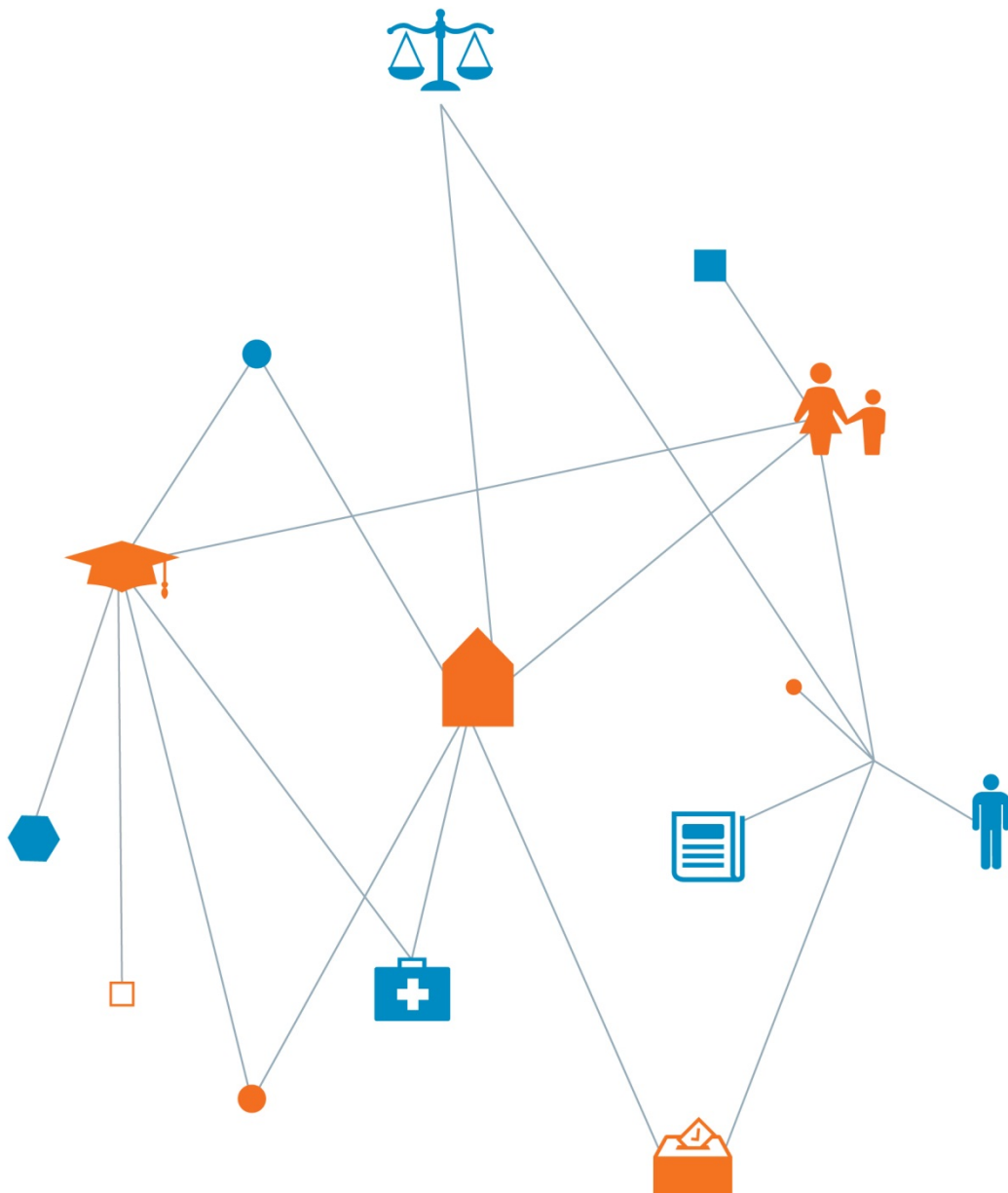




Economics and Private Sector Professional Evidence and Applied Knowledge Service (EPS PEAKS)

Literature Review

Understanding the Patterns of Climate Resilient Development





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Knowledge Service (EPS PEAKS)**

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Understanding the Patterns of Climate Resilient Development

Department for International Development (DFID)

Understanding the Patterns of Climate Resilient Development: a
Literature Review

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List of abbreviations

BCCSAP	Bangladesh Climate Change Strategy and Action Plan
CPI	Consumer Price Index
CRED	Centre for Research and Epidemiology of Disasters
CRGE	Climate Resilient Green Economy
DFID	Department for International Development
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Risk Reduction and Recovery
GMM	Generalised Method of Moments
IPCC	Intergovernmental Panel on Climate Change
NAPA	National Adaptation Programme of Action
NGO	Non-Governmental Organisation
NSDS	National Sustainable Development Strategy
OPM	Oxford Policy Management
PSNP	Productive Safety Net Programme
R&D	Research and Development
OECD	Organisation for Economic Co-operation and Development
UN	United Nations
UNISDR	United Nations International Strategy for Disaster Reduction
USD	United States Dollar
WIDER	World Institute for Development Economics Research

Executive summary

Overview

The UK Department for International Development (DFID) has worked to link adaptation and resilience in its work on climate change. Its work recognises that vulnerability and responses to climate change depend to some degree on developing countries' structures and patterns. Oxford Policy Management (OPM) carried out a literature review to assess the evidence for this line of thinking. The review covers the main findings, gaps and future prospects of the literature published since 2004. Specifically, the review examines four research questions, each of which has its own rationale, hypothesis and approach:

- (i) **Question:** Is there evidence that weather changes and climate shocks have a negative impact on economic growth?

Rationale: DFID will be able to justify the shift toward more climate-resilient development.

Hypothesis: Weather changes and climate shocks have a negative impact on economic growth in both the short and the long run.

Approach: Widely recognised sources, academic literature and grey literature are reviewed.

- (ii) **Question:** Do weather-related shocks that have an impact at the micro level translate to the macro level and vice versa?

Rationale: DFID will be better able to identify ways to support climate-resilient development.

Hypothesis: Weather-related shocks and trend changes that have an impact on the micro-economy can add up to macroeconomic impacts (and vice versa) because the economy is full of interlinked systems and networks.

Approach: The concepts discussed in the literature are analysed, along with their limitations.

- (iii) **Question:** Are there some patterns of development that increase or reduce the vulnerability of an economy to climate change?

Rationale: DFID will be better able to offer policy advice on climate-resilient development.

Hypothesis: There are some patterns of development that increase the vulnerability of an economy to climate shocks, and there are some that build resilience to deal with shocks (and, potentially, future trends).

Approach: Three development patterns are reviewed in greater detail.

- (iv) **Questions:** Is it possible to shape patterns of development using particular policies?

Rationale: DFID will be better able to offer policy advice and to determine areas where future research is needed.

Hypothesis: It is possible to shape patterns of development using policy levers. Some policy levers are more effective than others in shaping patterns toward resilience building.

Approach: Two countries' responses to climate change are assessed.

Research areas

1. Is there evidence that weather changes and climate shocks have a negative impact on economic growth?

Hypothesis 1 is: ‘Weather changes and climate shocks have a negative impact on economic growth in both the short and the long run.’ The studies related to this hypothesis use several econometric techniques. One of the most common involves use of cross-sectional data; however, a limitation of this method is that there is little spatial variation in climate. Panel (multidimensional) methods are also frequently used, and are able to identify the effects of climatic variation on economic outcomes.

As for data sources, studies often make use of the Emergency Events Database (EM-DAT), which is based on data reported by countries. There are several methodological drawbacks to EM-DAT that may bias results: underreporting of the impact of disasters in wealthier countries, lack of data on disaster magnitude, possible correlation between variables, and omitted variables. The other main types of weather data used in econometric studies are ground station, gridded, satellite and reanalysis data.

Authors tend to use a neoclassical growth model to theorise the effects of climate change on developing countries’ growth. According to this framework, climate change can influence drivers of growth, can lead to uneven growth, or can divert resources that could have been used to stimulate growth. However, the literature neglects some of the main drivers of growth identified in empirical studies.

The empirical studies reach several main findings. Weather variability and natural disasters are generally found to affect economic growth in developing countries more than in developed countries. Economic growth is considered more susceptible to natural disasters in countries with small economies or with limited economic sectors. There is mixed evidence as to whether disasters usually lead to a short-term decline in economic growth. Finally, climate change, which tends to increase poverty and inequality, is found to disproportionately affect the marginalised.

While most empirical studies find that weather variability is related to lower GDP, as measured in different ways, exceptions make it impossible to generalise. This is also the case with the relationship between weather variability and growth. However, there is abundant evidence of the negative impact of climate change on livelihood assets. These assets encompass natural, physical, financial, human, social and cultural types. Evidence also points to climate change influencing livelihood trajectories and dynamics, as well as increasing multidimensional inequality and vulnerability. There is less clarity about whether climate change affects poverty dynamics, poverty traps or critical thresholds. Risk is another variable explored in the literature.

Overall, there are two main gaps in the literature. First, most studies focus on the short run and there is scarce evidence on the impacts of weather variability in the long run. There are some fundamental challenges that need to be taken into account and addressed in models when moving from the short to the long run. This is crucial to assessing Hypothesis 1.

Second, most evidence looks at the direct impacts of weather variability on the economy. However, the measurement of indirect impacts has been less explored and is also much more challenging. Further empirical research is needed in this area.

2. Do weather-related shocks that have an impact at the micro level translate to the macro level and vice versa?

Hypothesis 2 is: ‘Weather-related shocks and trend changes that have an impact on the micro-economy can add up to macroeconomic impacts (and vice versa) because the economy is full of interlinked systems and networks.’ While this hypothesis makes intuitive sense, the literature does not strongly support or refute it. A conceptual model illustrating how this hypothesis might be borne out examines transmission effects from the micro to macro level. This model includes variables representing the initial impact of a disaster, possible responses and, consequently, potential sectoral and macroeconomic effects.

Some studies reveal underexplored factors when measuring the impacts of weather variability on the economy. This includes strong evidence that both direct and indirect losses are significant, although the latter are less studied. There are several approaches to measuring the impacts of weather variability on the rest of the economy, as well as on economic growth and development. These include general equilibrium models, sector-scale interactions, econometric studies and simulation models. However, these approaches have limitations and differing assumptions, which makes it difficult to reach overarching conclusions.

