the figure is barely over a quarter, with low-income households the most likely to be uninsured<sup>28</sup>.

<sup>24</sup> For example, these trigger levels for pay-outs correspond to rainfall levels at which the crop would begin to feel water-deficit stress.

<sup>25</sup> See the World Bank (2009).

<sup>26</sup> By April 2009 the number of people living in flood risk areas that know they are at risk had risen to 55 per cent, up from 46 per cent in 2005-2006 EA (2009c).

<sup>27</sup> ABI (2007c).

<sup>28</sup> ABI Response to the Interim Report of the Pitt Review.

### 3.1.3 Evidence of effects of climate change on the insurance market

The insurance industry has already reported an increasing number of claims due to weather related events. The ABI (2004) stated that in the case of property insurance, small changes in the severity of extreme events can result in increases in damage of four or five times greater, and “on reasonable projections of extreme events, the pure risk rate<sup>29</sup> for weather catastrophes is already rising at an unprecedented rate of 2-4% per year”. As regards specific classes of risks, the ABI estimated that changing weather risks have been increasing retail and commercial property insurance costs by 3-4% per annum due to incremental climate change and increasing frequency and severity of extreme events (ABI, 2007c).

Classes of insurance cover against weather-related losses are already available in the UK market, and the market has shown some changes in response to climate change. The Business Interruption (BI) cover for business covers firms for any periods when they cannot do business as normal because of damage to their premises (such as essential machines) due to flooding, for example.

The UK Government and the insurance industry co-operate to offer flood cover. In 2002, ABI agreed a statement of principles on flood cover with the Government, whereby the industry would continue to provide flood cover as a standard feature of household and small business policies conditional on the risk of flooding being no greater than once in 75 years. In return, the Government agreed to a set of actions intended to minimise the number of households and small businesses that would not be eligible for cover under this commitment<sup>30</sup>.

In the UK, flood cover is bundled with home building insurance, which is usually a condition for obtaining a mortgage. In 2007, around 92% of homeowners had home buildings insurance (ABI, 2007c). Following the floods in 2007, demand increased significantly, and some insurance companies have changed policies to encourage the uptake of measures to reduce flood risks<sup>31</sup>.

In the future the industry might respond to rising risks and liquidity issues by finding new ways to re-insure risks through alternative risk transfer markets, by raising premiums or by withdrawing from the market<sup>32</sup> (see Box 7). On the demand side, rising risks could lead to increasing demand for cover. For example, animal disease insurance, which currently has a low penetration rate of 10% (ABI, 2004), might become requested more in the future, as higher temperatures might increase illnesses associated with heat stress<sup>33</sup>.

<sup>29</sup> This is the average loss determining the pure premium, i.e. the premium which doesn't account for added taxes, expenses and commissions. The pure risk rate also reflects the monetary amount that would need to be set aside each year to fund the full range of future losses.

<sup>30</sup> See <http://www.defra.gov.uk/News/2008/080711a.htm>.

<sup>31</sup> In Carlisle, for example, policy excess levels have been reduced, and in some cases “no excess” policies have been granted to people who have built flood prevention measures (ABI, 2007c).

<sup>32</sup> Insurers could opt for a selective withdrawal of services, although this could generate loss of business in other insurance lines due to a consumer backlash; or lock the companies out for the medium to long-term, even if the risk profile to that area changes.

<sup>33</sup> Defra (2004), Publication of outputs arising from Defra CC03 and related programmes (CC0366).

### Box 7. Alternative Risk Transfer (ART) markets

The following instruments facilitate the broadening of the capital base of risks by transferring insurance risks to financial markets.

**Catastrophe bonds** are financial contracts that pay out a fixed amount whenever a defined event occurs: for example a Category-4 hurricane striking mainland USA. Payments are not linked to the actual loss suffered by the insured party. The benefit of this is that they are simple to administer, but they have proved expensive to set up. The capital is provided by investors, who receive a superior interest rate in exchange for the risk of losing their return – and, in some contracts, their capital.

**Weather derivatives** also pay out on a specified trigger, for example, temperature over a specified period, not on proof of loss. They apply in situations where profitability is sensitive to even moderate deviations from the norm, not catastrophes. In this case, the derivative is usually purchased by another party, who wants to avoid or 'hedge' risk in the opposite direction, and an active market in these securities can develop. However, a company could also accumulate a book of weather contracts, as a profit centre in its own right.

Insurers and large corporations are already experimenting with catastrophe bonds as an option instead of reinsurance. In the USA many corporations and local government bodies use weather derivatives to smooth their financial performance. ART tools are useful complements to conventional (re)insurance, but the accounting and taxation rules currently make it difficult to offer these products.

Source: ABI (2004), A Changing climate for insurance

#### 3.1.4 Implications for policy design

There is scope for the Government and the insurance industry to continue to co-operate to ensure risks are kept to a manageable level and coverage remains wide. This co-operation needs to develop while ensuring prices reflect (and signal) underlying risks. The current statement of principles is due to expire in 2013. The way in which this co-operation develops after then will determine the distribution of the risk burden between various parties, including low and high risk individuals (and within them, those who experience losses and those who do not), the industry and tax payers.

Implications for policy design could include:

- **Supporting the development of climate models and information sharing of risk data.** In June 2009 the Government launched the UK Climate Projections 2009 (UKCP09), which gives probabilistic distributions of a range of climate variables. In addition, the Government can help the industry acquire new data to help risk calculation, as is currently being done by the Environment Agency for surface water flooding<sup>34</sup>. Understanding how to reduce informational uncertainty by providing a legal framework, which favours the sharing of best practices within the industry, with a view to improving understanding of correlated and cross-sectors risks, will be important for any future policy development.
- **Regulation.** IIWG (2009) notes that “the uptake of insurance products partly reflects the extent to which the Government currently either enforces or encourages uptake of each product type”. Further investigation into whether active promotion of some types of cover, e.g. risk signalling which enables individuals to account for climate change over a relatively long time period (> 1 year),

<sup>34</sup> See <http://www.environment-agency.gov.uk/research/library/publications/56742.aspx>.

might be particularly useful in overcoming some of the market failures outlined above. In the case of risk-signalling this could be achieved by requiring insurance companies to signal possible upward trends in premiums for assets located in vulnerable areas.

- **Protecting the most vulnerable.** If the risks reach very high levels, a purely market-based approach may leave the most vulnerable financially excluded.
- **Managing moral hazard.** One of the ways in which responsible behaviour can be encouraged is to signal in advance if there are any specific circumstances under which the Government (and, ultimately, taxpayers) would bear losses. To control for moral hazard in any part of the system, the Government will continue to encourage responsible behaviour and clarify the split of responsibilities between the public, businesses and the Government in managing private and public assets.
- **Managing implicit liabilities.** In light of the trends of increasing losses and projected climate change projections, adequate care will need to be taken to ensure insurers and re-insurers will have sufficient reserves to meet their liabilities. Further research could help identify circumstances where the Government might be exposed to implicit liabilities due to extreme events.
- **Correcting for institutional distortions.** Care needs to be taken that existing policies and programmes do not create perverse incentives or increase the exposures of individuals and business to climate risks. This can be overcome by mainstreaming climate change into planning systems (e.g. accounting for the role of hard surfaces in increasing flood risk, green spaces etc in improving/reducing the impacts of climatic events) and sectoral policies (e.g. by ensuring agricultural policies do not inadvertently encourage individuals to remain in high risk flooding areas).

**Table 2 – Insurance. Implications for policy design**

Policy instruments	Main reasons for intervention	Implications for policy design
<b>Regulatory measures (including direct regulation and market / economic instruments)</b>	Regulatory failures Information failure Behavioural barriers Equity	<ul style="list-style-type: none"> <li>• Correct for existing institutional distortions</li> <li>• Provide legal certainty to insurance companies and favour sharing best practices<sup>35</sup></li> <li>• Promote insurance lines linked to adaptive measures</li> <li>• Ensure safety nets for the most vulnerable are appropriate</li> </ul>
<b>Research and monitoring spending programmes</b>	Public goods Information failures Behavioural barriers	<ul style="list-style-type: none"> <li>• Support the development of climate models</li> <li>• Encourage a better understanding of inter-related impacts across sectors (i.e. covariate risks)</li> <li>• Exploring the capacity of financial markets to absorb new risk management tools</li> </ul>
<b>Information provision and public engagement</b>	Information failures Behavioural barriers	<ul style="list-style-type: none"> <li>• Provide a clear signal of the Government's stance in relation to insurance</li> <li>• Encourage the public to adopt responsible behaviour in managing risks</li> </ul>
<b>Investment in infrastructure and other adaptive actions</b>	Public and club goods Externalities	<ul style="list-style-type: none"> <li>• Consider and help others consider options for investing in physical infrastructure to keep risks to a manageable level (e.g. flood barriers)</li> <li>• Continue improving early warning systems</li> </ul>

<sup>35</sup> The Block Exemption Regulation (BER) sets exception to competition rules to certain categories of agreements, decisions and concerted practices in the insurance sector. The BER will expire in 2010.

### 3.2 Built private assets

Climate change exacerbates the risks that private assets (such as housing, business buildings and contents) and their occupants are exposed to. Floods, for example, are expected to become more frequent and severe in the future<sup>36</sup>; rising sea levels will increase the risk of coastal erosion and floods for coastal communities; and increasing temperatures in the summer might increase discomfort in houses and buildings. There will also be benefits from climate change resulting from reduced risk of frost damage and reduced demand for heating in the winter.

Given the large scale of potential impacts to society, and the long-term nature of decisions needed to reduce those impacts, the literature suggests a wide range of potential adaptation options, from changes in individual behaviour, to incorporating adaptation into building regulations and planning policies.

#### 3.2.1 Climate change impacts

Flooding is one of the major weather related risks for the UK. During the flooding events in 2007<sup>37</sup>, over 55,000 properties were flooded and 7,000 people rescued from the flood waters by the emergency services (Pitt Review, 2008). A large proportion of the flooded properties were flooded from surface water<sup>38</sup>, and a study published by Defra<sup>39</sup> estimated an increase in flood volumes of 75% by the 2080s due to climate change and urbanisation.

The Environment Agency (2009a) estimated that in England around 5.2 million properties (or one in six residential and commercial properties) are at risk from river, coastal or surface water flooding. Of the 2.4 million properties at risk of flooding from rivers or the sea, almost half a million have a 1 in 75 chance of flooding in any given year. Some properties may be at risk of coastal erosion. The EA (2009a) points out that, “although the overall number is considerably smaller, local impact can be severe. Coastal erosion is progressive and practically irreversible”.

It is predicted that in England, flood management assets will need to cope with an expected average 20% increase in river flows by 2080. The degree of increase varies between regions.

The *Foresight Future Flooding* report published in 2004 identified the need for year-on-year increases of £10 – £30 million in funding for new and improved management assets (for England and Wales) every year until the 2080s on top of inflation to respond to climate change. Increasing losses will be the result of different drivers, including climate change, urban design and socio-economic conditions<sup>40</sup>.

Despite climate change modelling developed since then, the impacts remain uncertain (EA, 2009a).

Increasing summer temperatures affect living conditions for employees and residents in buildings and houses, generating potential discomfort and health problems, particularly during consecutive hot days (i.e. heat waves). Populations typically display an optimum temperature range<sup>41</sup>. Temperatures outside

<sup>36</sup> Due to climate change, but also socio economic and governance factors (Foresight study, 2004).

<sup>37</sup> Mainly localised in South Yorkshire and Hull in June, and Gloucestershire, Worcestershire and the Thames Valley in July.

<sup>38</sup> The Environment Agency (2007) reported that two thirds of the flooded properties were flooded from surface water.

<sup>39</sup> Gill (2008), “Making Space for Water Urban flood risk & integrated drainage (HA2)”, IUD pilot summary report, available at <http://www.defra.gov.uk/environment/flooding/documents/manage/surfacewater/urbandrainagereport.pdf>

<sup>40</sup> See Annexes A and B of the Foresight study (DTI, 2004).

<sup>41</sup> For example, WHO (2004) states that “perceptual scales have been developed to evaluate thermal comfort in an individual (such as the ASHRAE scale). In temperate climates, the optimum indoor temperature for health is between 18 °C and 24 °C. Warmer climates have a higher limit of comfortable temperature, such as 28 °C in Greece and 25 °C in France”.

this range can lead to discomfort and lower productivity levels<sup>42</sup>, with tolerance to heat tending to get narrower with age or infirmity (WHO, 2004). Kovats and Hajat (2007) point out that “high temperatures cause the clinical syndromes of heat stroke, heat exhaustion, heat syncope and heat cramps. Heat stroke has a substantial case-mortality ratio, and progression to death can be very rapid (within hours)”. The impacts of heat waves are more severe in urban areas, where buildings retain heat causing sustained thermal stress both during the day and night, while rural areas often obtain some relief from thermal stress at night (WHO, 2004; Clarke, 1972; Jendritzky, 2000).