Hallegate (2014) and Henriet et al. (2012) have addressed the need for measurement work by developing a conceptual model founded on the notion of economic resilience. According to their model, welfare disaster risk can be mitigated by less exposure or vulnerability of people and assets, or by more macroeconomic or microeconomic resilience. The model differentiates between asset losses and output losses (income losses), although output losses can be challenging to measure using classical economic indicators.

Given the dearth of conclusive evidence for or against Hypothesis 2, more research on this area is needed. Of particular benefit would be empirical work on whether micro effects contribute to macro effects and vice versa. In addition, output losses and the overall impacts of uninsured risk on the poor should be explored further.

3. Are there some patterns of development that increase or reduce the vulnerability of an economy to climate change?

Hypothesis 3 is: ‘There are some patterns of development that increase the vulnerability of an economy to climate shocks, and there are some that build resilience to deal with shocks (and, potentially, future trends).’ Evaluating this hypothesis is important due to the need to understand the macro-level impacts of climate change and adaptation, to achieve progress in adaptation, and to prevent patterns of development from increasing vulnerability to climatic hazards.

While the term ‘patterns of development’ is defined in varying ways, the economics literature contributes to the discussion by responding to key questions about definitions of vulnerability and exposure, the relationship between poverty and vulnerability, means of achieving poverty reduction, factors of economic growth, the effects of economic growth on vulnerability, and the relationship between economic growth and inequality. Patterns of development in the context of climate change resilience include geographical, sectoral and distributional types; DFID agreed that these particular patterns would be the focus of our literature review.

Reviewing the evidence base by particular patterns of development, it is clear that geographical patterns are implicated in vulnerability. For instance, economic development in hazardous zones, such as flood-prone areas, increases the vulnerability and exposure of assets to climate risks.

There is country-level evidence of this, as well as for the link between sectoral patterns of development and resilience. Agriculture is an example of a sector where this link can be seen. Agriculture is highly susceptible to climate risks, with effects on one part of the supply chain leading to impacts on other parts, and these risks are particularly prominent in less-developed economies. Finally, the picture is a bit more complicated for distributional patterns of development. While there is evidence that poverty and inequality, for example in the form of illiteracy, increase susceptibility to climate change, there is no single conceptual framework that can account for the dynamic landscape of social relations and the external structures and events that affect them.

The development pathway influences whether economic development facilitates or hinders adaptation. In this underdeveloped area of research, the analyses that do exist have focused on estimating the economic costs of climate shocks, as well as the potential costs and benefits of adaptation possibilities. While economic development is generally considered crucial to reducing vulnerability to climate change, it can sometimes increase vulnerability, for instance by increasing the cost of climate protection. Therefore, growth and development are not sufficient for climate resilience, and the need for adaptation remains.

Clearly, more research is required in these areas. To increase understanding of the patterns likely to promote climate-resilient development, case studies would be a good starting point for research. We recommend that these case studies analyse how a country's vulnerability has been affected by particular patterns, the likely influence of climate change on such patterns, and the dynamics of the shift to more climate-resilient development.

4. Is it possible to shape patterns of development using particular policies?

Hypothesis 4 is: 'It is possible to shape patterns of development using policy levers. Some policy levers are more effective than others in shaping patterns toward resilience building.'

Incorporation of climate resilience into national development planning, which takes the form of enhancing adaptive capacity or addressing climate exposure and vulnerability, is relatively new. Thus it is unclear what the best method to achieve this policy integration would be. From a policy-making perspective, this is the most significant research area covered by our literature review.

Due to the limited existing evidence, we have taken a case study approach to testing Hypothesis 4. While recognising the many variations across countries' climate change-related circumstances, and stressing the difficulty of reaching conclusions about such recent developments, we examine the cases of Ethiopia and Bangladesh.

Ethiopia is extremely vulnerable to climate change impacts, primarily because of the economy's dependence on agriculture. While growth-focused poverty eradication is at the top of the development agenda, climate change is an increasing area of focus. Several measures have sought to incorporate climate change into the development agenda and ensure social protection in light of climate threats.

Bangladesh is also at great risk of negative climate change impacts, with its susceptibility to natural disasters and its rural livelihoods that are sensitive to the weather. Following on decades of experience of disaster risk reduction and management, climate change has been incorporated into Bangladesh's national development strategy.

The cases of Ethiopia and Bangladesh attest to the need to mainstream climate change into national development planning. There should be specific policies that incorporate both mitigation and adaptation, in concert with other policies on disaster risk management, social protection and

other areas. These policies should be generated in a manner that is participatory as well as strongly evidence-based.

These cases show the utility of the case study approach in exploring how patterns of development can be shaped using particular policies. Case studies can be used as a jumping-off point to identify patterns and advise countries on climate-resilient policy-making. We consider these the most important items on the climate-resilient development agenda, given their crucial importance to policy-making.

Conclusion

This literature review had two main objectives: identifying recent evidence that would help to assess the four hypotheses and identifying gaps in the literature on climate-resilient development.

We found a great deal of research related to Hypothesis 1: 'Weather changes and climate shocks have a negative impact on economic growth in both the short and the long run.' This body of research has established that: weather variability affects economic growth in developing countries more than in developed countries; economic growth is at greatest risk from climate change in small economies; it is unclear whether disasters tend to lead to short-term declines in economic growth; and disadvantaged people are disproportionately affected by climate change, which exacerbates poverty and inequality. The two primary gaps in the literature relate to the impacts of weather variability in the long run and the measurement of indirect impacts of weather variability on the economy.

It has not been possible to verify Hypothesis 2: 'Weather-related shocks and trend changes that have an impact on the micro-economy can add up to macroeconomic impacts (and vice versa) because the economy is full of interlinked systems and networks.' While there is some conceptual work pertaining to this hypothesis, empirical evidence is sorely lacking. In particular, further research is needed on the relationship between micro and macro effects, the macro-level impacts of uninsured risk on the poor, and output losses caused by natural disasters.

We have focused on geographical, sectoral and distributional patterns when analysing Hypothesis 3: 'There are some patterns of development that increase the vulnerability of an economy to climate shocks, and there are some that build resilience to deal with shocks (and, potentially, future trends).' We have used case studies to determine how specific configurations of development patterns affect a country's climate change vulnerability and policy responses. We recommend that other researchers also adopt the case study approach, which should emphasise the dynamics of the shift toward more climate-resilient development.

Finally, the most fundamental policy-related hypothesis is Hypothesis 4: 'It is possible to shape patterns of development using policy levers. Some policy levers are more effective than others in shaping patterns toward resilience building.' It is difficult to reach conclusions about the effects of policy levers based on our limited case studies. Nevertheless, these cases demonstrate the necessity of mainstreaming climate change into development policies at a country level, in a manner that is holistic, participatory and evidence-based. This is the most urgent area of research. Our recommendation is that researchers use case studies to determine patterns and make suggestions on climate-resilient development planning.

1 Background: why is looking into climate-resilient patterns of development important?

There is a relatively recent move toward adopting resilience as a core approach that embraces different areas of work that can be complementary. These include climate change adaptation, disaster risk reduction, social protection, working in fragile contexts and humanitarian preparedness and response (DFID, 2011). In this context, this study is part of broader work underway in DFID to rethink adaptation to climate change and link it with work on resilience.

Vulnerability to climate change is not just a function of the severity of the events themselves but also of the exposure and sensitivity of people and the economy to those events, as well as of the economy's capacity to adapt (Arndt et al, 2012). The patterns of socioeconomic development that a country chooses will in turn shape exposure, sensitivity and adaptive capacity. For example, the impact and cost of flooding is greater where people or businesses are located on flood plains. This is important when thinking about adaptation to climate change because it means that developing countries are not just passive victims of climate hazards. Rather, to the extent to which they change their patterns of development, they may be able either to reduce the costs of the impacts of climate change or, in some cases, even avoid them.

This way of thinking also requires us to understand adaptation and resilience as something far wider than just applying to households, communities or firms. There will clearly be some climatic shocks or trends that will exceed the adaptive capacity of a community or even a town. Resilience will come from a wider set of systems, networks, response plans, and institutions.

1.1 What is the rationale for this study?

The main objectives of this study are to look into the existing evidence for:

- (v) The links between current weather variability and economic growth and development. **Why?** To help DFID to make the case as to why policy-makers should be interested in moving toward patterns of development that help build resilience to a changing climate.
- (vi) Whether there some patterns of development that increase/decrease vulnerability to the impacts of climate change. **Why?** To help DFID to better identify ways to support countries moving to more resilient patterns of development.
- (vii) Whether there are examples of policies and other responses that have proved effective in shifting people toward more resilient patterns of development, and what the factors behind their successes are. **Why?** To help DFID to start to form ideas about what policy advice can help countries develop in a more resilient way.
- (viii) What the major gaps are in the evidence and practice on climate-resilient development. **Why?** To identify areas for future research to better inform points i, ii and iii above.

1.2 The research hypotheses

The above issues will be addressed by looking into existing evidence against four research hypotheses:

1. **Hypothesis 1.** Weather changes and climate shocks have a negative impact on economic growth in both the short and the long run.
2. **Hypothesis 2.** Weather-related shocks and trend changes that have an impact on the micro-economy can add up to macroeconomic impacts (and vice versa) because the economy is full of interlinked systems and networks.

3. **Hypothesis 3.** There are some patterns of development that increase the vulnerability of an economy to climate shocks, and there are some that build resilience to deal with shocks (and, potentially, future trends). What are they?
4. **Hypothesis 4.** It is possible to shape patterns of development using policy levers. Some policy levers are more effective than others in shaping patterns toward resilience building.

1.3 Our methodological approach

The scope of this study is extremely broad, as providing answers to each of the questions involved has been a focus of a great deal of research over several decades. This study aims to identify the main areas of focus in recent literature (since 2004), outlining the main findings and the gaps identified and providing a foundation for future work. As such, the reader should bear in mind that the following approach has been followed.