Average temperatures are expected to rise in the future and heat waves are likely to become more frequent. For example, a report by the Health Protection Agency stated that, “there is a 1 in 40 chance that by 2012 South-East England will have experienced a severe heat wave that will potentially cause 3,000 immediate heat-related deaths” (DH, 2008).

Climate change will also bring benefits. For example, during the winter higher temperatures might reduce the need for heating, damage to buildings from frost, and the rate of cold-related diseases and deaths. Metroeconomica (2006) show that the benefits from lower winter heating demand from future climate may be greater than the increase in summer cooling demand in the UK, with likely net benefits in the UK for energy demand.

### 3.2.2 Market failures and other barriers

Uncertainty over climate impacts, and the long span of the built environment (typically in excess of 50 years)<sup>43</sup>, contribute to a range of barriers to adaptation.

The extent to which the built environment is adapted to climate change depends on the decisions of a range of decision makers, including developers, building companies, insurance companies, property owners and occupants. In this area, decision makers take their adaptive decisions on the basis of different timescales, something which may lead to misaligned or split incentives; and the adaptive decisions of some actors (e.g. developers and building companies) are likely to affect the adaptive capacity of other individuals (e.g. owners and occupants).

The expected timescale of the impact of climate change determines the incentives for people to adapt. Developers and building companies will generally bear some of the costs of climate change when they occur within the warranty time, currently 10 years<sup>44</sup>. However, even during this time many costs will be borne by the occupants. While the costs of introducing new technologies to increase the resilience of the built environment (e.g. new flood defences, cooling systems or climate resilient building materials) beyond that time would fall on developers, the benefits – if not fully captured in the sale price – such as lower maintenance costs and higher long-term property value, would be reaped by property owners and housing associations.

Due to the low turnover rate of the building stock, decisions taken today on where and how to build the new stock will have implications for those who live in those houses in the future. Future property owners and occupants are likely to bear the costs of badly-adapted properties, without generally exerting control on the design and location of the stock. Property owners and housing associations will typically bear the

<sup>42</sup> WHO (2004) states that productivity and efficiency are likely to be adversely affected as a result of rising temperatures. “Reduced mental concentration because of discomfort can lead to an increased risk of accidents. In addition, some people with existing health conditions such as heart problems, high or low blood pressure, respiratory conditions and kidney disease may be susceptible to adverse health effects from working in hot and/or humid conditions. Thermal comfort is determined by subjective judgement, and even in optimal conditions, some individuals may experience discomfort”.

<sup>43</sup> The housing stock turns over at a rate of about 1% a year, commercial property at about 2% so decisions today will still have an effect in the latter part of the century (ABI, 2009).

<sup>44</sup> The National House-Building Council (NHBC) is the leading warranty and insurance provider for new and newly-converted homes in the UK. Their 10-year warranty and insurance policy called ‘Buildmark’ covers more than 80% of new homes built in the UK. Around 1.7 million homeowners are currently covered by Buildmark policies. See <http://www.nhbc.co.uk/>

costs of maintaining or re-building the existing stock; and occupants will bear the costs of increasing discomfort in buildings, which are not well adapted to the current and future climate. Badly designed stock may require substantial retrofitting measures in the future<sup>45</sup>.

People do not react passively to the conditions buildings provide, but interact actively with them by adapting themselves (e.g. by changing clothing); and adjusting the conditions provided (e.g. by moving appliances to reduce exposure to flood risk; opening windows, or using air-conditioning to reduce indoor temperatures). It is important the built environment facilitates (and does not hinder) the natural ability of individuals to adapt, and enables occupants to exert control over the surrounding environment.

In some cases adaptation may require changes to typical behaviour – or coping strategies – especially in cases of extreme and unexpected events. In other cases, adaptation may include changes to the existing built environment (e.g. retrofitting). However, a more resilient built environment would come at a near-term cost. Uncertainty over the timescales of benefits from adaptation, along with the historically high turnover rate of property sales in the UK suggests that property owners today may have little incentive to pay for extra-resilience, as benefits are likely to be reaped in the long-term by future purchasers. Unless adaptation becomes a marketable commodity (in the same way as energy efficiency is via the Energy Performance Certificates) and buyers value adaptation features, developers and building companies may lack confidence that extra resilience will be fully reflected in sale prices, and thus be less likely to incorporate it into new developments.

In addition to the long and uncertain timescale of benefits, barriers to adaptation include financial barriers (when adaptation requires significant capital investments), physical/regulatory barriers (when for example the built environment is in historical or conservation areas), lack of information on the availability of existing measures, bounded rationality and inertia. For example, developers' ability and incentive to build climate resilient properties is shaped by internal organisational features (mainly financial and management capabilities), and the external regulatory frameworks, e.g. planning regulations and building codes.

Adaptation might also be undermined by asymmetric information or moral hazard, when individuals choose not to adapt to the appropriate level because they think losses will ultimately be borne by the Government or insurers, and they are not provided with adequate incentives for take up of preventive measures.

Some adaptive measures may generate positive (negative) externalities with public good characteristics. This would occur if an individual's adaptation behaviour generates benefits (costs) to other individuals. For example, a flood defence built to protect one individual's property might also protect neighbouring properties (generating positive externalities), and/or divert water to other properties (generating negative externalities).

Adaptation actions may have the characteristics of club goods, i.e. being non rivalrous but excludable<sup>46</sup>. In these instances, adaptation would require joint action that generates benefits to particular groups and communities, and could be managed and funded locally, e.g. community flood defences. However, the need for a coordinated action itself might represent a barrier to adaptation and there might be a role for Government to support adaptation.

<sup>45</sup> For example, for the regions of London, the East and South East of England it is predicted that by 2050, only 30% of the total stock will have been constructed post-2006 (The Three Regions Climate Change Group, 2008).

<sup>46</sup> Annex A describes these goods in more detail.

### 3.2.3 Evidence and existing policies

There are specific elements of the existing Government policy that support autonomous adaptation. These are described in more detail in Table 3. For example, to avoid inappropriate development in areas at risk of flooding, and direct development away from areas at highest risk, since December 2006 the Planning Policy Statement 25 (PPS 25<sup>47</sup>) requires regional planning bodies (RPBs) and local planning authorities (LPAs) to do the following:

- prepare and implement planning strategies accounting for flood risks;
- avoid flood risk to people and property where possible; and
- only permit development in areas of flood risk when there are no reasonably available sites in areas of lower flood risk and the benefits of the development outweigh the risks from flooding<sup>48</sup>.

Adaptive instruments to reduce the impacts from floods are also available. As explained in section 3.1 on insurance, different stakeholders including Government, the Environment Agency and the insurance industry have introduced a range of information tools and regulatory measures to overcome some of the barriers to adaptation.

Notwithstanding existing measures, evidence suggests that there remains scope for making the built environment more resilient. The Environment Agency estimates that 45% of people living in floodplains do not understand the risk affecting their property, something that may prevent them from taking adaptive measures to reduce risks. Following the 2007 floods, the Pitt Review stated that the existing water and flood management systems could be improved, and proposed several recommendations such as: better defining the responsibilities for flood risks, including surface water and groundwater flood risk; improving warning systems for flooding; incorporating existing guidance for home buyers with accurate and clear information on risks (e.g. by extending the Home Information Pack contents); and removing the automatic right to connect surface water drainage of new developments to the sewerage system<sup>49</sup>.

The Pitt recommendations are being taken forward by Defra. In June 2009, Defra published a Progress Report<sup>50</sup> setting out progress made in the six months since the publication of the Government's response to the Pitt Review in December 2008. This report shows what has been achieved and what remains to be done to fulfil the Government commitments. Some of the recommendations are being addressed through forthcoming legislation: the draft Floods and Water Management Bill included proposals to give responsibility for local flood risk management to local authorities and to remove the automatic right to connect to the public sewers for new developments.

Improving information to help people make better informed decisions about flood risk is important. Defra has published guidance to assist local authorities in drawing up Surface Water Management Plans (SWMP)<sup>51</sup>; the Environment Agency are working with Local Resilience Forums and Regional Resilience teams to improve their response to flooding from surface water<sup>52</sup>; and changes to regulations will encourage households to lay permeable surfaces in their front gardens<sup>53</sup>.

<sup>47</sup> <http://www.ambiental.co.uk/flood-risk-assessment-legislation-pps25>

<sup>48</sup> In particular, planning strategies are aimed at identifying land at risk of flooding; framing policies for the location of development, which avoid flood risk to properties and people where possible, and manage any residual risk; reducing flood risk to and from new development through location, layout and design, including making the most of the benefits from green infrastructure for flood storage, conveyance and sustainable drainage systems (SUDS) (DCLG, 2006).

<sup>49</sup> Such automatic rights bring the risk of overloading sewage systems and any sewage treatment works forming part of or connected with the system (with the risk of subsequent overflowing); and are a disincentive to design and implement more sustainable drainage systems (SUDS).

<sup>50</sup> Available at <http://www.defra.gov.uk/environment/flooding/risk/floodreview2007.htm>

<sup>51</sup> <http://www.defra.gov.uk/News/2009/090304b.htm>

<sup>52</sup> The Environment Agency will complete a third generation surface water maps by 31 December 2010.

<sup>53</sup> Changes were made to the Town and Country Planning (General Permitted Development) Order 1995 so that as from 1 October 2008, households in England can lay permeable surfaces without planning permission. Impermeable surfaces, where the surface area exceeds five square metres require specific approval from the local planning authority.

Flooding is not the only risk faced by built private assets. Private properties are also exposed to the risks of subsidence and ground disruption<sup>54</sup>. For example, the heat wave in the summer 2003 has been estimated to have caused 22,000 extra-cases of subsidence above business as usual (Metroeconomica, 2006), and hot summers similar to those of 2003 could be normal within 30-40 years (Shaw *et al.*, 2007). Adaptive actions can be taken now to prepare for future climate. For example, urban vegetation management that accounts for both increasing risk of subsidence and need for cooling in the summer would be a sensible option.

**Table 3 – Built private assets. Existing measures to encourage adaptation**

Regulation	Regulatory measure	Link with adaptation
	Building Regulations (review in 2010 to include adaptation)	The Building Regulations (Approved Document L – 2006) introduced a requirement for builders to consider heat gains as well as heat losses in domestic buildings and to prevent solar gain. Building Regulations encourage new developments to incorporate sustainable drainage systems (SUDS) to avoid overloading sewers during storms and to recharge groundwater. Reviews of Building Regulations will be considering the standards that need to be applied to meet current and future climate challenges including those of flooding, temperature, wind, rain and ground conditions.
	Code for Sustainable Homes <sup>55</sup>	The Code encourages new developments to incorporate sustainable drainage systems (SUDS). Within the Code, mandatory requirements include meeting minimum standards to meet current and future climate challenges, including water management and flood risks.
	Planning Policy Statement: Planning and Climate Change – Supplement to Planning Policy Statement 1 <sup>56</sup>	Planning Policy Statements (PPS) set out the Government's national policies on different aspects of spatial planning in England. PPS1 sets out the overarching planning policies on the delivery of sustainable development through the planning system. This PPS on climate change supplements PPS1 by setting out how planning should contribute to reducing emissions and stabilising climate change and take into account the unavoidable consequences. In particular, the supplement requires applicants for planning permission to consider climate change into all spatial planning concerns, and to consider mitigation and adaptation jointly when planning new development.
	Planning Policy Statement 25 (PPS25) <sup>57</sup>	It sets out Government policy on development and flood risk. It aims to ensure that flood risk is taken into account at all stages in the planning process to avoid inappropriate development in areas at risk of flooding, and to direct development away from areas of highest risk. Where new development is exceptionally necessary in such areas, policy aims to make it safe, without increasing flood risk elsewhere, and, where possible, reducing flood risk overall.
	Planning Policy Guidance 14 (PPG14) <sup>58</sup>	Planning Policy Guidance 14 (PPG14) sets out the broad planning and technical issues to be addressed in respect of development on unstable land.

<sup>54</sup> According to the British Geological Survey this has cost the economy an estimated £3 billion over the last decade.

<sup>55</sup> The Code for Sustainable Homes has been developed to enable a step change in sustainable building practice for new homes. The Code is intended as a single national standard to guide industry in the design and construction of sustainable homes by using a sustainability rating system to communicate the overall sustainability performance of a home. Minimum standards exist for a number of categories – these must be achieved to gain a one star sustainability rating. Apart from these minimum requirements the Code is completely flexible; developers can choose which and how many standards they implement to obtain 'points' under the Code in order to achieve a higher sustainability rating.