1. For Hypothesis 1. There is a broad body of literature studying this hypothesis. Our literature review assessing this hypothesis comprises three parallel phases: (i) consulting with widely recognised sources (including major reports such as the World Development Report and the Intergovernmental Panel on Climate Change (IPCC) reports and academic journals such as the *Journal of Economic Literature*); (ii) conducting a semi-systematic review of the academic literature; and (iii) looking at the grey literature from the websites of donors, NGOs and international organisations working in relevant topics. More details on this methodology are given in Annex A.
2. For Hypothesis 2. Given the theoretical importance of this issue and the limited existing empirical evidence that has so far addressed it, this literature review focuses on studying the conceptual elements that identify gaps and propose ways to improve the existing research.
3. For Hypothesis 3. This hypothesis poses a challenge as it is a very new area of research and is therefore understudied. However, there are relevant learnings that can be drawn from other areas of research. In order to do this, this literature review is narrowed down to three particular patterns of development agreed with DFID and presents examples that are relevant for the case of climate change.
4. For Hypothesis 4. This is a fundamental question for policy-makers and we propose that this area of research should be the main focus of future work. We look into what two countries are currently doing in order to shift toward more climate-resilient patterns of development. However, it is still too early to know whether these programmes have been successful.

1.4 The structure of this report

As a general approach, each of the four hypotheses is reviewed and presented in the following way:

1. What is the theory behind the hypothesis statement? A quick review of the conceptual literature is presented for each case, when relevant. This will inform the rationale of why we are looking into each of these questions.
2. What are the areas of evidence to support or contest it? A more thorough review of the literature looks at the empirical evidence used to support or refute each hypothesis where available.

3. Based on analysis of that evidence – what next? Following the findings, the report presents suggestions of gaps and recommendations for further work.

The following four chapters present the evidence for each of the four hypotheses, and they are then followed by a chapter presenting our main conclusions. We provide details of the search methodology used for the literature review and a summary of the main papers identified in our search in annexes A and B.

1.5 Overview of the research team

The research team was led by Dr Marcela Tarazona, the Senior Consultant and Technical Lead of the Climate Change Portfolio at OPM. The team also included two further technical specialists on climate change – Federica Chiappe (Consultant at OPM) and Chris Hearle (Assistant Consultant at OPM).

2 Is there evidence that weather changes and climatic shocks have a negative impact on economic growth?

We first introduce the research hypothesis and its rationale, followed by a discussion of the theoretical and empirical findings. The section concludes with a reflection on methods and data, followed by specific recommendations for further research. The search methodology used to address Hypothesis 1 can be found in Annex A. Summaries of the main academic papers identified in this search appear in Annex B.

2.1 The hypothesis and rationale

This section explores the following hypothesis:

‘Weather changes and climate shocks have a negative impact on economic growth in both the short and the long run’

Our central aim in this section is to review recent academic literature studying the relation between current weather variability and patterns of economic growth. Our review focuses on studies looking at historical data and does not include works estimating the future impacts of climate change. By answering this question, we aim to identify reasons why policy-makers should be interested in moving toward more resilient patterns of economic growth. Our study has a particular emphasis on developing countries, but in some cases that we consider relevant we also include findings from more developed countries.

2.2 The theoretical background

We begin this section with a brief overview of the theory around the mechanisms through which weather variability has an impact on economic growth.

According to Vivid Economics (2010), climate change and economic growth are likely to be linked in developing countries in three main ways:

1. Climate change will affect a number of potentially important drivers of economic growth, including capital accumulation, infrastructure provision, human health, and productivity growth in the energy and agriculture sectors. These impacts also potentially put a strain on governance and institutions;
2. Climate change is also likely to alter the composition of growth because of its uneven sectoral, geographic and social impact; and
3. Resources that could have been used elsewhere to stimulate growth will be used in efforts to adapt to climate change.

The majority of studies on the impact of climate change on growth use a neoclassical growth model (see Fankhauser and Tol, 2005). Climate change enters the models through the impact on the exogenous variables of population growth, productivity levels, technological progress, capital depreciation, time preference, and form of the production function.

The long-run equilibrium rates of growth of consumption, capital, and output per head are equal to the rate of technical progress, so the impacts of climate change on productivity growth are important (Vivid Economics, 2010). Climate change can have an impact on the medium-run rates

of growth through changes in the equilibrium capital–labour ratio (Vivid Economics, 2010). Vivid Economics (2010) also report that the impacts of climate change on output through reduced growth are larger than direct ‘level’ effects.

However, some of the key drivers of growth emphasised in many empirical growth studies (such as increasing returns to scale, market size, human capital accumulation, R&D etc. from Barro and Sala-i-Martin, 1995) are neglected. There have been some attempts to ‘enrich’ the basic model; for example, Fankhauser and Tol (2005) treat climate change as reducing the output available for investment in human capital or R&D, thereby reducing productivity growth.

2.3 The existing evidence base

2.3.1 Key findings of the empirical evidence

Most of the papers identified in our search analyse the relation between weather variability and economic growth in the very short term (less than five years from the climatic shock or natural disaster). Studies mainly look into direct impacts and do not include indirect ones (see Section 3.4 for a detailed discussion on this point), which may lead to underestimates. Most studies were multi-country studies (as opposed to single country studies). A significant number of papers looked at the research objective from a sectoral perspective (and not purely from a macro or micro perspective).

Common methodologies include using a time-span of five years to measure the impacts of climatic shocks, and to use the counterfactuals to predict what would have happen to economic growth had the shock not had taken place (see Hochrainer, 2009; Cavallo et al., 2011).

Key findings are:

1. Climate shocks and natural disasters are generally found to affect economic growth in developing countries more strongly than in developed countries (Rasmussen, 2004; Loayza et al., 2009; Noy, 2009; Fomby et al., 2013).¹
2. Economic growth is more vulnerable to natural disasters in small economies or countries where there are only a few large sectors (Heger et al., 2008; Noy, 2009). There is some discussion about whether it is the physical shocks (damages to capital) or the human shocks (through lives lost and affected) that cause a lowering of economic growth.²
3. There is contrasting evidence as to whether disasters commonly cause a short-term decline in economic growth (Benson and Clay, 2004) or whether they do not (Cavallo et al., 2011). In the case of the latter, in fact there is evidence that smaller but still large natural disasters have no discernible effect on output in the short or in the long run.
4. Socially and economically disadvantaged and marginalised people are disproportionately affected by climate change and climate change generally contributes to increased poverty and inequality (IPCC, 2014).

¹ An exception is Cunado and Ferreira (2011), who state that flood shocks tend to have a positive average impact on GDP growth for developing countries only.

² Noy (2009) notes that there are macroeconomic costs when disasters are measured in terms of the amount of property lost, but there are no macroeconomic costs if disasters are measured as lives lost and affected. In Vietnam, this conclusion holds steady with even disasters that cause higher levels of damage to capital boosting the economy in the short run (see Noy and Vu, 2010). However, the opposite is true from a panel study of 98 countries conducted by Noy and Nualsri (2007), who conclude that negative shocks to stocks of human capital lower growth rates but shocks to stocks of physical capital have no statistically observable effect.

2.3.2 The evidence on the relation between macroeconomic variables and weather variability

In this section we discuss in more detail the empirical evidence found on the existing relation between macroeconomic variables and variables measuring weather changes. We split the evidence into two main groups: first, we consider studies that explore the relation between different measures of GDP and weather variability and, second, those that analyse the relation between growth rates and weather changes.³ However, it is important to bear in mind that, given that the climatic change happens in parallel with many other non-climatic changes, causality cannot be established.

Box 2.1. GDP and growth in the short and long run

- Measuring the relation between GDP and weather variability can give us an indication of the particular direction of the effect of a climatic shock on the economy at a particular moment in time.
- Measuring instead the relation between growth rates and weather changes indicates the effect of the climate shock on economic growth for a given period.
- We have defined long run to mean those impacts that are longer than 30 years and have taken short-run impacts to be those lasting less than 30 years.

What is the relationship between weather variability and different measures of GDP?

There is a broad body of literature looking at the relation between GDP measures and weather variability. Despite most studies suggesting that the relation is negative (i.e. weather changes are related to reductions of GDP), it is not possible to generalise this finding as in most cases there are some exceptions:

- *GDP and temperature*: most studies find evidence that there is a negative relation between temperature changes and GDP, both in the short and long run.

Hsiang (2010) links the response of GDP to increased temperature to the response of labour productivity to high temperatures. Nordhaus (2006) discovered that there is a strongly positive relationship between the temperature and GDP of a country. This conflicts with the conclusion of Dell et al. (2012), who claim that higher temperatures reduce agricultural output and industrial output. Hsiang (2010) concludes that higher temperatures reduce GDP in contrasting ways: output losses in non-agricultural production are higher than in agricultural production.

Variations in temperature can cause increased incidence of disease, which has a knock-on effect on GDP rates. Blanco et al. (2009) found that, in Colombia, the temperature variable was significant in explaining increases in cases of dengue fever. Likewise, increases in rainfall in Colombia generate increased rates of malaria incidence. The direct and indirect unit costs of malaria and dengue cases are US\$ 2.5 and US\$ 7.6 million for the 50- and 100- year scenarios respectively.

Projections by Mideksa (2010) suggest that climate shocks in Ethiopia will cause a redistribution of output in sectors with a strong linkage to the rest of the economy. It will

³ There is a broad body of literature studying the impact of climate change on other variables such as health that we have not reviewed in this study.

particularly reduce agricultural production and output in sectors linked to the agricultural sector, which will reduce Ethiopia's GDP by about 10%.

Schlenker and Lobell (2010) observe the long-term impacts of temperature and weather measurements, taken from 1961 to 2006, on aggregate production changes in sub-Saharan African crops. Given the importance of the agricultural sector in this region, this can have substantial consequential effects in relation to GDP. The authors note that, by 2050, the mean estimates of aggregate production changes in sub-Saharan Africa are -22%, -18%, -17%, -17% and -8% for maize, groundnut, sorghum, millet and cassava respectively. In all cases except cassava there is a 95 percent probability that damages exceed 7% and a 5% probability that they exceed 27%.