Available at: [http://www.planningportal.gov.uk/uploads/code\\_for\\_sust\\_homes.pdf](http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf)

<sup>56</sup> <http://www.communities.gov.uk/publications/planningandbuilding/ppsclimatechange>

<sup>57</sup> <http://www.communities.gov.uk/publications/planningandbuilding/pps25practiceguide>

<sup>58</sup> <http://www.communities.gov.uk/planningandbuilding/planning/planningpolicyguidance/planningpolicystatements/planningpolicyguidance/ppg14/>

Regulation (Cont...)	Regulatory measure	Link with adaptation
	Strategy for Sustainable Constructions <sup>59</sup>	The strategy sets out targets to improve the productivity, efficiency and sustainability of the UK's construction sector. The strategy includes a section describing measures to support climate change adaptation.
	Sustainability appraisal (SA) <sup>60</sup> produced by regional planning bodies (RPBs) and local planning authorities (LPAs) <sup>61</sup>	The sustainability appraisal (SA) promotes sustainable development through the integration of social, environmental and economic considerations into the preparation of revisions of Regional Spatial Strategies (RSS) and for new or revised Development Plan Documents (DPDs) and Supplementary Planning Documents (SPDs). The SA encourages RPBs and LPAs to account for climate change impacts (e.g. flooding, subsidence, water quality).
	Local Authorities National Indicator <sup>62</sup>	NI188 is designed to measure progress in preparedness in assessing and addressing the risks and opportunities of a changing climate. The aim of this indicator is to embed the management of climate risks and opportunities across local government services, plans and estates. It is a process indicator which gauges progress of a local area to: assess the risks and opportunities comprehensively across the area; take action in any identified priority areas; develop an adaptation strategy and action plan setting out the risk assessment, where the priority areas are – where necessary in consultation and exhibiting leadership of local partners – what action is being taken to address these, and how risks will be continually assessed and monitored in the future; and implement, assess and monitor the actions on an ongoing basis.

<sup>59</sup> Published by BERR in June 2008, <http://www.berr.gov.uk/whatwedo/sectors/construction/sustainability/page13691.html>

<sup>60</sup> Under Section 39(2) of the Planning and Compulsory Purchase Act 2004 (hereafter referred to as 'the Act'), sustainability appraisal is mandatory for RSS revisions and for new or revised Development Plan Documents (DPDs) and Supplementary Planning Documents (SPDs).

<sup>61</sup> See Guidance <http://www.communities.gov.uk/documents/planningandbuilding/pdf/142520.pdf>

<sup>62</sup> <http://www.defra.gov.uk/corporate/about/what/localgovindicators/ni188.htm>

Information, Research, Funding	Regulatory measure	Link with adaptation
	UK Climate Projections <sup>63</sup>	The UK Climate Projections are based on a method that looks at the strength of evidence for different outcomes, called probabilistic modelling. Through UKCP09 information is provided for temperature, precipitation, humidity, cloud, radiation, sea level rise and sea level pressure. Probabilistic projections give an indication of the likelihood of different outcomes, in this case the change in a given climate variable under a set of pre-specified conditions.
	Your Home in a Changing Climate: Retrofitting Existing Homes for Climate Change Impacts <sup>64</sup>	This research investigates the climate change impacts on our existing housing stock, and identifies the primary options, and attendant costs, of retrofitting the stock. The study covers dwellings from private individuals to housing associations, with an emphasis on water conservation, drainage, flood risk and ventilation', and outlines the main technologies, designs, appliances, installations and practices for retrofitting.
	GeoSure dataset and reports	Produced by the British Geological Survey, GeoSure national datasets and reports provide geological information about potential ground movement or subsidence that can help planning decisions.
	Environment Agency Flood Map <sup>65</sup>	Provides information on floodplains, along with data on the likelihood (significant, moderate or low) of flooding.
	Climate Change & Your Home <sup>66</sup>	Developed by English Heritage, this is an interactive web portal designed specifically to help further understanding about the ways climate change affects houses built before the Second World War.
	Home Information Packs (HIPs)	Introduced in 2007 these packs are designed to provide home buyers with the information necessary to make an informed choice a property they wish to buy. However, the packs do not provide information on flood risk from groundwater, rivers and the coast, but only from surface water flooding, or risk of flooding due to an overloaded public sewer.
	Adaptation and Resilience to a Changing Climate (ARCC) programme <sup>67</sup>	ARCC provides funding to support engineering research on adaptation options for buildings, infrastructure and utilities. ARCC has been developed in order to build upon on the successes of the EPSRC/UKCIP programme Building Knowledge for a Changing Climate (BKCC) and the knowledge transfer and networking activity Sustaining Knowledge for a Changing Climate (SKCC).

### 3.2.4 Implications for policy design

Given the existing market failures (mainly information failure and misaligned incentives) there is scope for the Government to encourage appropriate incentives by providing the supply side with a regulatory framework conducive to adaptation and supporting the development of well informed demand for adaptive measures.

There is a low turnover rate for the building stock. The majority of the housing stock in 2050 has already been built. This has two implications: first, there is a more urgent need to investigate options for

<sup>63</sup> <http://ukclimateprojections.defra.gov.uk/>

<sup>64</sup> <http://www.london.gov.uk/ccp/publications/home-feb08.jsp>

<sup>65</sup> Guidance available at <http://www.environment-agency.gov.uk/homeandleisure/floods/31656.aspx>

<sup>66</sup> <http://www.climatechangeandyourhome.org.uk/live/>

<sup>67</sup> See <http://www.ukcip-arcc.org.uk/>

adapting the existing housing stock; second, there is a need to ensure that the appropriate regulatory framework exists for new-build.

The implications for policy design can be summarised as follows:

- **Incorporating adaptation into existing regulatory frameworks.** Regulatory measures can be used to encourage climate resilience. For example, building regulations and development plans can help to ensure that potential future damage costs are minimised by requiring that new developments are not located in areas exposed to significant climatic hazards, and that the buildings themselves are resilient to the future climate. Regulation can also help to ensure that people are provided with all the necessary information to incorporate climate change costs in their decision making. There may also be a case for intervention when individual actions result in significant negative externalities.
- **Adopting an integrated approach, which accounts for climate and non-climate factors.** For the built environment to be appropriately adapted it is important to ensure that policy objectives are set so as to account for multiple climate and non-climate factors. Upstream policies that cut across the built environment (housing, healthcare, natural resources) will need to incorporate adaptation in a consistent way, and provide regional and local bodies with a consistent framework, which enables them to implement regional and local adaptive strategies.
- **Improving understanding of costs and benefits of adaptive measures for the built stock.** Further research is needed to understand the cost and benefits of different adaptive measures to improve the robustness or build in flexibility into new buildings (e.g. materials, design)<sup>68</sup>; and options for retrofitting. Due to the low turnover rate of the building stock, it will be important to find ways of incorporating adaptation measures through retrofitting.
- **Correcting for information failures.** This could include organising information campaigns and devising guidance on climate risks, as well as information on existing adaptive tools tailored to specific audiences. Individuals should be encouraged to adopt measures which improve their living conditions at low costs first (e.g. use existing internal shadings in houses; or place vulnerable items in dry-bags). Consistent with the Pitt Review's recommendations, information on climate risks could also be incorporated into existing frameworks and practices (as flood risk became part of the Home Information Pack).
- **Investing in adaptive actions.** The lessons learnt from the 2007 floods will inform the development of future adaptive strategies to reduce the vulnerability of the built environment to flooding. Recommended measures in the Pitt Review that have been taken forward by Government include: systematically incorporating flood risk assessments into the Regional Spatial Strategy (RSS), Local Development Framework and individual planning applications; ensuring that developers make a full contribution to the costs both of building and maintaining any necessary defences; improving warning systems, and communication systems in case of emergency; and considering the roll-out of new schemes (e.g. telephone opt-out flood warning schemes).
- **Addressing distributional issues.** When climate change leads to significant distributional impacts, the Government will aim to ensure that all socio-economic groups have equal adaptive opportunities; and planning legislation accounts for climate change, while avoiding creating or exacerbating existing equity issues. It will be important to ensure that the social housing stock is resilient to the future climate; and there is a need to investigate options for increasing the uptake of cost-effective adaptive measures by vulnerable groups, including risk management tools (e.g. insurance) and investments in hard measures (e.g. foundation deepening).

<sup>68</sup> Robustness is the ability to accommodate any uncertain future events or unexpected developments such that the initially desired future state can still be reached. Flexibility is the inherent capability to modify a current direction to accommodate and successfully adapt to changes in the environment.

**Table 4 – Built private assets. Implications for policy design**

Policy instruments	Main reasons for intervention	Implications for policy design
<b>Regulatory measures (including direct regulation and market / economic instruments)</b>	Regulatory failures Externalities Equity	<ul style="list-style-type: none"> <li>• Correct for existing institutional distortions</li> <li>• Incorporate climate change risks in existing regulations (building regulations, planning systems)</li> <li>• Ensure externalities are incorporated into autonomous adaptive strategies (polluter pays principle)</li> <li>• Investigate price-based instruments to incentivise adaptation</li> </ul>
<b>Research and monitoring spending programmes</b>	Public goods Information failures	<ul style="list-style-type: none"> <li>• Improve understanding of costs and benefits of adaptive measures for the built stock</li> </ul>
<b>Information provision and public engagement</b>	Information failure Behavioural barriers	<ul style="list-style-type: none"> <li>• Consider guidance for the public on ex-ante adaptive measures and ex-post coping strategies (including information on dealing with services disruption in case of extreme events)</li> </ul>
<b>Investment in infrastructure and other adaptive actions</b>	Public and club goods Externalities Financial barriers	<ul style="list-style-type: none"> <li>• Consider and help others consider options for investing in physical infrastructure to reduce risks (e.g. flood defences, sea walls)</li> <li>• Continue improving early warning systems</li> <li>• Improve risk management and emergency planning (e.g. define accountability of different bodies in case of extreme events)</li> </ul>

### 3.3. Public infrastructure

The focus of this section is on the basic physical and organisational structures that are needed by society to operate, and are key to UK competitiveness and economic growth. These include infrastructure assets in a wide range of sectors such as water, energy, transport, telecommunications and so forth.

Today, national infrastructure is a system of networks, where failure in one part can cascade through to others. It is mostly owned, operated, built and maintained by the private sector, subject to a variety of regulatory frameworks. In light of this, it is important that both Government and the private sector implement the necessary adaptive measures to ensure the national infrastructure is prepared to operate under current and future warming scenarios.

Due to the wide range of sectors covered under this section, and the complex interconnectivity and interdependency of the infrastructure network, the analysis presented does not intend to be exhaustive but rather provide insights into the overarching aspects of adaptation for public infrastructure and utilities.

#### 3.3.1 Climate change impacts

The supply of services such as transport, energy, water and health care, has been subject to pressures due to climate change. Extreme weather conditions can disrupt or cause physical damage to infrastructure, resulting in knock-on effects. A review of the impacts of climate change to some sectors is provided as follows:

- **Transport**

In 2001 the Department for Transport (DfT) provided £23 million to 22 authorities to help deal with flood damage to their transport infrastructure. More recently, during the flooding events of 2007, in South-West England 10,000 motorists were trapped overnight between 2 junctions of the M5, and about 200 people were stranded after the rail network failed in Gloucester (Pitt Review, 2008).

Other events, such as heat waves, might cause network disruption due to road deformation, rail buckling or underground network failure, as well as passenger discomfort and heat exhaustion. The heat wave in 2003 for example, led to major time delays on the rail network from speed restrictions and very high temperatures on the London Underground<sup>69</sup>.

Along with increasing temperatures and increased frequency of high or extreme temperature episodes, other changes might impact on the transport sector. The existing literature on the likely impacts of climate change<sup>70</sup> reports that changes in soil moisture content might increase the risk of structural failures of infrastructure such as bridges, tunnels and embankments; maritime transport is likely to be subject to increasing pressures due to sea level rises and coastal erosion; and aviation might be affected by more frequent and severe extreme events such as storms and higher temperatures (affecting the conditions of the runaways).

Some positive impacts are also likely: less frequent fog, frost and snowfall are expected to result in a decreased number of related accidents, restrictions and disruptions, particularly during the winter. All of these impacts, both positive and negative, are likely to differ at the regional level, even within the UK.

<sup>69</sup> In the hot summer of 2003 there were 165,000 delay minutes nationally (compared with just 30,000 in the cooler summer of 2004). The number of buckled rails (approximately 130) was also high and consistent with other hot years (1976 and 1995) (Greater London Authority, 2005). On one day in July 2003, 4,000 passengers were trapped on London Underground in broken down trains for at least 90 minutes, and subjected to combined temperatures and humidity approaching 40 °C (DfT, 2004).

<sup>70</sup> Metroeconomica (2006) reports a summary of the literature on the likely impacts of climate change on the transport sector.

### • Energy

Warmer winters and hotter summers will change the seasonal pattern of energy use by decreasing the demand for space heating in the winter, and increasing the demand for cooling in the summer. It is challenging to estimate net changes in demand for energy due to the need to make extensive assumptions to model the changes. Metroeconomica (2006) estimated that net changes for both the domestic and service sectors will be negative: decreases in energy demand during the winter will outweigh increases in demand during the summer<sup>71</sup>. Along with changes in average temperatures, more extreme events (such as heat waves) might lead to spikes in demand, put pressures on supply capacity, and increase the risks of blackouts.

More frequent floods and more intense and frequent storms will also place significant pressures on energy infrastructure. Damage to power lines, transmission grids and offshore infrastructure can lead to power disruption<sup>72</sup>. Metroeconomica (2006) estimated the costs of supply disruption<sup>73</sup> caused by the severe storms in October 2002 to be approximately £30 million.

### • Water

In the UK, there is evidence of a reduction of groundwater layers<sup>74</sup> throughout the country by 5–15%, which is mainly due to reduced precipitation during the winter (UKWIR, 2003). Water scarcity might be exacerbated by more frequent droughts, along with increases in the demand for water (particularly during the summer) for irrigation and drinking water<sup>75</sup>, cooling systems and recreation. However, water shortages are likely to be unevenly distributed across the country and concentrated in some periods of the year<sup>76</sup>.

Water infrastructure and sewage systems are likely to be placed under increased pressure, particularly in those areas most exposed to flooding. The events in July 2007, for example, culminated in the temporary loss of supply from the Mythe Water Treatment Works in Gloucestershire<sup>77</sup>.

The quality of water resources is also likely to be indirectly affected. Changes in temperatures are likely to affect the bacteriological conditions and oxygen content of water, in some cases leading to changes in the distribution of habitats and ecosystems responsible for services such as water regulation and purification. Moreover, floods might result in sewage overflow, and increase the potential for spread of water-borne disease.

### • Health service

More frequent flooding would have indirect but significant impacts on this sector by putting localised strain on NHS services. Floods increase the risk of contaminated waters (e.g. with chemical waste, oil, diesel, pesticides, fertilisers, etc.), and related infectious diseases, in addition to causing potential damage to hospitals, nurseries, clinics, general practices etc., in some cases forcing the evacuation or closure of some utilities. In addition, flooding might have implications for mental health<sup>78</sup>, and lead to increased levels of anxiety amongst the population (Pitt Review, 2008).

<sup>71</sup> Impacts on the demand for heating and cooling are based on several assumptions, including for example people's ability to adjust their demand for energy to take account of changed energy needs i.e. switch off heating systems according to temperature signals; and penetration rates of air conditioning etc. The study concluded that values for the service sector are particularly uncertain. It is highlighted that with different assumptions, than the values above could change significantly and possibly even the overall energy balance.

<sup>72</sup> Indicative values for the costs of disruption have been estimated at between €3.8/Kwh for one-hour outage to €1.8/Kwh for an outage of longer than 24 hours (Egenhofer *et al.*, 2004).

<sup>73</sup> This figure does not include the costs of infrastructure damage and maintenance (Metroeconomica, 2006).

<sup>74</sup> Water availability is particularly affected by changes in rainfall patterns, lower snow cover (with lower retention of water as snow), and changes in the soil conditions. These factors reduce the natural recharge of groundwater, which is a crucial source of water for nature, especially wetlands and coastal ecosystems, and for water supply, especially for drinking water.

<sup>75</sup> Estimates of rises in water demand are provided by Downing *et al.* (2003), who estimated increases in irrigation use in England of around 20% by the 2020s and around 30% by the 2050s, and rises in per capita domestic demand by 2 to 5% during the coming 20 to 50 years as a result of climate change.

<sup>76</sup> For example, it has been estimated (UKCP09) that under the medium emissions scenario (central estimates) the South West is expected to experience 23% less rain by 2080, whereas winter rainfall is projected to increase, for example in the North West of England by 16% in 2080s. The demand for irrigation in the summer is likely to be concentrated particularly on lighter soils, sands and sandy loams, in Eastern England, the East Midlands and the South East, where most field crop irrigation is carried out.

<sup>77</sup> The loss of piped drinking water affected around 350,000 people and constituted a major incident requiring a multi-agency response to deliver alternative water supplies to the affected areas (Defra, 2008).

<sup>78</sup> A case-control study found that psychological distress among adults whose homes were flooded is fourfold higher than for those whose homes were not flooded (Reacher *et al.*, 2004).

Changes in climate variability are likely to affect seasonal demand for services. For example, warming temperatures during the winter are likely to reduce the number of cold-related diseases. During the summer, extreme events such as heat waves are likely to cause health problems (e.g. heat exhaustion). More frequent droughts may lead to more frequent water shortages (particularly in the South East), possibly increasing the demand for health services for particular groups such as the elderly and disabled.

### 3.3.2 Market failures and other barriers to autonomous adaptation

Due to the distinctive nature of the services under consideration – public goods generating positive externalities (e.g. health), natural monopolies (e.g. energy distribution)<sup>79</sup>, and merit goods (e.g. water<sup>80</sup>) – the national infrastructure is subject to specific regulatory interventions. In different sectors, public bodies and private organisations that manage, operate and maintain infrastructure have to meet statutory requirements and performance standards for the services they provide, and climate change is one of the risk-factors that they should account for in the decision making in order to fulfil their obligations.

Investment decisions on infrastructure involve multiple actors. From 2010, a new independent body introduced by the Planning Act 2008, the Infrastructure Planning Commission (IPC), will take land use planning decisions on Nationally Significant Infrastructure Projects (NSIPs)<sup>81</sup>. The IPC will refer to National Policy Statements (NPSs)<sup>82</sup> while examining the applications<sup>83</sup>. NPSs must set out how they address adaptation (as a statutory requirement set by the Planning Act 2008), including providing guidance to the applicants on how to account for climate change adaptation, and to advise the IPC on how adaptation must be part of its decision making framework. For infrastructure other than NSIPs (e.g. schools, hospitals, small scale renewable and smaller transport infrastructure), investment decisions will continue to be framed within regional strategies, and be part of local authorities' development plans.

When investment decisions are taken by companies subject to economic regulation (e.g. water companies), adaptation may be potentially affected by regulators' price setting, or more in general by the framework the regulated companies are subject to. Regulators have powers and remits designed to reflect the different needs of their sector and therefore different channels to influence adaptation in regulated companies. In sectors, which are exempt from regulation, decisions on the resilience of the infrastructure will be at the discretion of individual companies.

Due to the multiple levels of decision making involved, in this area barriers to adaptation might stem from a lack of consistency between the frameworks used. The interconnectivity between the infrastructure assets means that any poorly defined responsibilities, or lack of coordination between the various operators, could undermine their ability to contribute to the adaptation of the national infrastructure and public services in an efficient and effective way, and exacerbate the impacts of climate change.

There is an important interface between infrastructure and users. The public and businesses could also contribute to reduce the impacts of climate change on infrastructure through, for example, a more sustainable use of water; a more sustainable use of drainage systems; and a better understanding and implementation of emergency strategies in case of disruption of services. Barriers to adaptation in this case might stem from lack of information, price signals that do not reflect the costs of provision or

<sup>79</sup> A natural monopoly exists when there is great scope for economies of scale to be exploited over a very large range of output. Natural monopolies tend to be associated with industries where there is a high ratio of fixed to variable costs. For example, the fixed costs of establishing a national distribution network for a product might be enormous, but the marginal (variable) cost of supplying extra units of output may be very small.

<sup>80</sup> Water is both excludable and rivalrous. Unlike a public good, there is a marginal cost attached to each unit of water consumed associated with production, purification and delivery of water to an individual's home. However, given the strong positive (particularly health-related) externalities related to its consumption, water has the characteristics of a "merit good".

<sup>81</sup> The definition of "nationally significant infrastructure project" covers specified categories of project in the energy, transport, water, waste water and waste sectors. For further details on the types of project which fall within the definition of a "nationally significant infrastructure project" see sections 14 to 30 of the Planning Act 2008.

<sup>82</sup> NPSs are produced by central Government departments for nationally significant infrastructure. These will integrate environmental, social and economic objectives, including climate change commitments, in order to help deliver sustainable development. They will set out the national need for infrastructure development and set the policy framework for IPC decisions.

<sup>83</sup> In cases where no NPS has effect, the IPC will examine the application and make recommendations to the Secretary of State who will determine the application.

behavioural inertia. Research also suggests that lack of or low social capital also undermines communities' adaptive capacity, particularly when dealing with unforeseen and periodic hazardous events<sup>84</sup>.

### 3.3.3 Evidence of autonomous adaptation and existing policies

To ensure national infrastructure is well adapted to climate change, several policy measures are already in place. Along with responsibility for providing essential services, statutory undertakers and public bodies are now subject to specific requirements aimed at ensuring climate change and adaptation are incorporated into the decision process in a systematic way. These include measures explicitly aimed at supporting adaptation, such as the Reporting Power set in the Climate Change Act; the Green Book guidance for policy appraisal; the local authorities' adaptation indicator (NI188); and other measures to improve the readiness of the country to one-off threats and risks (including extreme weather events) as set in the Civil Contingency Act, and the National Risk Register.

In 2008 the Government started the Adapting to Climate Change (ACC) programme. The programme brings together the work being led by Government and the wider public sector on adapting to climate change, and will co-ordinate and drive forward the development of the Government's work on adaptation in the future. Box 8 provides an overview of the different projects under the programme.

#### Box 8. The Adapting to Climate Change (ACC) programme

The UK Government's ACC programme started in 2008 and consists of two phases. Phase 1 (2008-2011) comprises 4 workstreams:

1. **Providing the evidence**, through the UKCP09; the Climate Change Risk Assessment; and a cross-departmental project on infrastructure and adaptation coordinated by the ACC programme.
2. **Raising awareness and support actions**, e.g. through asking public bodies and statutory undertakers to report on climate change adaptation (through implementing the Reporting Power); and providing funding to Regional Climate Change Partnerships.
3. **Ensuring and measuring progress**, e.g. through developing indicators for the success of the cross-Government Programme; and monitoring the performance of local authorities' indicator on adaptation (NI188).
4. **Embedding adaptation in Government policy and process**, through the Green Book supplementary Guidance on adaptation (published in June 2009).

Phase 2 (2012 and beyond) will build on the results of the National Climate Change Risk Assessment and the Adaptation Economic Analysis to start the statutory National Adaptation Programme in 2012, as stated in the Climate Change Act.

Given the nature of adaptation, this policy area is very wide ranging and constantly developing. Up-to-date information about the programme's work can be found at <http://www.defra.gov.uk/adaptation>

<sup>84</sup> Social capital, and in particular networking social capital, is thought to enhance adaptive capacity, encourage self-regulation and the sustainable use of environmental resources (see Adger, 2003; Agrawal, 2001). Social capital is thought to be important for communities' coping and recovery, particularly in the absence of Government support. However, it does not necessarily facilitate pro-active adaptation and the enhancement of well being (Dasgupta, 2003 in Adger, 2003).

In April 2009, the ACC Programme established a cross-departmental Infrastructure and Adaptation project to identify, examine and implement strategic solutions to “improve the long-term resilience of new and existing infrastructure in the energy, transport and water sectors to future climate change impacts”. This also encompasses the role of ICT/telecommunications and interconnectivity within and across the sectors.

The Government has recently announced the creation of a body – Infrastructure UK – to advise on management and planning for the UK’s critical infrastructure, taking a 5-50 year horizon it will identify the country’s long-term infrastructure needs. The impacts of climate change will be considered in doing this.

Alongside the ACC Programme, the Government has other instruments to support adaptation. These include:

- the Local Authority performance indicator (NI188);
- an adaptation indicator against which all local authorities in England report each year as part of the local area agreements framework<sup>85</sup>;
- the Cabinet Office Civil Contingency Act and National Risk Assessment, aimed at improving understanding of the impacts of one-off threats and hazards to the UK, and devising emergency plans to deal with them; and
- the Heat Wave Plan 2009, which raises awareness on the health impacts of heatwaves and provides guidance on preventive measures to reduce those impacts.

### 3.3.4 Implications for policy design

Climate change is one of the main challenges faced by the UK national infrastructure<sup>86</sup> and the public services that rely upon it. The interdependency between various infrastructure assets and services highlights the need to improve understanding of where vulnerabilities and accountabilities lie; and the importance of having a coordinated and coherent approach to reducing those vulnerabilities. Given the highly regulated nature of this sector, it is important to consider whether the overall regulatory framework is conducive to good adaptation.