- *GDP per capita and temperature*: the majority of the literature suggests there is a negative relation between GDP per capita and temperature variations.

For all 'large countries' measured at a 1°C latitude and longitude scale, Nordhaus (2006) has found that there is a negative relationship between temperature and GDP per capita. This is a similar finding to Dell et al. (2012), who report that higher temperatures 'substantially reduce' log per capita GDP in poor countries.

Dell et al. (2012) state that changes in precipitation have relatively mild effects on log per capita GDP in rich and poor countries. However, using a regional perspective, Barrios Cobos et al. (2008) discover that, while rainfall has been a significant determinant of poor economic growth for sub-Saharan Africa, this has not been the case for other countries in the Global South.

- *GDP per worker and temperature*: there is a significant negative relationship between income and temperature when looking between countries and within countries, although the relationship is substantially smaller in magnitude within countries than across countries. However, cross-country context adaptation offsets approximately half of the negative effects of higher temperatures (Dell et al., 2009).
- *GDP and natural disasters*: evidence suggests that the relation between disasters and GDP is negative.

Comparing estimated with observed GDP, Hochrainer (2009) finds that natural disasters on average lead to negative consequences, leading to a median reduction of GDP of about four percentage points (of baseline GDP) to year five after the event. Although the negative effects may be small, they can become more pronounced depending mainly on the size of the shock. In China, Vu and Hammes (2010) discover that there is a negative impact from the number of people killed on GDP.

After tropical cyclones GDP declines, relative to its pre-disaster trend, and does not recover within 20 years. A 90th percentile event reduces per capita incomes by 7.4% two decades later, effectively undoing between three and seven years of average development (Hsiang and Jina, 2013). In countries with regular or continuous exposure to disasters, they can have a dramatic influence in regard to long-term development. Linking these results to projects of future cyclone activity, Hsiang and Jina (2013) estimate that the cost of climate change are approximately US\$ 9.7 trillion larger than previously thought. Floods are also associated with a negative influence on GDP (Brown et al., 2010).

- *GDP per capita and natural disasters*: natural disasters negatively affect GDP per capita (Heger et al., 2008; Raddatz, 2007; Raddatz, 2009). Specifically, Raddatz (2007) found that floods, droughts, extreme temperatures and wind storms result in reductions to the per capita GDP of 2%, while a later paper by the same author made a more conservative estimate of 0.6% with droughts having the largest average impact, with cumulative losses

of 1% of GDP per capita (see Raddatz, 2009). GDP per capita lowered not just through the mere incidence of the natural disaster but also on the victims that it causes (Heger et al., 2008). In countries where there are a few large sectors that dominate the economic landscape, the interruption of the production of goods and services can be particularly devastating (Heger et al., 2008).⁴

- *Investment and natural disasters:* natural disasters lead to a substantial decline in investment growth (Auffret, 2003). Longer-term investment plans for both physical and human capital are disrupted and governments may divert resources away from planned investments to fund relief and rehabilitation. Disasters further contribute to economic instability and to an atmosphere of uncertainty, deterring potential investors (Benson and Clay, 2004).

What is the relationship between weather variability and growth rates?

Most evidence suggests that economic growth is negatively related to weather changes (see Section 2.2). However, as in the previous case, there are also exceptions.

- *GDP growth and climate change:* according to the study by Brown et al. (2010), precipitation extremes (such as floods and droughts) are the dominant climate influence on economic growth and the effects are significant and negative. Droughts, in particular, have a highly significant influence and floods have a lagged effect on growth. Higher temperatures reduce growth rates by reducing agricultural and industrial output and by affecting political stability (Dell et al., 2012).
- *GDP growth and natural disasters:* most studies state that natural disasters lead to a decline in GDP growth (Auffret, 2003; Rasmussen, 2004; Jaramillo, 2009; Vu and Hammes, 2010) and impact is usually stronger in developing than developed countries (Fomby et al., 2013). For example, Rasmussen (2004) establishes that, from 12 large natural disasters in the Eastern Caribbean Currency Union, there was a median reduction in same-year real GDP growth of 2.2 percentage points, as well as a large decline in agricultural production and an offsetting increase in investment. On average, natural disasters cause damage amounting to well over one-half of 1% of GDP. The study finds that the relative costs tend to be far higher in developing countries than in advanced countries. Yet when observing the effects of droughts, floods, earthquakes and storms, Fomby et al. (2013) claim that the growth response induced by natural disasters can sometimes be positive, and also that the timing varies with the type of disaster and with the sector of economic activity. They also note that severe disasters tend to carry stronger effects. This is similar to the conclusion made by Loayza et al. (2009), who note that, in the events they analyse, severe disasters never have positive effects on GDP per capita growth rates.

The effect of natural disasters on GDP growth can be analysed as effects on physical capital or through increased fatalities (lives lost and affected). A study from Vietnam (Noy and Vu, 2010) concludes that more costly disasters (higher damages to capital) boost GDP growth rates in the short run while more fatal disasters cause lower output growth.

Jaramillo (2009) runs regressions to identify the differential long- and short-term impacts of large natural disasters. He asserts that, for some countries, the disaster impact persists beyond the two to five years in which reconstruction and adaptation are expected to have an effect on the economy. Negative effects are permanent for countries that have a history of highly devastating natural disasters, signalling the need to observe and analyse long-term (i.e. longer than 30 years) effects as well.

- *GDP per capita growth rate and natural disasters:* most studies suggest that damage resulting from natural disasters results in a collapse in the GDP per capita growth rate (see,

⁴ See Section 4 for a discussion on how the development of some sectors can be beneficial (or not) for resilience.

for instance, Heger et al., 2008). However, Loayza et al. (2009) suggests that the effects are not always negative; moderate disasters can have a positive growth effect in some sectors (this is not the case for severe disasters). These authors offer a more nuanced approach, suggesting that the GDP per capita growth rate has differential impacts across disasters and economic sectors. Loayza et al. (2009) affirms that GDP per capita growth in developing countries is more sensitive to natural disasters because more sectors are affected. Another abnormal result is that found by Cunado and Ferreira (2011), who claim that flood shocks tend to have a positive average impact on GDP growth. However, this impact is limited to developing countries only. The same relationship can be seen in the agricultural and non-agricultural sectors.

Other authors that have attempted to better understand the relationship between natural disasters and the consequential effect on GDP per capita growth rate include Noy and Nualsri (2007), who claim that a negative shock to the stock of human capital results in a decreased growth rate, with no eventual return to the previous growth trajectory. Negative shocks to the stocks of physical capital, on the other hand, do not seem to have much statistically observable effect. This is opposite to the results found by Noy (2009), who looks at the effect of hydro-meteorological, geophysical and biological disasters on GDP growth, per capita income, CPI inflation, unemployment rate and population. He notes that natural disasters have an impact on the macro-economy when measured as the amount of property damage. On the other hand, when disasters are measured as population indicators (lives lost and affected) there is no evidence of macroeconomic costs.

- *Consumption growth and natural disasters:* in the short term, there is a moderate decline in consumption growth following a natural disaster. Most of this reduction in growth is in private consumption, while public consumption declines moderately (Auffret, 2003). Dercon (2004), using panel data from Ethiopia, suggests that food consumption dips dramatically after a disaster, but grows substantial as time goes on. However, he notes that there are diverse experiences across villages and individuals. The drought of 1984/85 was severe enough to lower consumption growth in the 1990s by 16%, when comparing groups that suffered substantially compared to those only moderately affected. He claims that a 10% lower rainfall about four to five years earlier had an impact of one percentage point on current growth rates.

Mechler (2009) attempts to explain the variations in post-disaster consumption per capita following floods, storms, earthquakes, droughts, mass movements, wildfire and extreme temperatures. He argues that including disaster asset losses helps to better explain post-disaster consumption variations, albeit almost exclusively for the group of low-income countries. For developing countries, capital stock and changes therein – such as those forced by disaster shocks – play a more important role, and human capital and technological process play less of an important role.

2.3.3 The evidence on the impacts of climate change on livelihoods and poverty

The IPCC Fourth Assessment Report found that socially and economically disadvantaged and marginalised people are disproportionately affected by climate change (IPCC, 2007). The Fifth Assessment Report comprehensively reviews this question and recognises that climate change interacts with other non-climatic factors to affect poverty dynamics, which makes both detection and attribution challenging (see Chapter 13 of IPCC, 2014).

What are the impacts on livelihood assets and human capabilities?

There is plenty of evidence pointing to climate shocks negatively affecting all assets.

There is plenty of evidence on the impact on *natural assets* (such as rivers, lakes, and fish stocks), on which certain livelihoods are dependent (see Thomas et al., 2007; Nelson and Stathers, 2009; Osbahr et al., 2008 among others). Weather events and climate change also erode farming

livelihoods via declining crop yields (see Hassan and Nhemachena, 2008) and can threaten cattle (Thornton et al., 2007). With high levels of erosion land can disappear, especially on islands and in coastal regions (Solomon et al., 2009).

There is also robust evidence of damage to *physical assets* for poor urban settlements, often built in risk-prone floodplains and on hillsides susceptible to erosion and landslides (Douglas et al., 2008; Hardoy and Pandiella, 2009). Such effects also lead to population displacement (Douglas et al., 2008).

Impacts on *financial assets* are seen in losses of farm income and jobs (Hassan and Nhemachena, 2008) or in a general increase in the cost of living and production inputs (Thomas et al., 2007).

Human assets are also significantly affected: the poor are found to reduce consumption (Carter et al., 2007) and have reduced ability to carry out work due to climate-related health issues (Kakota et al., 2011), also leading to extreme psychological consequences (IPCC, 2014).

Furthermore, *social and cultural assets* are also affected through disruptions to formal and informal social networks (Osbahe et al., 2008; Douglas et al., 2008).

What are the impacts on livelihood dynamics and trajectories?

Weather events and climate also exacerbate livelihood trajectories and dynamics in livelihood decision making, generally driven by annual and inter-annual climate variability (Gabrielsson et al., 2012). Changes in livelihoods by changing crops or to more lucrative activities also occurs due to changes in climatic trends (Thomas et al., 2007; Coulthard, 2008).

What are the impacts on poverty dynamics?

There is limited evidence of the extent to which climate change intersects with poverty dynamics, although there is a high level of agreement regarding the shift from transient to chronic poverty due to weather and climate (see Scott-Joseph, 2010). Of course, other stressors may contribute to this shift, including population growth.

What are the effects on poverty traps and critical thresholds?

There is some evidence pointing to climate change contributing to poverty traps arising, whereby the poor are kept poor or made poorer, although also here attribution is difficult. Urban waged labourers see an erosion of financial capital (Ahmed et al., 2009) or damage to informal settlements (Hardoy and Pandiella, 2009), while the rural poor are mostly affected through stress to ecosystems (Kates, 2000). There is insufficient evidence to refer to the existence of a critical threshold or to irreversible damage resulting from climatic change.

What are the relations between climate change and multidimensional inequality and vulnerability?

Climate variability and change and climate-related disasters are found to contribute to and exacerbate inequality in urban and rural areas, in interaction with multiple deprivations at the intersections of gender, age, race, class, caste, indigeneity, and (dis)ability, which are embedded in uneven power structures (see Kaijser and Kronsell, 2013 in IPCC, 2014: Chapter 13).

2.3.4 Risk, poverty and vulnerability

There is a strand of the literature that looks at risk as a fundamental variable affecting livelihoods in developing countries, with a particular focus on Africa. Risks include not only weather-related ones such as recurrent drought and floods but also health risks, pests, commodity price shocks, political strife, conflict and many other issues. This body of work looks into how risk and vulnerability link with poverty by determining household living conditions.

There are many ways in which risks affect people's livelihoods: they determine whether people can maintain assets and endowments, how these assets are transformed into incomes via activities and how incomes and earnings are translated into broader developmental outcomes, such as those related to health and nutrition (Dercon, 2005).

In general, risk and shocks are treated as exogenous variables, not directly under the control of people. However, there is also recognition in the literature that households use strategies to manage or reduce risk (ex-ante) and strategies to cope with the consequences of risk once shocks occur (ex-post). These strategies have some impact and consumption is more smooth than income but shocks are not fully insured against, leading to fluctuations in consumption and other welfare outcomes (Hoddinott and Harrower, and Christiaensen and Subbarao, in Dercon, 2005).

There are two types of risk-related consequences in relation to poverty. First, the impact of the shock: the event and the coping responses of the household may destroy or reduce the physical, financial, human or social capital of the household. Second, the behavioural impact: households faced with shocks and with limited access to insurance substitutes are driven to look into risk-management strategies, such as low-risk activities and asset portfolios, which will reduce their incomes. In Dercon's (2005, pg. 485) words, 'risk is then a cause of poverty and its persistence'.

2.4 A reflection on methods and data

2.4.1 Most commonly used econometric methods

Understanding how climatic factors affect relevant economic outcomes is essential for the effective design of contemporary economic policies and institutions. Academic literature (mainly coming from the economics discipline) has addressed this challenge using a variety of methods. Dell et al. (2014) present a reflection on how these models have evolved and managed to improve estimates. Their main findings are summarised below.

Studies using cross-sectional data (estimates using spatial variation at one point in time) pose substantial challenges, as they fail to incorporate the fact that spatial variation in climate is largely fixed. For instance, Nordic countries are colder on average than tropical countries. While estimates may find cross-sectional correlations between a country's climate and its economic outcomes, it is difficult to distinguish the effects of the current climate from the many other characteristics potentially correlated with it.

In recent years, a new empirical research approach has been pioneered that uses panel methods – an approach that simultaneously looks at two dimensions, i.e. time and space (meaning data are collected over time and over space for the same locations). This is used to examine how weather variability (temperature, precipitation, and windstorms) influences economic outcomes. These studies focus on changes in weather realisations over time within a given spatial area and show impacts on agricultural output, industrial output and labour productivity. The main advantage of this method is the fact that such studies can causatively identify the effects of climatic variation on economic outcomes.⁵

2.4.2 Most commonly used data sources

Many studies referred to in this review use data from the Emergency Events Database (EM-DAT). Such studies mainly look at the impacts of disasters on national income and other variables by

⁵ Table 1 in the Appendix to Dell et al. (2014) provides an excellent summary of the variables and methods used in panel studies. The appendix is available here: <http://scholar.harvard.edu/dell/publications/what-do-we-learn-weather-new-climate-economy-literature-0>.

using direct economic losses as the dependent variable in cross-country studies (Raddatz, 2009; Loayza et al., 2012; Fomby et al., 2013).

EM-DAT contains data that countries self-report. A limitation of this database is that it does not contain data on damaging but non-fatal disasters that did not generate a call for international assistance. Thus, damages to richer countries will be underreported. No paper discusses the implications of this for the findings reported. In addition, none of the EM-DAT-based studies is able to control for disaster magnitude in the full sample, as these data are frequently missing from the database. A related issue is the potentially high correlation between the various national variables used in these studies, as well as many plausible omitted variables that may bias results (Kousky, 2013).

There are four other main types of weather data that are mainly used in econometric studies: ground station data, gridded data, satellite data and reanalysis data (Dell et al., 2014). Appendix Table 2 of Dell et al. (2014) provides details on the specific data sources used by a wide list of studies,⁶ with some highlights of this analysis being the following:

- Ground station data directly observe temperature, precipitation, and other weather variables such as wind speed and direction, humidity, and barometric pressure. One of the most used ground station data sources is the Global Historical Climatology Network. Ground station data in general provide highly reliable weather measures for the areas where stations are located, but in poorer countries it is often their data is less reliable. Even though this does not appear to substantially affect aggregate conclusions, it can nonetheless lead to measurement errors.
- Gridded data provide more complete coverage by interpolating station information over a grid. However, their coverage is incomplete particularly in poor countries or areas with sparse population density. The most common used dataset is that on global temperature and precipitation produced by the Climatic Research Unit at the University of East Anglia.
- Satellite data use satellite-based readings to infer various weather variables. The most used sources include the datasets produced by the University of Alabama Huntsville and by remote sensing systems. Satellite data have some disadvantages such as the fact that they are recent and thus provide shorter spans of historical information.
- Reanalysis data combine information from ground stations, satellites, weather balloons, and other inputs with a climate model to estimate weather variables across a grid. Examples are the National Centers for Environmental Prediction in the US and the European Centre for Medium-Range Weather Forecasting.

2.5 Recommendations for further research

This research hypothesis has been studied widely. Some of its limitations have been discussed in section 2.4. Its main findings have also been acknowledged in reports such as the world development reports and those produced by the IPCC. However, we have identified two main gaps in the literature:

1. As mentioned above, most studies focus on the short run and **there is scarce evidence on the impacts of climate shocks in the long run (at least, based on historical data)**. As discussed in Dell et al (2014), there are some fundamental challenges that need to be taken into account and addressed in models when moving from the short to the long run. This is the case both for studies using historical data and for studies estimating potential

⁶ Ibid.

future impacts, and four key questions arise: (i) How can the effects of adaptation be taken into account in models? (ii) How can we account for the intensification of climate effects? (iii) What are the general equilibrium effects? and (iv) What is the extent to which observable weather variation includes changes that may occur in the future? Despite these challenges, we consider this area of research fundamental to the provision of more adequate answers to the questions posed by hypothesis explored in this section.

2. As discussed in this chapter, most evidence looks at the direct impacts of weather variability on the economy. However, **the measurement of indirect impacts has been less explored and is also much more challenging**. This may lead to underestimated findings. Section 3 looks in detail at this question mainly from a conceptual point of view and suggests ways to improve estimates. We recommend further empirical research in this area.

3 Do weather-related shocks that have an impact at the micro level translate to the macro level and vice versa?

We first introduce the research hypothesis and its rationale, followed by conceptual discussion of why such questions seem intuitive and a summary of empirical findings. We then present a discussion on a related topic – i.e. the challenges inherent in measuring the impacts of climate change – and of ways to advance our understanding beyond the failures of existing studies.

3.1 The hypothesis and rationale

This section explores the following hypothesis:

‘Weather-related shocks and trend changes that have an impact on the micro-economy can add up to macroeconomic impacts (and vice versa) because the economy is full of interlinked systems and networks’

Our findings related to Hypothesis 1 show that, although there is a large body of literature pointing to there being a negative relation between weather variability and economic growth and poverty (potentially suggesting that the impacts of weather variability on economic development are negative), we have also mentioned how the evidence is not always clear – indeed, it is often the case that we find mixed evidence and/or contradictory examples. From an intuitive perspective, it is also puzzling that, although there is evidence of impacts of weather variability at the microeconomic level (discussed in sections 2.3.3 and 2.3.4), these impact are not always reflected at the macroeconomic level (and vice versa).

The main aim of this section is therefore to unfold the rationale for such questions from a conceptual point of view and to summarise the existing evidence.

3.2 Macro impacts resulting from micro impacts – a conceptual proposal

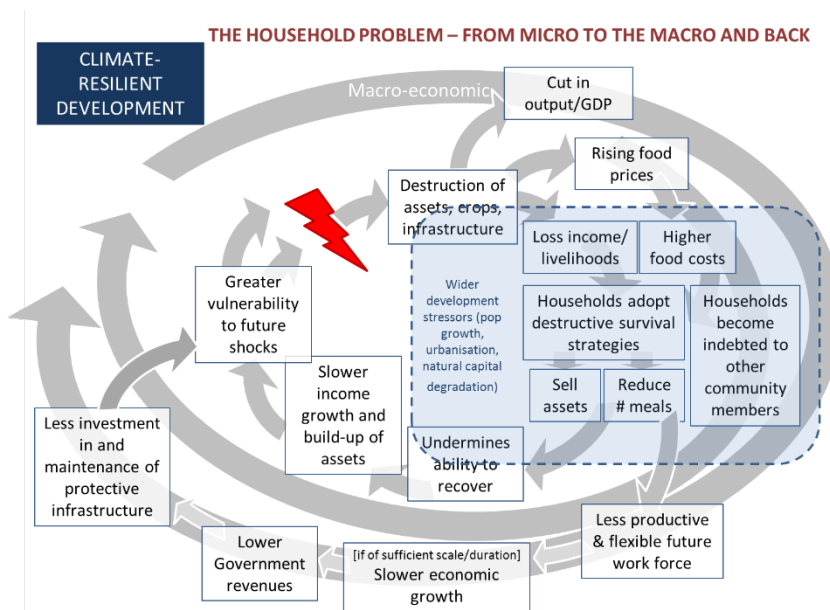
Even though we did not find a strong body of literature to support or refute this hypothesis (see Section 3.3), it does seem intuitive. Figures 3.1 and 3.2 represent a conceptual proposal that can help our understanding of how this process would work, both at the household and at the firm level.