The Government can play a role in ensuring the national infrastructure is adapting well in two ways. On the supply side, it can help to ensure that the institutional framework supports adaptation in a coherent and coordinated way, where the benefits justify the costs of doing so. On the demand side, it can promote the efficient use of scarce resources, and help individuals and firms deal with emergency situations and public services disruption.

Maintaining current levels of resilience against the effects of a changing climate may require additional resources. For example, in the long-term investment strategy for flooding and coastal risk management, the Environment Agency estimated that it would require an increase to around £1040 million a year (in real terms) by 2035 to maintain current standards of protection<sup>87</sup>.

Research on the long-term fiscal implications of climate change is not well developed and needs to be considered carefully. There is a two-way relationship between climate change and the fiscal stance of the UK. In one direction, more frequent and severe extreme weather events may have an impact on

<sup>85</sup> The Local area agreement framework including responsibilities and process are led by CLG and further details can be found at <http://www.communities.gov.uk/localgovernment/performanceframeworkpartnerships/localareaagreements/>

<sup>86</sup> The Council for Science and Technology (2009) identified three main challenges for UK infrastructure: its highly fragmented nature (both in terms of delivery and governance); its weak resilience to systematic failure; and the existing pressures posed by climate change and socio-demographic changes. The report is available at <http://www.cst.gov.uk/reports/files/national-infrastructure-report.pdf>

<sup>87</sup> This figure is an increase of around 80 per cent on 2010-2011 levels (£570 million) and excludes the costs of managing the risk of surface and groundwater flooding (EA, 2009a). <http://publications.environment-agency.gov.uk/pdf/GEHO0609BQDF-E-E.pdf>

public finances<sup>88</sup>. Although research suggests that advanced economies have been able to cope well so far, this may not continue to be the case as extreme events become more frequent and more severe<sup>89</sup>. In the other direction, the fiscal stance of the UK in the future may affect investment in adaptation. Although outside the scope of this paper, this is a critical area for future work.

Implications for policy design can be summarised as follows:

- **Harmonising adaptation in existing regulatory frameworks.** In order to create a regulatory environment, which is supportive of adaptation, it is important to investigate potential regulatory barriers, and support a coordinated approach to adaptation when this is cost-effective to do so. Climate change is likely to exacerbate existing inefficiencies, and make an even stronger case for removing such inefficiencies. Overall, consideration should be given to how climate change risks are accounted for across the different networks, and whether these accounting methods create the right incentives for regulated bodies and organisations to adapt.
- **Investigate options for mainstreaming adaptation into direct public investment decisions in a systematic way.** Some of the existing policy instruments (e.g. Green Book guidance on adaptation) and powers (e.g. Reporting Power) aim to ensure public infrastructure and Government investments more in general are adapted to climate change. It has also been suggested that responsibility for adaptation could be built into contracts with private operators (OECD, 2008). For example, adaptation could be mainstreamed into public procurement through setting performance requirements or specifications for private companies so that they account for climate change in a more systematic way<sup>90</sup>; and allocating climate change risks between private and public partners in a more transparent way<sup>91</sup>. The costs and benefits of these arrangements should be assessed against conventional models of public finance (OECD, 2008). The ACC programme is working jointly with the Office of Government Commerce to produce guidance to help incorporate climate change adaptation into public procurement.
- **Improve understanding of customers' role, including adaptive capacity.** It is important to understand customers' willingness to pay and which incentives they need in order to contribute to increase the resilience of the national infrastructure. More research is needed to improve understanding of individuals' tolerance to risks resulting from the failure of infrastructure, their willingness to pay to reduce those risks; and what barriers prevent people from changing behaviour and reducing their use of scarce resources. This critically needs cross-disciplinary study (including social, economic and engineering sciences).
- **Devising participatory awareness/information campaigns.** These could promote a more sustainable use of resources, and create a better understanding of how to behave/co-ordinate during emergencies in order to reduce the pressure on infrastructure and public services. Measures, which contribute to building up social capital, should be implemented as win-win options. These could include, for example, programmes to raise awareness and encourage simple changes in behaviour to help the most vulnerable in case of extreme events (e.g. providing support to the elderly living next door during heat waves).
- **Investing in protective measures,** such as sea walls and flood defences when this would reduce the vulnerability of the infrastructure and public utility services in the most cost-effective way. Options should include investing in robustness and flexibility. Also, various funding options will need to be explored, to ensure close alignment between payments for such protective measures and beneficiaries.

<sup>88</sup> There are 2 mechanisms through which extreme weather events affect fiscal policies: i) directly, through financing relief payments, and recovery response; and ii) indirectly, through causing a drop in output (and therefore in fiscal revenues), and increasing public expenses on social payments.

<sup>89</sup> See European Central Bank (2009).

<sup>90</sup> See the study by PwC (2009).

<sup>91</sup> Acclimatise (2005) reports that there is little evidence that PFI/PPP participants have any appreciation of the threats and opportunities arising from the impacts of a changing climate on assets and users during concession periods. Through reducing operating and financing costs, loss of income, construction delays, asset failures, poor performance, and customer concerns, adaptation would result in benefits to projects participants, but also to the Government and the public.

**Table 5 – Public infrastructure. Implications for policy design**

Policy instruments	Main reasons for intervention	Implications for policy design
<b>Regulatory measures (including direct regulation and market / economic instruments)</b>	Regulatory failures Public goods	<ul style="list-style-type: none"> <li>• Harmonise existing regulatory frameworks</li> <li>• Incorporate climate change risks in existing appraisal frameworks and decision making in policy making</li> <li>• Introduce performance standards in procurement which account for climate change risks</li> <li>• Allocate climate change risks between public and private actors in a more transparent way</li> </ul>
<b>Research and monitoring spending</b>	Public goods Information failures	<ul style="list-style-type: none"> <li>• Improve understanding of customers' role, including adaptive capacity</li> </ul>
<b>Information provision and public engagement</b>	Information failures Behavioural barriers Equity	<ul style="list-style-type: none"> <li>• Consider producing guidance for the public on ex-ante adaptive measures and ex-post coping strategies</li> <li>• Consider producing guidance tailored to specific audience (e.g. the most vulnerable)</li> </ul>
<b>Investment in infrastructure and other adaptive actions</b>	Public goods Externalities	<ul style="list-style-type: none"> <li>• Consider and help others consider options for investing in physical infrastructure to reduce risks (e.g. flood defences, sea walls)</li> <li>• Improve forecasting, monitoring and warning systems</li> <li>• Improve communication and ensure a coordinated response between public bodies responsible for dealing with emergencies</li> </ul>

### 3.4 Natural Environment and Biodiversity

Humanity relies heavily upon the services provided by the natural environment, and climate change will be mediated through the natural environment. The natural environment has the capacity to adapt to a changing climate: the boundaries of ecosystems can change, and species migrate. However, there are limits to the pace and extent of this adaptation, and there is a risk of experiencing permanent changes or losses to our environmental assets. Moreover, the natural environment is already subject to significant stress from other sources.

Adaptations by humans and the natural environment are inter-related. The way the natural environment will change in response to a changing climate will have an impact on agriculture and land use management, for example, and farming practices and land use management will affect the capacity of the natural environment to adapt. This inter-dependency points to the need to investigate the links between climate and non-climate drivers to environmental adaptation, and adopt a coordinated and consistent approach to supporting adaptation of the environment and across different sectors.

#### 3.4.1 Climate change impacts

The impacts of climate on natural resources are likely to differ depending on their location and adaptive capacity. When ecosystems are not able to recover or adapt at the same rate as climatic hazards, climate change is likely to result in changes in the availability of natural resources (such as water), along with changes in the location, composition and number of species. These impacts might compromise ecosystems' equilibrium, exacerbating the vulnerability of the environment to current and future climate scenarios, and reducing the supply of ecosystem services that people rely upon (Defra, 2007). The services are explained in Box 9.

#### Box 9. Ecosystem services

The term Ecosystem Services was developed to describe the benefits humans derive from nature. The concept was brought into popular use by the Millennium Ecosystem Assessment<sup>92</sup> which categorised services into four distinct groups:

**Supporting services** – such as nutrient cycling, oxygen production and soil formation. These underpin the provision of the other 'service' categories.

**Provisioning services** – such as food, fibre, fuel and water.

**Regulating services** – such as climate regulation, water purification and flood protection.

**Cultural services** – such as education, recreation, and aesthetic value.

The economic value of an ecosystem will depend on the sum of the value of final services. For example, the value of a service like pollination will come through in the delivery of other services like the provision of food. Here pollination would be an intermediate service and food would be a final service.

Investment in ecosystems can help adaptation to climate change in many ways. Examples would include flood alleviation and regulating fresh water supplies.

<sup>92</sup> See MEA (2003).

Metroeconomica (2006) estimated that the number of species experiencing changes in their suitable climate space<sup>93</sup> will increase as climate change progresses, with losses of climate space almost doubling between the 2020s and 2050s in UK-based scenarios. This study concluded that many wetland habitats in southern England could see a net loss of species; while those in the north, especially Scotland could have net gains, counteracted to some extent in losses in certain upland and montane species at their southern range margins. These conclusions are predicated on the assumption that species will adapt quickly and autonomously to the changes in their climate space<sup>94</sup>.

Ecosystems and natural resources are going to be affected directly by climate change, and indirectly through changes in socio-economic drivers, working practices, policies and resources use, in some cases triggered by climate change itself. An extensive report on adaptation and biodiversity was published by Defra in 2007 (Mitchell *et al.*, 2007). Based on a previous set of climate projections to UKCP09, this report identifies the following ways that climate change could affect biodiversity:

- loss of synchronisation between species as a result of changes in the timing of their natural cycles;
- changes in species distribution (including arrival of non-native species and potentially loss of species for which suitable climate conditions disappear);
- changes in community composition;
- changes in ecosystem functions; and
- loss of physical space due to sea level rise and increased storminess.

The report indicates that of the 32 habitats considered, 7 are at high risk of direct impacts, based on good to moderate evidence available, and 5 of these are coastal or marine.

Climatic changes will have complex effects on the ecosystem services that people rely on. For example, changes in annual and seasonal rain fall patterns will have effects on agricultural systems, cooling systems for industry and the availability of drinking water. More frequent extreme events might affect the conditions in which some sectors operate (e.g. agriculture, water management), and undermine the quantity, quality and sustainability of certain outputs (e.g. food production).

There is interdependency, however, between the natural environment and various sectors, meaning that changes in the availability and quality of natural resources might trigger changes in practices and vice versa decisions on adaptation might hinder or support the natural environment's adaptation.

The sectors identified by the Defra (2007) study as responsible for indirect changes on habitat and species include: agriculture; water and wetlands; woodland and forestry; towns cities and development; and coasts and seas, including fishing.

### 3.4.2 Market failures and other barriers to autonomous adaptation

In the context of natural environment, barriers to spontaneous adaptation of species and habitats may stem from their inability to keep up with the speed of climatic perturbations and shocks (i.e. lack of resilience); and/or the inability to adapt given the prevailing conditions in the immediate environment (i.e. land management, urban development, pollution or *non-climate* factors affecting their adaptive capacity).

<sup>93</sup> Climate space is the geographic area that is projected to have climatic conditions similar to the climate of those areas currently occupied by the species and likely to be climatically suitable for their survival.

<sup>94</sup> However, given the species considered (mainly plants) the authors highlight that 'many of the gains are unlikely to be realised, while losses are more likely to occur as species become stressed and suffer a mortality response. The loss, however, may also be delayed, especially for long-lived species [...]. This provides a further level of uncertainty relating to the degree to which the simulated changes will be realised' (Metroeconomica, 2006).

Ecosystem services often have characteristics of public goods, which make them difficult to value in traditional markets. This can lead to the over-exploitation of natural resources, which provides the underlying rationale for many Government interventions in this area. Climate change will pose stresses on natural resources over and above these existing pressures, making an efficient framework an even more important tool for protecting the environment.

If not incorporated into the existing policies, climate change could exacerbate existing inefficiencies, or lead to inappropriate adaptation. For example, in order to exploit new opportunities offered by a warming climate, businesses operating in the tourism sector might want to invest in facilities and premises to meet an increased demand for outdoor activities and leisure. These investments might result in increasing water consumption, noise, litter and road congestion. Good adaptation would require that the cost of using scarce resources is fully internalised by agents; noise and waste regulation are enforced effectively; and travellers pay for the cost of congestion and air pollution they cause.

Another example is farmers switching to different crops, which can be grown in a warmer climate (e.g. grapes). On a large scale, this could have significant implications for the natural environment. Ensuring agricultural regulation and agri-environmental schemes account for both the impacts of climate change and autonomous adaptation is necessary to send the right incentives to farmers to adapt in the appropriate way and support the environment's adaptive capacity.