Both figures present variables that reflect the initial impact of a disaster (for instance on the destruction of livelihood assets or infrastructure), possible responses (households adopt destructive survival strategies or replacement of assets) and how this could translate into sectoral and macroeconomic effects. The diagrams are circular, as the ultimate macroeconomic consequences – i.e. the reduction of GDP – will ultimately have an effect on the households and firms again.

In the case of the household, the logic is as follows. Let us think of the case of a community mainly deriving its income from agricultural sources. A disaster that affects most households in the community will have an impact on the whole community (in the form of reductions in their income and their possible sources of labour). This effect can have a wider impact if, for instance, the affected community was the main source of food for a region. The region would be affected by a

shortage of food with its consequent increase in food prices. There will be a number of follow-up effects (on prices and markets) that will determine the final aggregate output of this disaster.

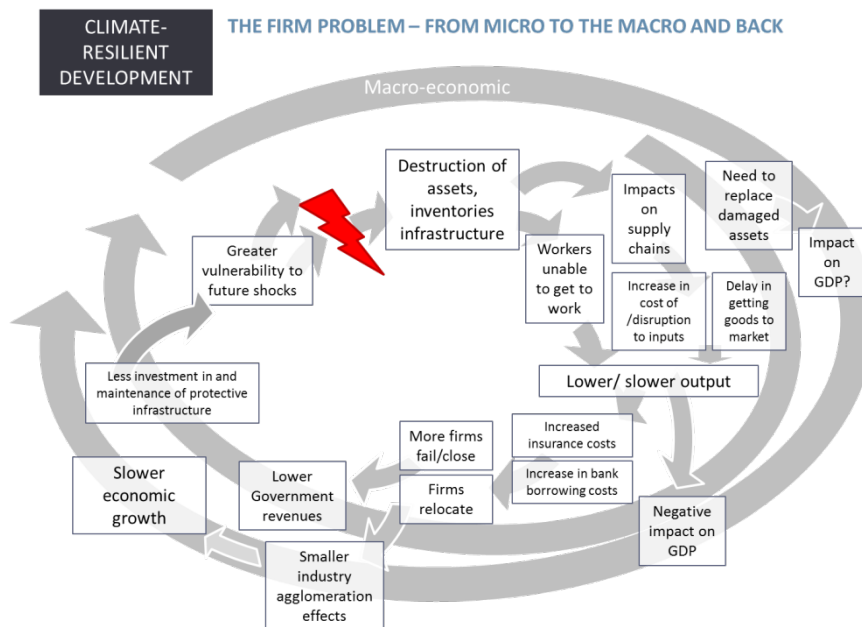
Figure 3.1. Transmission effects from the micro to the macro level – the household



Source: DFID staff

In the case of the firm, a disaster that destroys the infrastructure of a firm could have knock-on effects on other firms, affecting a whole sector. If this effect is wide, it can translate into a reduction of output that can have aggregate consequences.

Figure 3.2. Transmission effects from the micro to the macro level – the firm



Source: DFID staff

The conceptual framework discussed in Section 3.5 addresses how most existing studies fail to take into account some output losses such as the ones just mentioned (e.g. business and supply-chain interruptions, etc.).

3.3 Is there empirical evidence that impacts at the micro level affect the macro level and vice versa?

We found very little evidence to support or refute this hypothesis.

As discussed in Section 2.3.3, there is a body of literature studying the relations between risk, vulnerability and poverty. Within this strand, there is some evidence of a long-term impact of uninsured risk on the poor. Despite the fact that this literature is not specifically looking at the transmission effects from the micro to the macro levels, some of its findings reveal evidence that micro effects ultimately have macro consequences. These include the long-term impact on nutrition, educational attainment and lifetime earnings from a serious conflict and drought shock in Zimbabwe in the early 1980s (Alderman et al., 2003) or the persistent impact on consumption growth in the 1990s for those households that had specifically suffered in the notorious 1984/85 drought in Ethiopia (Dercon, 2004b). Dercon et al (2005) find evidence for Ethiopia that the collapse of output prices in 2001 and a serious drought in 2002 were still significantly affecting consumption outcomes in rural Ethiopia several years later. However, most of this evidence is at the micro level and there is very little work that quantifies the overall impact on growth and poverty. This is an area on which more research is needed.

On the other hand, we did not find empirical evidence that macro impacts translate into micro impacts. Intuitively, one can think that macroeconomic shocks will affect livelihoods. However, we did not come across studies specifically looking into this question for the case of climate shocks and disasters. As discussed in Section 2, the broad body of evidence is either on the relation between weather-related shocks and macroeconomic variables or on weather-related shocks and livelihoods and poverty.

Sections 3.4 and 3.5 conceptually discuss how shocks at the micro level (to a firm) can be transmitted via networks to other firms, subregions and regions (Henriet et al., 2012). This is an example of a broader body of literature on systems and networks, according to which globalised systems involving highly interactive and optimised production give rise to large-scale vulnerabilities. This can be the case when it comes to disasters, which bring a range of indirect and secondary impacts in addition to direct losses (e.g. mortality, injury, physical damage and economic loss) (Pelling et al., 2013).

3.4 How to measure the impacts of climate change on the economy

While we did not find strong evidence to support or refute the second research hypothesis of this study, we did find a body of relevant literature that uncovers aspects that have been understudied and that are related. Without specifically looking into the transmission from the macro to the micro level and vice versa, this strand of work looks into other reasons why the impacts of disasters and climate shocks seem to often be underestimated.

When measuring the impacts of climate change on the economy, there is strong evidence that we need to look into both direct and indirect losses (Saltmarsh, 2010). There is a broad body of literature looking at the direct impacts of climate change on the economy sector by sector (see Chapter 10 in IPCC, 2014). There are also attempts to measure indirect impacts of climate change, which has been approached in two ways by the literature: looking at the impacts from one sector to the rest of the economy and at the impacts on economic growth and development. However, the measurement of indirect impacts has been less explored and it is also much more challenging (Henriet et al., 2012). We present a summary of studies looking into the measurement of impacts of climate change on the economy and on economic growth and development below.

3.4.1 Measuring the impacts of climate change on the rest of the economy

According to the IPCC (2014), there are three channels through which economic impacts on one sector of the economy diffuse to another. First, the outputs of one sector are used as inputs in other sectors. For instance, a disaster that affects crop yields will indirectly affect the food-processing industry. Second, products compete for the consumers' finite budget. For example, if food becomes more expensive, consumers would buy other cheaper food and would be likely to have less income available to spend in other products. Third, sectors compete for the primary factors of production (labour, capital, land and water). After a disaster, more labour may be demanded by the agriculture sector, which in turn means less labour is available for other sectors.

One of the most common approaches for measuring the indirect impacts of climate change on the economy is the use of general equilibrium models. These models describe how the impacts of the shock (i.e. climate change) in one sector extend to the rest of the economy, or how the impacts of the shock in one location extend to other places (Ginsburgh and Keyzer, 1997). However, these models rely on strong assumptions (e.g. the rationality of consumers and producers and the absence of market imperfections) (IPCC, 2014), which restricts their usefulness in terms of analysing climate change impacts.

Sector-scale interactions are another attempt to measure these effects (Cochrane, 2004; Okuyama and Chang, 2004; Rose and Liao, 2005; Hallegate, 2008). These studies also have their limitations given that they fail to incorporate small businesses. Business interruptions and production losses may be caused by production bottlenecks caused by small businesses (for instance, supply and transportation failures, customers and workers not being able to reach the business location, etc.) (Henriet et al., 2012). These interactions between firms are likely to lead to significant underestimates of the impacts of natural hazards.

According to the IPCC (2014), there are five key findings that emerge from the attempt to estimate the indirect impacts of climate change:

1. **Markets matter:** the impacts of climate change are transmitted across locations and across multiple sectors of the economy.
2. **Consumers and producers are affected differently:** for instance, an increase in price due to a reduction in production may benefit producers while negatively affecting consumers.
3. **The distribution of the direct impacts can be different from the distribution of the indirect effects:** an example is the case of a loss in production in one firm that may benefit other companies in other locations not affected by the shock.
4. **A loss of productivity or productive assets in one sector leads to further losses in the rest of the economy.**
5. **Markets offer options for adaptation:** this can affect the size and the direction of the estimated impact.

Most of these effects are transmitted through changes in relative prices due to the shock (disaster), to which both firms and households react. Ignoring these effects leads to biased estimates of the impacts of weather-related disasters and climate change (Hallegate, 2014).

3.4.2 Measuring the impacts of climate change on economic growth and development

Climate change will also affect economic growth and development, but our understanding of this issue remains limited (IPCC, 2014).

The measurement of climate change's impact on welfare has been addressed via different methods, including expert elicitation, econometric studies and simulation models. According to

most studies, the effect of the excluded impacts is negative (Tol, 2008; Yohe, 2008; Füssel, 2010). However, the studies make different assumptions about intersectoral, interregional and intertemporal interactions, adaptation, and the monetary values of impacts, which makes comparisons quite challenging.

Fankhauser and Tol (2005) use four models of economic growth and three transmission mechanisms – economic production, capital depreciation and the labour force. In three models they find that economic output is reduced further when allowing for indirect impacts. However, on the fourth model (which emphasises human capital accumulation) indirect impacts are 1.5 times as large. The difference is due to the following: in the first three models the impacts of climate change crowd out consumption and investment in physical capital, while in the fourth model investment in human capital is also crowded out; thus, lower investment implies slower growth.

Hallegatte and Thery (2007), Hallegatte and Ghil (2008), and Hallegatte and Dumas (2009) state that the impacts of climate change through natural hazards on economic growth can be amplified by market imperfections and the business cycle.

Henriet et al. (2012) propose a conceptual framework that addresses the challenges posed above. Their proposal may help explain the reason for the initial puzzle found when looking at the mixed evidence on the impacts of climate change on the economy at the micro/sectoral/macro levels. This framework is discussed in Section 3.5.

3.5 Measuring the welfare impact of a disaster: a new conceptual framework

This section discusses the conceptual framework introduced by Hallegatte (2014) and Henriet et al. (2012) that proposes a way to improve the measurement of the indirect impacts of climate change via natural hazards on the economy. The framework is based on the concept of economic resilience, which is introduced next, followed by a discussion of its measurement.

3.5.1 What is economic resilience?

The Hyogo Framework of Action (2005) underlines the importance of building the resilience of nations and communities to disasters by improving national and local capabilities to manage and reduce risk. According to the United Nations International Strategy for Disaster Reduction (UNISDR), resilience is ‘the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures’ (UNISDR, 2005, pg. 4). Given the scope of our research, we focus on ‘economic resilience’ and adopt the definition by Hallegatte (2014, pg. 2) as ‘the ability of an economy or a society to minimize welfare losses of a disaster of a given magnitude.’

3.5.2 How to measure the welfare impact of a disaster

According to Hallegatte (2014), the welfare impact of a disaster depends on three main factors (see Figure 3.3):

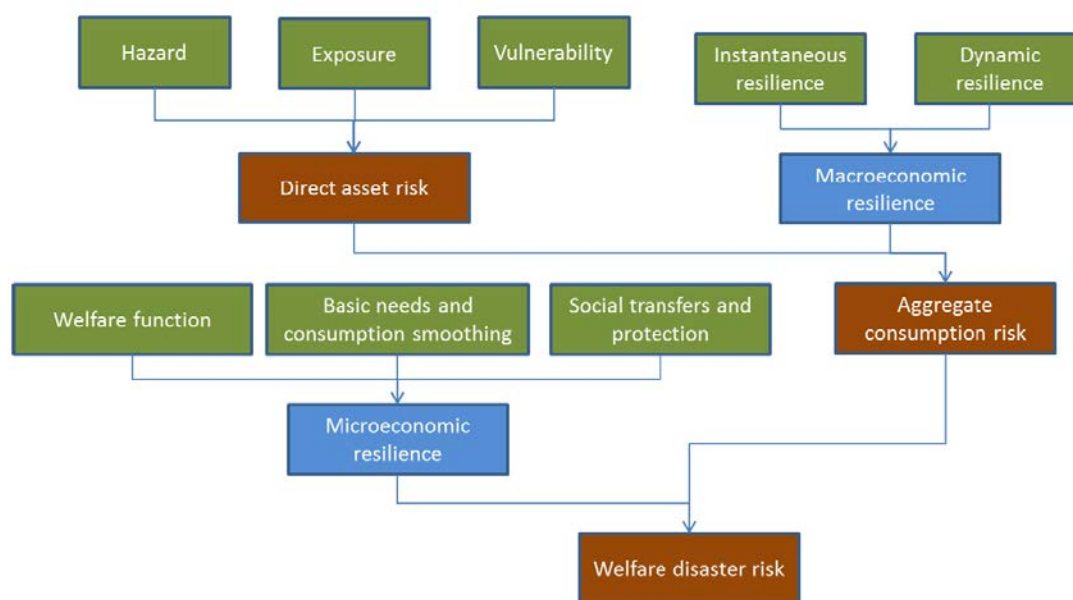
- (i) the direct impacts of the disaster;
- (ii) the macroeconomic resilience; and
- (iii) the microeconomic resilience.

The *direct impacts* of the disaster are determined by the physical characteristics of the event and the direct impacts in terms of lives and assets lost, which in turn are explained by the hazard, exposure and vulnerability of the economy.

The *macroeconomic resilience* has two components: the instantaneous resilience (i.e. the capacity of the economy to limit the magnitude of immediate production losses for a given amount of asset losses) and dynamic resilience (i.e. the capacity to reconstruct and recover). In other words, the macroeconomic resilience is the capacity that the economy has to minimise aggregate consumption losses, via its ability to cope, recover and reconstruct after the disaster. Depending on the ability of the economy to cope, recover and reconstruct, the reconstruction will be more or less difficult and its welfare effects smaller or larger.

The *microeconomic resilience* depends on the distribution of losses across households (especially households with different wealth levels), the vulnerability of the households (i.e. their pre-disaster income and their ability to smooth shock over time) and on the social protection system (i.e. the mechanisms to share risks and protect the most vulnerable in a country).

Figure 3.3. Defining welfare disaster



Source: Hallegate (2014)

3.5.3 Macroeconomic resilience and measurement of output losses

Instead of focusing on indirect vs. direct impacts, when looking at the macroeconomic resilience this framework distinguishes between asset losses (i.e. the stock of assets is reduced) and output losses (i.e. a reduction in a flux of income).

Output losses include production by both the productive sector and by households. They include different categories that often overlap:

- Production losses directly due to asset losses (because damaged or destroyed assets cannot produce);
- Business interruptions (the interruption in production during the event);
- Supply-chain disruptions (when lack of input or reduced demand is responsible for a reduction in production from a production site that is not directly affected);

- Macroeconomic feedbacks (e.g. the impact of reduced final demand because consumers and businesses suffer from their reduced income and the effect of lost tax revenue on public demand);
- Long-term adverse consequences for economic growth (e.g. due to changes in risk perception (including over-reactions) that can drive investors and entrepreneurs out of the affected area); and
- Increased production from the 'reconstruction boom' that acts as a stimulus for the economy.

As Hallegate (2014) discusses, some of these output losses can be measured with classical economic indicators, such as GDP. However, there are various problems with this approach. First, the scale of the event and the scale of GDP measurement are very different for large countries, and a large shock for local populations can be hardly visible in national GDP. This does not, however, mean that welfare impacts are negligible. Second, GDP does not capture a significant share of output losses represented by non-market and household production. Third, GDP does not capture wealth (e.g. stocks of assets) and does not account for inequality and distributional effects (Fleurbaey, 2009). Many studies presented in the section looking at Hypothesis 1 of this study use GDP as a proxy for the economy, which suffers from the problems just highlighted. **Measuring output losses**

The measurement of indirect losses includes output losses that are consequences of direct losses. Output losses are in part caused by the disaster and the consequent capital losses, but also stem from the complex interactions between businesses. For instance, they arise from production bottlenecks through supply-chains of suppliers and producers. Measuring these is very difficult, as they will be specific to the economic structure and to the particular shock (disaster) (Henriet et al., 2012).

For example, the impact of the 2004 hurricanes in Florida was very different to the impact of Hurricane Katrina in Louisiana. This may be due to the fact that Katrina affected the systemic functioning of Louisiana's economy, by affecting businesses not only directly, but also indirectly affecting other businesses that could not function normally. This led to an almost complete collapse in the local economy. In Florida, the losses did not impair the whole economic production and this allowed for a more prompt reconstruction.

Hallegate (2014) introduces a framework to measure output losses by estimating how much output is lost because of the direct asset losses, and also takes into account the dynamic resilience of the economy. His model also takes into account how output losses translate into consumption losses, given that losses in economic output do not directly affect people's welfare and that, for households, what matters most is consumption.

Henriet et al. (2012) suggest a model that takes into account the increase in cost due to the heterogeneity of losses and business interactions within the production network. Their model represents an economy as a network of interactions between production units. One of the main assumptions of this model is that prices do not adapt too rapidly after a disaster and do not allow for coordination between production units to re-establish equilibrium.

The authors explore three specific network structures: concentration, clustering and connectedness between subregions. Concentration refers to the role of the redundancy in suppliers and clients (which can act as a risk-sharing mechanism against the risk of a shock on a supplier or client); clustering to the what happens if the clients of the production unit are also suppliers of its suppliers; and connectedness to whether it is useful to connect with many links in different regions.

Their results suggest the following:

- The more concentrated the economy (i.e. the less redundancy in the suppliers and clients of each production unit), the larger the output loss.
- Results regarding clustering are mixed: small groups of production units are highly vulnerable to shocks affecting one of their members but these groups are isolated in regard to disasters affecting other groups. This suggests that in order to improve the robustness of an economy, small groups of production units should interact as little as possible so as to contain disaster losses (i.e. an isolation approach) and that all production units that are connected to the largest possible number of production units to mitigate the impact of a shock affecting one production unit (i.e. an insurance approach).
- When subregions are connected, each region becomes vulnerable to shocks affecting other regions.

3.5.4 Microeconomic resilience

Microeconomic resilience is the capacity of an economy to minimise household welfare losses for a given level of aggregate consumption losses. In order to estimate the welfare impact of a macroeconomic loss in consumption, one needs to account for the distributional impacts of the disaster and for the capacity of households to cope with the shock (Adger et al., 2002; Hallegate, 2014). To assess welfare impacts, we need to account for the heterogeneity in consumption losses and for the pre-disaster income distribution.

Hallegate's model looks at the welfare impact for the affected population, taking into account the capacity to smooth the shock over time and the impact of social protection and transfers that is likely to happen after a disaster hits.

3.5.5 How to reduce welfare disaster risk and increase economic resilience

The framework proposes ways to reduce welfare disaster risk and to increase economic resilience. Basically, the welfare disaster risk can be reduced by reducing the exposure or vulnerability of people and assets (i.e. reducing asset losses), by increasing macroeconomic resilience (i.e. reducing aggregate consumption losses for a given level of asset losses) or by increasing microeconomic resilience (i.e. reducing welfare losses for a given level of aggregate consumption losses).