When climate and non-climate stresses directly or indirectly put protected areas, high-quality wildlife habitats<sup>95</sup> and ecosystems services at risk of permanent damage or extinction, intervention might be required. Designing intervention in this sector poses a number of challenges, including:

- understanding of the direct and indirect impacts of climate change on ecosystem services;
- prioritising planned adaptations, which can be challenging because of incomplete evidence on the value of the ecosystem services affected by climate change; and
- ensuring sustainability, which requires that we understand the substitution possibilities between affected assets (e.g. natural and manmade) and how environmental limits should be set.

### 3.4.3 Existing policies

A number of measures are already in place to protect the environment and directly or indirectly support adaptation. These include research funding; evaluation frameworks requiring the incorporation of environmental costs and benefits into policy making; legislative frameworks; and environmental regulation incorporating objectives such as sustainable use of natural resources and biodiversity preservation.

Following the Millennium Ecosystem Assessment, the UK will undertake a National Ecosystem Assessment (NEA). This project aims to provide a comprehensive assessment of the current state of all of the ecosystems in the UK, and will produce the world's first national assessment of its kind. The assessment is intended to raise awareness among institutions on the importance of ecosystems and the services they provide to society, and to strengthen policy making and management.

<sup>95</sup> High quality wildlife habitat is used to describe any semi-natural habitat of high biodiversity value due to its species richness, scarcity as a habitat and / or presence of rare and local species.

Adaptation is explicitly part of the Ecosystem Approach Action Plan<sup>96</sup>, and the Strategy for England's Trees, Woods and Forests<sup>97</sup>. There are other programmes and policies aimed at biodiversity preservation that indirectly address climate change adaptation. For example, the objectives of Environmental Stewardship<sup>98</sup> include conservation of wildlife (biodiversity); maintenance and enhancement of landscape quality and character; and protection of the historic environment and natural resources (Box 10).

In 2009, the European Union (EU) published "Adapting to climate change: the challenge for European agriculture and rural areas", which summarises the main impacts of climate change on EU agriculture, examines adaptation needs, describes the implications for the Common Agricultural Policy (CAP) and explores possible orientations for future action. Pillar 2 of the CAP presents farmers with some options for short to medium term adaptive solutions. However, climate risks are only one aspect influencing farmers' decisions, which involve many other socio-economic and market considerations.

### Box 10. Role of agri-environment schemes (AES) in supporting climate change adaptation

It is widely recognised that agriculture has a key role to play in contributing to overall resilience to climate change.

Pillar 2 of the European Union's (EU) Common Agricultural Policy (CAP) contains a list of possible interventions, some of which provide opportunities to help offset the adverse effects of climate change. Most prominently, agri-environment support schemes (AES) that encourage better management of soil and water resources, conservation of a broad genetic resource base, restoration of woodlands and prevention of forest fires will aid adaptation to varying and harsher environmental conditions. Guidelines have been given to Member States for rural development programmes for the period 2007-13 to address climate change.

Coherent AES can contribute to wider climate change adaptation objectives including safeguarding water quality, carbon storage, biodiversity and habitat conservation. For instance, new research suggests that integrating Sustainable Flood Management (SFM) principles into agricultural practice will require relatively few changes under the current legislative framework (Kenyon *et al.*, 2008). In the UK, the Environment Agency's Organisational Adaptation Strategy (2005-08)<sup>99</sup> agreed on actions influencing the development of AES to include options for water efficiency, rural Sustainable Drainage Systems (SUDS) and better soil management (EA, 2009b).

Nevertheless, there are a number of issues that could limit the potential of AES to support climate change adaptation. Currently AES are voluntary in nature and there is scope to increase farmer participation. Local schemes, which play a significant role in AES, do not currently have to take climate change adaptation into account. Climate change is also a long-term challenge that requires agreements and commitments on appropriate timescales (AEA & Universidad de Politécnica de Madrid, 2007).

<sup>96</sup> Published in December 2007, the Plan states that the priorities and targets identified in the UK Biodiversity Action Plan (UK BAP) will need to be reviewed periodically to ensure they continue to be relevant and achievable, and that adaptations in sectors such as agriculture, forestry, water management and energy also contribute to biodiversity objectives. See <http://www.defra.gov.uk/wildlife-pets/policy/natural-environ/documents/eco-actionplan.pdf>

<sup>97</sup> Launched in June 2007, the strategy aims to ensure that existing and newly planted trees, woods and forests are resilient to the impacts of climate change and also contribute to the way in which biodiversity and natural resources adjust to a changing climate. Available at <http://www.defra.gov.uk/wildlife-countryside/forestry/strategy.htm>

<sup>98</sup> An agri-environment scheme which provides funding to farmers and other land managers in England who deliver effective environmental management on their land.

<sup>99</sup> This established a detailed methodology, based on work by the UK Climate Impacts Programme (UKCIP), for integrating adaptation into business planning.

### 3.4.4 Implications for policy design

There is still limited knowledge of the impacts of climate change on the natural environment, making planned adaptation particularly challenging. As a result, a dynamic approach to intervention is required, where ecosystem management is based on testing assumptions, monitoring and adjusting management plans accordingly.

There are some actions that are a priority, and are likely to yield net benefits regardless of uncertainty over the future climate. These include addressing existing inefficiencies which risk exacerbating the vulnerability of ecosystems (e.g. ensure compliance with existing regulations on the use of land, water and marine resources); lessening existing pressures on ecosystems (e.g. pollution); and creating a framework which includes adaptation to climate change in resource planning and management objectives.

Areas to consider for future policy design include:

- **Reducing uncertainty and information failure.** Research and monitoring programmes can improve understanding of the impacts of climate change on ecosystems characteristics and functionality, the risks of invasive species, the spontaneous adaptation by habitats and species, and the inter-linkages between the natural environment's and manmade adaptation. Also, greater research is needed to improve understanding and valuation of ecosystems able to provide 'adaptive services' (see final point below).
- **Mainstreaming climate change adaptation into existing environmental regulation.** Natural resources are protected as a public good through existing regulations covering land use and agriculture, coastal zone management and water management. The complex interdependencies between agriculture and the natural environment and the challenges that both are faced with, support the need for adopting a joined-up approach to supporting adaptation in these two areas. In particular, due to the potential implications of climate change and adaptations on food security and ecosystems, in the long run adaptive strategies in the agriculture sector may need to go beyond current practices to include coordinated strategies accounting for environmental risks and market considerations.
- **Investigating the potential for environmental markets and pricing.** Policies such as payments for ecosystem services (PES) should be investigated. These could help reduce the pressures on environmental resources while ensuring the social cost of using environmental resources are internalised and encourage adaptation.
- **Investing in green infrastructure for adaptation.** There is the potential to identify win-win options for adaptation. These include those which increase the resilience of ecosystems by reducing other pressures (manmade pollution) or countering habitat fragmentation; or options that exploit the 'adaptive value' provided by some natural resources while contributing to environmental outcomes (e.g. natural reservoirs providing water resources, wetlands absorbing runoff and filter discharges flowing into bays and estuaries etc.)<sup>100</sup>. Also, when protected areas such as high-quality wildlife habitats<sup>101</sup> and other essential ecosystems services are at risk of permanent damage or extinction, the Government could investigate the need for refuges, parks, and reserves with corridors to enable species' adaptation.

<sup>100</sup> The Economics of Ecosystems and Biodiversity (TEEB) study identified three broad areas for adaptation: agricultural productivity, fresh water supply, and natural hazard management.

<sup>101</sup> High quality wildlife habitat is used to describe any semi-natural habitat of high biodiversity value due to its species richness, scarcity as a habitat and / or presence of rare and local species.

**Table 6 – Natural environment and biodiversity. Implications for policy design**

Policy instruments	Main reasons for intervention	Implications for policy design
<b>Regulatory measures (including direct regulation and market / economic instruments)</b>	Regulatory failures Public goods Externalities	<ul style="list-style-type: none"> <li>• Ensure environmental policies (e.g. agriculture and land use policies, coastal management policies, water management policies) account for climate change risks</li> <li>• Explore the potential for supporting private adaptive strategies through environmental markets (e.g. payments for ecosystem services) and price-based instruments (e.g. conservation payments)</li> </ul>
<b>Research and monitoring spending programmes</b>	Public goods Information failures	<ul style="list-style-type: none"> <li>• Improve the understanding of climate change impacts on biodiversity and non-native species</li> <li>• Improve understanding of the interdependency between manmade adaptation and the natural environment</li> </ul>
<b>Information provision and public engagement</b>	Information failure Behavioural barriers	<ul style="list-style-type: none"> <li>• Raise awareness of climate change impacts on ecosystems' services</li> </ul>
<b>Investment in infrastructure and other adaptive actions</b>	Public goods Externalities	<ul style="list-style-type: none"> <li>• Invest in win-win options, or environmental resources with adaptive value</li> <li>• Investigate options for active management of ecosystems (e.g. creating corridors to allow species migration, planting desired species)</li> </ul>

# Conclusions

Due to past carbon emissions, we are already committed to inevitable climate change effects for the following 40 years, and to over 100 years of sea-level rise. Global average temperatures are likely to rise by between 1.1 and 6.4°C by 2100 (compared to the 1980-99 average) depending on which emissions pathway the world follows for the rest of this century. Projected rises in global mean temperatures could result in a faster rate of climate change this century than the Earth has experienced for at least 10,000 years (Met Office, 2008). The UK is faced with increasing average temperatures, rising sea levels and more frequent floods and droughts. It will also be affected by the impacts of climate change occurring in other countries.

Adaptation entails minimising the damage and exploiting the new opportunities posed by climate change. The right decisions on adaptation today are likely to contribute to economic growth in the long run.

This paper contributes to the existing literature by describing the economic theory underpinning adaptation and considering the role of Government in supporting adaptation within that economic framework. The framework has been applied to four areas (insurance, built private assets, public infrastructure and the natural environment) to identify existing market and regulatory failures preventing autonomous actions from being undertaken at the appropriate level. Based on this analysis, it has proposed some implications for policy design.

Adaptation will have public (national, regional and local) and private impacts. For this reason, adaptation will need to be undertaken at different levels of decision making. Individuals and businesses play a key role in ensuring the UK adapts to climate change. To ensure the sum of individual actions leads to the appropriate level of adaptation for the UK, the Government can play a coordinating role by providing an environment conducive to adaptation which is effective, efficient and equitable; creating consistent incentives across the wide range of Government policy areas; and presenting individuals and businesses with the right signals to drive changes in behaviour.

Options for action include mainstreaming climate change adaptation into existing frameworks; raising awareness among households, businesses and the different actors involved in decision making across different areas; promoting systems that are able to incorporate learning potential; and, when identified, investing in adaptive measures which are robust across a range of possible future scenarios.

Overall, there is a need to define and measure whether the UK is adapting enough and in the right ways. In mitigation policy there is a single, measureable, global metric of success – reducing net greenhouse gas emissions. This is not the case for adaptation where the benefits will be local, context specific and (in some cases) subject to long lead times. When offsetting all the impacts of climate change will not be cost-effective, the most appropriate decision will be to accept some losses. Individual adaptation decisions can be assessed against the criteria of effectiveness, efficiency and equity, based on current knowledge. It is also possible to assess whether the processes and institutional framework underpinning adaptation are appropriate and provide the right incentives for decision makers. However, further work is needed to assess whether the cumulative result of these decisions is a 'well-adapting' UK.

To support adaptation, the Government can create consistent incentives across the wide range of policy areas. The context specific nature of adaptation makes this difficult to achieve. The research priority here is to provide pragmatic decision rules that help people to make sensible decisions, with the depth of analysis required proportional to the potential consequences of the decisions.

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There is a need to develop and apply tools for making decisions with incomplete information in the presence of uncertainty. The evidence base is improving rapidly, but dealing with incomplete information and uncertainty is an inherent feature of adaptation. Government appraisal guidance on adaptation emphasises the importance of designing flexibility into decisions. It would be valuable to explore alternative decision-support mechanisms.

Finally, the analytical work of this paper along with the applied analysis allowed it to identify areas for future research that could usefully contribute to filling the existing evidence gaps on adaptation, and inform the development of future policies. Future areas of work could include:

- the macro economics of climate change adaptation, including the impact of climate change on the fiscal stance and growth of the UK;
- equity and distributional implications of climate change adaptation;
- climate change adaptation and risk burden – the split of responsibilities between Government, the insurance industry and the public;
- costs and benefits of adaptation of built private assets;
- individuals' tolerance of risks resulting from the failure of infrastructure, their willingness to pay to reduce those risks, and the barriers that prevent people from changing their behaviour;
- adaptation of the natural environment, including improving understanding of the impacts of climate change on ecosystems' functionality, spontaneous adaptation by habitats and species, and the interrelationships between the natural environment's and society's adaptation;
- the adaptive value of ecosystems, e.g. investigating the value of green infrastructure for adaptation; and
- investigating the feasibility of policies to incentivise a more efficient use of scarce resources, such as payments for ecosystem services (PES).

# Annex A – Market failures and other barriers to adaptation

Market failure refers to where the market has not and cannot of itself be expected to deliver an efficient outcome (HM Treasury, 2003). Alongside market failures, other barriers can prevent the market from achieving an efficient outcome. These include institutional arrangements, behavioural and organisational barriers.

Building on Stern (2006), this annex discusses market failures and other barriers that may prevent individuals and firms from undertaking adaptation that is effective, efficient and equitable.

## A.1 Market failures

'Market failures' occur when the market leads to an inefficient allocation of resources<sup>102</sup>.

### Information failures<sup>103</sup>:

There are three main information failures in the context of adaptation:

- **Lack of awareness.** Individuals and businesses might not be aware of the effects of a changing climate and the various adaptive options which are at their disposal. For example, they may not know about the range of different options to reduce damage from flooding (from soft measures such as placing vulnerable items in dry-bags or raising appliances above flood level to more substantive measures such as replacing carpet with hard flooring). They may not be aware of the costs and benefits of different adaptive strategies.
- **Misaligned incentives and missing markets.** In some instances, the costs of adaptation will fall on certain individuals, while the benefits will accrue to others. A typical example of this is the split between property owners and tenants. In theory, the value of investments in water efficiency should be reflected in the rent charged if the supply is metered, but uncertainty and lack of information (combined with short-planning horizons) may prevent this from occurring. The result of this can be an inefficient level of investment in adaptation, because there is then a lack of incentive for the owner to invest if they do not pay the water bills.
- **Asymmetric information and moral hazard.** Asymmetric information occurs when information is known to some people but not to others. This can lead to opportunism as one party seeks to take advantage of superior information. For example, individuals and organisations will be less likely to take action to adapt if the actions they take are unobservable to insurers, and hence not reflected in premiums.

### Public and club goods

Some adaptation measures have the characteristics of public goods. Pure public goods are characterised by non-excludability, that is if a public good is made available to one consumer it is effectively made available to everyone<sup>104</sup>; and non-rivalry in consumption, that is the consumption of the good by one person does not prevent someone else from using or consuming that good<sup>105</sup>. Classic examples of these goods are clean air and national defence.

The characteristics of pure public goods generally make them unlikely to be supplied in the private market, because of the free-rider problem. This problem occurs because people can benefit from the existence of a public good without having to contribute to its provision. In practice, however, public goods are rarely pure: most public goods exhibit degrees of excludability and rivalry.

<sup>102</sup> Barr (1993) states that "the Invisible Hand theorem asserts that a market allocation will automatically be efficient if and only if the standard assumptions all hold". [These] concern perfect competition, the absence of market failures, and perfect information."

<sup>103</sup> In Barr (1993), complete information is said to require "at least three types of knowledge: about the quality and nature of the products; about prices; and about the future."

<sup>104</sup> HM Treasury (2003). Also, a good is non-excludable when it is not feasible to exclude those who do not pay for it (Bruce, 2001 in Robbins, 2005). This can be due to the physical characteristics of the goods (e.g. for natural resources such as clean air, sunlight) or the lack of an efficient exclusion mechanism (e.g. city streetlights).

<sup>105</sup> HM Treasury (2003).

Public goods that exhibit some rivalry in consumption and excludability are generally referred to as club goods<sup>106</sup>. For example, television transmission through satellites is restricted to those who have a decoder. In the context of adaptation, community flood defences can have the characteristics of club goods. However, these may be underprovided privately because high transaction costs prevent potential beneficiaries from finding mutually satisfactory agreements for the provision, or additional members could lead to crowding which in the long run could be regarded as rivalrous consumption (McNutt, 2000).

Public goods can be classified as:

**Global**, such as biodiversity preservation, climate models explaining climate change and its likely impacts, and Research & Development (R&D) in drought-resistant crops<sup>107</sup>. The large scale of investments required, the nature of benefits from investments (uncertain, typically realised in the long-term, and on a global scale), and the existence of effects that spill over across international boundaries (when investors can not entirely exploit the benefits from their investments), generate a rationale for policy and legal intervention.

**National**, such as infrastructure protection measures, ecosystems and wildlife protection, public health and safety, emergency preparedness and security planning<sup>108</sup>. Different countries have different degrees of exposure, sensitivity and adaptive capacity which determine the urgency with which adaptation is required, and what intervention is needed to address domestic priorities.

**Local**, such as sea walls and barriers to protect specific areas (e.g. the Thames barrier in London). Some regions or areas might be subject to more frequent or severe hazards, or be more vulnerable to future warming scenarios. Local adaptation actions might be provided as club goods under certain circumstances: when the costs and benefits occur locally, and the beneficiaries can be identified and efficiently share the costs. However, the scale of the required investments, information failures, equity considerations or coordination problems might prevent the private sector from adapting in an efficient way, and may call for Government intervention to provide a supportive institutional framework.

## Externalities

Externalities can occur when actions by some individuals result in unintended consequences for other individuals. In the context of adaptation, they occur when adaptive actions generate social costs or social benefits to third parties without compensation or payment taking place between the parties (i.e. markets for such externalities are missing). Negative externalities can be internalised by having prices that reflect the social costs and benefits of people's actions. For example, the price of electricity can make people internalise the negative externality of the resulting carbon emissions. However, other externalities might need to be captured as well. For instance, air conditioning systems used on a large scale contribute to the urban heat island (UHI) effect, with negative effects on air quality which may lead to health and environment impacts<sup>109</sup>.

<sup>106</sup> "A club is a voluntary group of individuals who derive mutual benefit from sharing one or more of the following: production costs, the members' characteristics, or a good characterised by excludable benefits" (Cornes and Sandler, 1996). The exclusion mechanism for these goods needs to be effectively enforced to avoid free-riding, which would undermine the incentive to pay a fee to join the club. Non-excludability is not immutable and may change with technology for example (Robbins, 2005).

<sup>107</sup> There are reasons why R&D may be excludable however. This includes the tacit nature of complex knowledge and existence of intellectual property rights.

<sup>108</sup> National public goods are often non-excludable but only within a country's borders. However, they may lead to positive spillovers that go beyond national boundaries (e.g. ecosystem protection, health).

<sup>109</sup> The term urban heat island is used to describe the dome of warm air that frequently builds up over towns and cities. Among the consequences of UHI effects are increasing discomfort and increases in mortality rates during the summer; and altering the development of clouds, fog, humidity and precipitation.

Adaptive decisions may result in positive externalities (where the social return remains higher than the return that will be captured by private investors). This might be the case when individual decisions generate benefits to other individuals as well, or when the benefits from joint actions are greater than individual actions. For example, a sea wall built by an individual to protect their own property might also protect neighbours' properties.

### A.2 Institutional and regulatory barriers

Individual adaptation actions may be constrained by existing institutional processes and regulatory structures. Some of the existing regulations (e.g. biodiversity, water, and agriculture regulations) which have been designed to achieve policy objectives other than adaptation, will nonetheless have an impact on adaptation decisions. For example, agriculture policies can affect the resilience of the natural environment.

For policy intervention to be as efficient as possible, it is important to understand how climate change might affect sectoral policies and the delivery of policies and programme objectives; where institutional barriers to adaptation lie; and how they can be effectively overcome to obtain the most efficient outcome.

### A.3 Behavioural barriers

Along with market failures, there are other factors which affect the decision making of individuals and firms. A common problem for decision makers is dealing with future uncertainty, and taking inter-temporal decisions which affect present and future utility. Evidence suggests that behaviour patterns often include inertia, procrastination, and implicit high discount rates which may lead to high costs in the long run, and are inconsistent with classic economic models of utility maximisation<sup>110</sup>. For example, O'Donoghue and Rabin (2000) found that when people are faced with more than one option (and in some cases, the more important and ambitious their plans are), they are likely to procrastinate, even if this might result in significant losses of well-being in the future.

When behavioural patterns generate negative externalities, Government intervention may be considered. Behavioural barriers can be the result of people's short sightedness, inertia, or inability to take decisions which are perceived as complex. Whatever the reasons are, individual choices not to adapt today can defer costs to future generations<sup>111</sup>, which might require Government intervention<sup>112</sup>.

The following paragraphs examine the reasons behind observed behavioural patterns such as inertia and procrastination. This will provide insights into understanding why individuals and firms procrastinate or do not take adaptive actions that would be in their interest. Adaptation is the sum of multiple individual decisions, and behavioural patterns will heavily influence autonomous adaptation, and therefore resilience in the UK.

<sup>110</sup> "Economists use the term utility to represent the satisfaction people derive from their consumption activities. The assumption is that people try to allocate their incomes so as to maximise their satisfaction, a goal that is referred to as utility maximisation" (Frank and Bernanke, 2004).

<sup>111</sup> In the form of high costs of refurbishing, maintaining or retrofitting the built stock, for example.

<sup>112</sup> When defining the basis for intervention, Government should investigate whether the problem to be addressed changes in scope or magnitude over time e.g., effects can multiply over generations (HM Treasury, 2003).

## Bounded rationality

For agents to undertake the appropriate level of adaptive action they should be able to acquire and use complex information on climate change, including: probabilistic distributions of climatic hazards and impacts; understanding of the different factors causing them (including non-climate drivers); and predicting how their decisions would affect themselves and other agents. Even when information is available and individuals are motivated to make optimal inter-temporal decisions, the ability to assimilate and use complex data, and solve cost-benefit optimisation problems may be limited.

Uncertainty makes decision-making even more challenging. In the presence of uncertainty, the perceived rather than the actual riskiness of events is likely to drive people's behaviour. The perception of risk can be affected by several factors, including memory and emotions, which may lead to people over-estimating the likelihood of low probability events occurring<sup>113</sup>. In the case of adaptation, people and firms may find it difficult to estimate the timing of climate risks, and therefore the urgency with which they need to adapt. Finally, factors such as habit<sup>114</sup>, cultural transmission, and imitation of others<sup>115</sup> may affect individuals' decisions on adaptation.

## Hyperbolic discounting and time-inconsistency

The way people implicitly discount<sup>116</sup> the future explains behaviours such as procrastination and inertia. An individual's impatience has been found to increase as the time-horizon of payoff shortens, with people tending to attach greater weights to those payoffs which are perceived as relatively more imminent<sup>117</sup>. In other words, the implicit discount rate used by individuals over longer time horizons is lower than the rate over shorter time horizons, i.e. they use hyperbolic discounting. Hence, hyperbolic preferences are time-inconsistent, in the sense that preferences at time  $t$  are inconsistent with preferences at time  $t+1$  (Laibson, 1997). This helps explain why individuals and firms tend to put off investment decisions up to the point when it is no longer feasible or it would be too costly to procrastinate further.

Finally, hyperbolic discounting can affect the incentives for individuals to acquire new information and lead to "strategic ignorance" (Carillo and Mariotti, 2000), i.e. they prefer to ignore information that could increase the risk of withdrawing from a course of action (Frederick *et al.*, 2002).

Adaptation measures may require agents to invest financial resources today in order to protect their assets from climate events with unknown probability distributions, or that might occur in the distant future. Payoffs (including their time-horizon) are therefore highly uncertain. If individuals do not see risks as imminent, they may procrastinate in taking action.

<sup>113</sup> "For example, a recent disaster or a vivid film could seriously distort risk judgement (Kahneman *et al.*, 1982). The authors also stress the role of media coverage in forming people's risk perception.

<sup>114</sup> When faced with complex decisions, individuals are likely to use nonlinear strategies whereby they chose between options by assessing them against threshold goals determined by habit or living standards (see Binswanger, 2008).

<sup>115</sup> Social factors affect decision-making in that people respond not just to the risk itself, but to other people's responses to risk (Kasperson *et al.*, 2003). Dawney *et al.* (2005) showed that people tend to observe the behaviour of others and, if successful, imitate it, especially under ambiguous situations, in crises, and when others are seen as experts.

<sup>116</sup> "Discounting is a technique used to compare costs and benefits that occur in different time periods [...] and is based on the principle that, generally, people prefer to receive goods and services now rather than later" (HM Treasury, 2003).

<sup>117</sup> See, for instance, Ainslie (1975, 1991, 1992), Ainslie and Haslam (1992), Thaler (1991), and Thaler and Loewenstein (1992).

### A.4 Financial constraints, immobility of assets, and other organisational barriers

When adaptive actions have upfront costs, some individuals and firms, particularly low income groups and small businesses, can be financially constrained. This can delay the uptake of adaptive measures or explain the preference for measures which do not have the highest expected net benefits in dealing with the impacts of climate change.

Alongside financial constraints, organisational inertia can result from the gap between the timing of costs and benefits. Given the long-term nature of climate change, the benefits of adaptation decisions may occur beyond the organisation's planning horizon. This favours the use of adaptation decisions with low capital costs and/or immediate benefits, even if other measures would be more cost-effective in the longer-term. For example, using portable air-conditioning units to deal with hotter summers, rather than retrofitting buildings to reduce solar gain.

## Annex B – Range of instruments

There are a range of instruments that the Government could use to support adapting to climate change. These include:

### Direct regulation

This includes regulatory measures such as standards or prohibitions relating to particular processes and technologies.

Standards and prohibitions can help overcome information failures, and prescribe specific methods which align private incentives to the socially optimal level of adaptation. For example, the use of hosepipe restrictions can help to ease water shortages in times of drought. However, high uncertainty and the lack of a common metric of success for adaptation mean that these instruments may lock in practices or technologies which may lead to outcomes that appear to be inefficient as new evidence becomes available – while also creating little incentive for investment in alternative adaptation actions with greater benefits, or investing in R&D.

Other regulatory instruments include regulatory measures such as Planning Policy Statement 25 (PPS 25), which requires regional planning bodies and local planning authorities to prepare and implement planning strategies while accounting for flood risks.

### Market-based (economic) instruments

These instruments use price or other economic variables to create incentives for people and firms to adapt. They include *fiscal instruments*, such as charges, taxes and subsidies; *marketable* (or tradable) *permits*; and other instruments such as licenses and property rights.

Market-based instruments can make individuals and businesses internalise the externality generated through their adaptive actions (e.g., by setting a tax capturing the negative externality); create a price for natural resources (e.g., licenses); or restrict the available quantity of natural resources and use the market principle of scarcity (e.g., marketable permits). Compared to direct regulation, these instruments can lead to efficiency gains, and generate incentives for technology innovation, as well as potential Government revenues. However, this needs to be balanced against the potential transaction costs, for example in terms of obtaining the necessary information to ascertain the level of scarcity necessary for an efficient market of permits.

The most appropriate instrument should be selected with care. For instance, for a tax to be efficient, the value of the negative externality to be corrected has to be known and measurable. In addition, a tax does not necessarily lead to the desired level of externality. When a specific level of externality is required, a quantity-based market instrument (e.g., marketable permits) may be more appropriate.

### Research and monitoring programmes

Research on climate change risks and adaptation technologies have the nature of public goods in that, given their non-rivalrous and non-excludable nature, they are likely to be underprovided by the private sector. Spending programmes on R&D and monitoring would contribute to improving the understanding of climate change risks, reduce information failures, and help the Government define priorities in adaptation.

Instruments under this category would include, for example, spending programmes on climate modelling; R&D of systems to monitor climate change hazards and progress in adaptation; R&D of resilient materials and technologies; research and monitoring of climate impacts on ecosystems; and R&D of climate-resistant crops.

### Information provision and public engagement

A communication strategy for adaptation can contribute to the widespread dissemination of the best information available on climate change risks and adaptation options. This can include guidance, information and awareness campaigns, and systems (e.g. warning systems) to help individuals handle climate risks and cope with the consequences of climate hazards in the most efficient way. These instruments can help overcome problems relating to misaligned incentives (by raising awareness among the public on climate change risks); behavioural and organisational barriers (by providing individuals with information on risks and the time-horizon of events, thus affecting their private discounting); incomplete markets (by providing businesses with the information they need to offer adaptive tools, such as insurance cover); and stimulate R&D of adaptive measures. To be effective in overcoming behavioural and organisational barriers, it is important that information on climate risks and adaptation is as clear and simple as possible, easily accessible, and tailored to the intended audience.

### Investment in infrastructure and other adaptive actions

Adaptive actions include investing in new infrastructure for adaptation, or enhancing the resilience of the existing stock. These include, for example, improving the resilience of roads and railways; investing in large-scale infrastructure such as sea walls, coastal defences and flood barriers; or investing in green infrastructure for adaptation. To ensure the best use of public finances, different options for funding and delivering infrastructure services and other adaptive actions can be investigated. For example, the Organisation for Economic Co-operation and Development (OECD, 2008) suggested that responsibility for adaptation could be built into contracts with private operators.

### Redistributive measures

Redistributive measures include compensation or credit schemes which look at correcting for the distributional impacts caused by climate change. These may be used to help the most vulnerable adapt, or ensure their vulnerability is not exacerbated by climate change. The existing trade off between equity and efficiency in adaptation requires redistributive measures to be used carefully, and with a view to ensuring they do not weaken the incentives created by other measures or encourage moral hazard.

### Institutional reforms

When existing programmes and policies prevent adaptation from being undertaken at the appropriate level, intervention might entail reforming existing regulation. This should be pursued with a view to ensuring climate change risks are accounted for across sectoral policies (e.g. water, agriculture, biodiversity) in a coherent and effective way.

Some reforms can also contribute to reducing transaction costs and building adaptive capacity. For instance, institutional reforms could be introduced to improve communication and co-operation between different stakeholders at different levels of decision making (national, regional and local).

## Annex C – Policy appraisal in the presence of uncertainty: the Real Options Approach<sup>118</sup>

A common issue for both private and planned adaptation lies in dealing with uncertainty, and defining the timescale and nature of adaptation responses in the face of a continually changing environment. The design of policies in supporting adaptation is, therefore, particularly challenging. Intervention (in particular delivering adaptive actions) might require large capital investments in infrastructure for which cost-effectiveness is likely to become clearer as uncertainty reduces over time or better information is gathered. For example, protective measures might be effective today, but not be as effective in the future if climate pressures are greater than expected. In the presence of uncertainty, current investments might result in irreversible costs or costly retrofits in the future.

Adaptation is intrinsically a dynamic process. For planned adaptation to be cost-effective in the long-run, it should be flexible or able to incorporate learning potential as far as possible. At the same time, policies need to provide individuals and businesses with the stability necessary to make investment decisions. Therefore, Government intervention should be the result of balanced decision making where flexibility and policy certainty are traded-off in a sensible way.

The Green Book appraisal framework provides policy makers with several tools for addressing uncertainty. The standard approach to appraisal involves defining different policy intervention options; weighting the costs and benefits of each option according to the probability of occurrence; discounting them by using a discount rate of 3.5% (which is reduced for projects with a schedule beyond 30 years); and summing them to obtain comparable Net Present Values (NPVs). Sensitivity analysis is also carried out to test the assumptions about costs and benefits. Once implemented, policy measures are monitored and, if necessary, refined after three years.

The Government's standard appraisal framework addresses issues of uncertainty through discounting and risk assessment. To incorporate flexibility into investment decision making, the recent Green Book supplementary guidance on adaptation recommends the use of the Real Options Approach (ROA). This approach allows the inclusion of incorporating flexibility as part of the costs of investment (i.e. as an opportunity cost). Pindyck (1989) and Dixit and Pindyck (1994) applied ROA to explore firms' optimal investment decisions under uncertainty. Their analysis concentrated on the value of waiting when:

- the investment is irreversible or implies large sunk costs;
- there is uncertainty about the payoffs of the investment;
- the investment can be delayed; and
- more information about payoffs becomes available during any waiting period.

Pindyck (1989) showed that under these conditions the NPV rule is invalidated. Unlike the standard NPV approach where the probabilities of costs and benefits are taken as given over the whole time of the appraisal, the ROA incorporates what may be defined as uncertainty relaxation or dissipation points, after which a programme or project will be continued, stopped or changed so as to generate the highest benefits or minimise losses<sup>119</sup> in the light of new information.

<sup>118</sup> Further information and applied examples of the Real Options Approach can be found in the Green Book Supplementary Guidance for Adaptation in appraisal, available at: [http://www.hm-treasury.gov.uk/data\\_greenbook\\_sugguidance.htm#Adaptation\\_to\\_Climate\\_Change](http://www.hm-treasury.gov.uk/data_greenbook_sugguidance.htm#Adaptation_to_Climate_Change)

<sup>119</sup> The value at the date of the original investment is given by the probability that the manager will decide to continue the project multiplied by the expected (discounted) value of profits that are enjoyed if the project is continued. Thus the value of delaying the decision (i.e. the value of new information) is given by the expected value of losses multiplied by the probability of losses.

Having a ‘real option’ means there is the possibility for a certain period to choose either for or against an action, without the decision being initially binding. In practice, the ROA incorporates a dynamic learning mechanism which provides the opportunity to phase investments and stage key decisions, to then assess the costs and benefits of options such as<sup>120</sup>:

- investing now and make follow-up investments later if the original project is cost-effective (a growth option);
- abandoning the project if losses outweigh the benefits (an exit option); and
- waiting and learning before investing (a timing option).

The ROA is readily applicable to a number of adaptation measures. For example, to reduce the impact of flooding, rather than investing in high protective barriers immediately, a real option could be building only the base of a wall (or low walls) today, with the option of raising them in the future, if and when necessary. Another example could be in the context of the built environment. Buildings are long-lasting durable assets, and the building stock in the future will include some of current stock and some future stock. Designing in flexibility can help to extend the useful life of the building stock. Investment in R&D should also be considered as a possible option to be pursued prior to other investment decisions in physical assets.

Despite its attractiveness, the application of ROA poses some practical challenges. These include:

- **The stochastic nature of climate patterns.** Uncertainty may not be significantly reduced in the future because of the inherently non-linear nature of climate hazards and impacts.
- **Irreversibility.** Climate change might result in irreversible damage. Due to the uncertainty over tipping points (after which climate stresses have irreversible consequences), and low-probability catastrophic events, delaying decisions might lead to irreversible damage.
- **Timing.** To be effective, the ROA requires a good understanding of when the cut-off points will occur. An inaccurate estimate of these points would ultimately affect the outcomes of the appraisal.
- **Costs of information.** Gathering information incurs a cost, and given the high level of uncertainty around climate change, significant investment in information gathering does not ensure the complete resolution of uncertainty.

Allowing for these caveats, the conceptual approach of real options is applicable to investment appraisals regarding adaptation measures, including the evaluation of complex and long term adaptation projects<sup>121</sup>. The ROA is a useful analytical tool that can enrich standard NPV analysis<sup>122</sup>. The extent of benefits for ROA will depend upon the type of investment decisions to be made. The supplementary Green Book guidance on adaptation provides a 1-page filter to identify where the ROA will be most useful.

<sup>120</sup> See Munn (2006), Swartz and Trigeorgis (2004).

<sup>121</sup> An example is provided by the Thames Estuary 2100 (TE2100) project by the Environment Agency, which develops a tidal flood risk management plan for the Thames estuary for the next 100 years. The TE2100 strategy incorporates flexibility to account for uncertainty in the effects of climate change. It identifies options to cope with different levels of sea level rise, and the thresholds at which they will be required. The options were designed so as to leave major irreversible decisions as far as possible into the future to make best use of the information available (Defra and HM Treasury, 2009).

<sup>122</sup> Vadoros and Pantouvakis (2006) show that ROA represents a better analytical approach to evaluating Public Private Partnership (PPP) or Private Financial Initiative (PFI) projects.

# Glossary

**Adaptation** is defined by IPCC (2007) as “adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities.”

**Adaptive capacity** is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. In social systems, adaptive capacity is determined by factors such as economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit and Pilifosova, 2001; Yohe and Tol, 2002).

**Climate change** refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer – the World Meteorological Society uses 30 year time periods to describe climate).

**Exposure** is the nature and degree to which a system is exposed to significant climatic variations.

**Hazards** are defined as physical manifestations of climatic variability or change, such as droughts, floods, storms, episodes of heavy rainfall, long-term changes in the mean values of climatic variables, potential future shifts in climatic regimes and so on (Brooks, 2003). A hazard should be thought as a source of danger, which might have an impact on human and natural systems, depending on their exposure, sensitivity and adaptive capacity.

**Likelihood** is the probability of an outcome occurring.

**Mitigation** is defined by IPCC (2007) as an anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.

**Resilience** is the degree to which a system can absorb disturbance and still return to its pre-disturbance steady state (Holling, 1986 and Gunderson *et al.*, 1995). The Resilience Alliance<sup>123</sup> defines “resilience” as a property of social-ecological systems with three defining characteristics: a) the amount of change the system can undergo and still retain the same controls on function and structure; b) the degree to which the system is capable of self-organisation; and c) the ability to build and increase the capacity for learning and adaptation.

**Risk** is defined here as a combination of the probability of an event and its consequences, with several ways of combining these two factors being possible (Defra, 2009).

**Sensitivity** is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (IPCC WG2, 2001). The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea level rise).

**Vulnerability** is defined as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity and adaptive capacity.

<sup>123</sup> <http://www.resallianceresilience.org>

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