3.6 Recommendations for further research

There is practically no evidence in the literature that one can satisfactorily employ to either support or refute Hypothesis 2. This section has reviewed empirical evidence looking into this and has presented some conceptual proposals on how to improve existing methods. As such, it is an area that would particularly benefit from further work. Here are some specific suggestions:

1. **We found very little empirical evidence that micro effects add to the macro level.** The findings that are available come from the literature on risk, vulnerability and poverty and do not systematically address the question. For this reason, we consider further research addressing this specific question to be of great use.
2. **Most empirical evidence looking at the long-term impacts of uninsured risk on the poor is at the micro level,** and there is very little work that quantifies the overall impact on growth and poverty. This is again an area on which more research is needed.
3. **We did not find empirical evidence that macro impacts translate into micro impacts.** As discussed in Section 2, the broad body of evidence is either on the relation between

weather-related shocks and macroeconomic variables or on weather-related shocks and livelihoods and poverty. Additional research on this topic too is thus recommended.

4. **Most existing studies fail to take into account output losses** such as business and supply-chain interruptions, etc. Further empirical research in this area, which is related to the recommendations in Section 2, is therefore suggested.

4 Are there some patterns of development that increase or reduce the vulnerability of an economy to climate change?

We first introduce the research hypothesis and its rationale, followed by a discussion of what we mean by ‘patterns of development’ and the relation of this to other key concepts in the literature, also providing a description of the particular patterns of development we focus on and a review of the empirical evidence. The section ends with recommendations for further research.

4.1 The hypothesis and rationale

This section explores the following hypothesis:

‘There are some patterns of development that increase the vulnerability of an economy to climate shocks, and there are some that build resilience to deal with shocks and, potentially, future trends’

Analysing whether patterns of development have an impact on resilience has a three-fold rationale:

- 1. The need to focus not only on the impacts of climate shocks and of adaptation at the micro level, considering communities and household necessities, but also and increasingly on understanding impacts at the macro level.**

Economic growth is considered the engine of development and of poverty reduction (Pye et al., 2010; Stern et al., 2006) but growth could instead ultimately be conducive to an increase – either directly or indirectly – in vulnerability. According to the World Development Report, ‘growth is necessary for greater resilience, but not sufficient’ (WDR, 2010, pg.7).

This could happen for the following reasons, among others:

- The scale of many climate impacts could be far greater than individual communities can cope with (IPCC, 2014);
- Indirect effects can be very severe for some more than others (ODI, 2013); and
- While adaptation could be beneficial to one community, it could result in increasing vulnerability in another (IPCC, 2014).

- 2. Adaptation is considered effective only if it entails incremental change.**

It is important to have a long-term vision and not to uniquely focus on current weather and climate variability. Incremental change can be possible only if a country has a clear development pattern: *‘Transformations in economic, social, technological, and political decisions and actions can enable climate-resilient pathways’* (IPCC, 2014, Summary for Policymakers, pg. 25).

- 3. There is a need to prevent current patterns of development from increasing people’s exposure and vulnerability to climatic hazards.**

The costs of climate change not only depend on the impacts of the climate but also on the patterns of development, which can lock in exposure to certain hazards. Some of these are evident but

some are less visible: ‘For most economic sectors, the impacts of drivers such as changes in population, age structure, income, technology, relative prices, lifestyles, regulation and governance are projected to be large relative to the impacts of climate change’ (IPCC, 2014, Summary for Policymakers, pg.19).

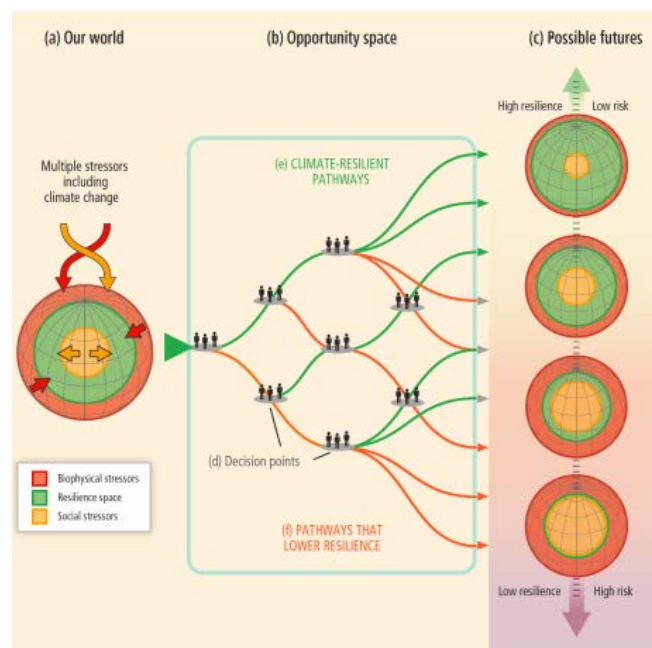
4.2 What do we mean by ‘patterns of development’?

The development of countries is shaped by a number of different factors that combine to create a ‘pattern of development’ at any point in time, resulting in these patterns being different for each country. These factors include geography, natural resources, weather, culture, institutions (and differences in the historical processes by which these have evolved), the markets they face or can take advantage of, etc. It is important to note that there is no agreed definition of ‘patterns of development’.

The IPCC in its 5th Assessment Report, Working Group II, considers ‘climate-resilient pathways [to be] sustainable-development trajectories that combine adaptation and mitigation to reduce climate change and its impacts. They include iterative processes to ensure that effective risk management can be implemented and sustained’ (IPCC, 2014, Summary for Policymakers, pg.25).

Figure 4.1 shows this relation as follows: the world (a) is threatened by multiple stressors that have an impact on resilience from many directions (represented as biophysical and social stressors). Stressors include climate change, climate variability, land-use change, degradation of ecosystems, poverty and inequality, and cultural factors. Opportunity space (b) refers to decision points and pathways that lead to a range of possible futures (c) with different levels of resilience and risk. These decision points (d) result in actions or failures-to-act throughout the opportunity space, and together they constitute the process of managing or failing to manage risks related to climate change. Climate-resilient pathways (e) (in green) lead to a more resilient world through adaptive learning, increasing scientific knowledge, effective adaptation and mitigation measures, and other choices that reduce risks. Pathways that lower resilience (f) (in red) include insufficient mitigation, maladaptation, failure to learn and use knowledge, and other such actions (IPCC, 2014).

Figure 4.1. Opportunity space and climate-resilient pathways



Source: IPCC (2014)

Before discussing the literature on ‘patterns of development’ as such, we introduce a number of relevant points that are highly pertinent in the actual development economics debates. Indeed, the economics literature does not look specifically into ‘patterns of development’ but rather addresses the question in other ways that are closely related and that we summarise below:

- *What is vulnerability?* Vulnerability is a function of two main factors (see Vivid Economics, 2010 and others): (i) *exposure* – the value of assets (physical and environmental) or number of people in places that are affected by climate hazards; and (ii) *sensitivity* – the degree to which people and businesses are affected by or respond to climate hazards. Sensitivity to hazards will depend on the types of economic activity that people rely on, as well as the degree to which the effects of hazards transmit through the economy.
- *What is the relation between poverty and vulnerability?* Poverty is not synonymous with vulnerability. Vulnerability is shaped by wider social, institutional and political factors that govern entitlements and capabilities, with issues such as gender, ethnicity and caste relations exerting a strong influence over levels of disaster risk and adaptive capacity. It is the social institutions and power relations associated with each of these issues that determine vulnerability to disasters. How they influence vulnerability also depends partly on the nature and type of disaster (ODI, 2013).
- *How can poverty reduction be achieved?* Dercon (2012) identifies four requirements for poverty reduction, in a context of structural and sectoral change:
 - A decline in the poor’s dependence on agriculture;
 - A vast reduction in the number of peasants;
 - A reduction in informal sector employment; and
 - Increasing wage employment in other sectors.
- *What are the main factors of economic growth?* Vivid Economics (2010) identifies nine essential factors of economic growth:
 - Sufficient capital: i) Natural capital; ii) Infrastructure; iii) Human capital;
 - Sound business environment: iv) Macroeconomic stability; v) Institutional and regulatory framework;
 - Easy access: vi) Access to markets; vii) Access to capital;
 - High productivity: viii) Competitive markets; ix) Firm performance.
- *How does economic growth affect vulnerability?* Economic growth almost always increases the adaptive capacity of people (World Bank, 2010g). Development allows an economy to diversify and reduce dependency on sectors such as agriculture that are more vulnerable to the impacts of climate change. It also makes more resources available to reduce risk. According to Millner and Dietz (2011), there are two schools of thought as to the best response to climate change in developing countries:
 - The first school argues that ‘development is the best form of adaptation’ and that it is better to prioritise traditional developmental goals over protective actions aimed specifically at reducing vulnerability to climate impacts. This argument is based on Schelling (1992), who reasoned that, given that one of the main reasons developing countries are vulnerable to climate change is their high sensitivity and low adaptive capacity – both essentially problems related to a low level of development – ‘their best defence against climate change may be their own continued development’ (Schelling, 1992, pg. 6). Subsequent work has supported the argument that development is the best form of adaptation (e.g. Fankhauser and Burton, 2011).
 - The second school of thought argues that ‘development is contingent on adaptation’. According to this school, development will be severely compromised by

climate impacts unless specific adaptation actions take place. According to the WDR (2010), economic growth alone is unlikely to be enough to counter the threats from climate change.

However, whether economic growth ultimately increases or decreased adaptive capacity depends on patterns of development, as there are examples of economic development that increase vulnerability to climate events (Pye et al., 2010; Stern et al., 2006; Vivid Economics, 2010; Barr et al., 2010).

- *What is the relation between economic growth and inequality?* Deininger and Squire (1996), Chen and Ravallion (1997), and, more recently, Dollar and Kraay (2002) all suggest that growth does not have an impact on inequality, therefore suggesting that a typical pro-growth strategy would not be useful in addressing high levels of inequality and that there is no virtuous circle between higher growth and falling inequality levels.

4.3 Geographical, sectoral and distributional patterns of development

In this section of the study we consider the existing evidence on the patterns of development that increase or decrease resilience to the impacts of a changing climate, as well as how development affects segments of society in different ways. We will consider geographic (ODI, 2013; IPCC, 2014), sectoral (IPCC, 2014; Hallegate, 2008 and others), and distributional patterns of development (Dercon, 2012; Aghion and Williamson, 1998).

1. *Geographic patterns of development* refer to where in a country or area development is taking place in a physical sense. For instance, development can be in areas that are susceptible to flooding, to growing water scarcity, to storm surges, sea-level rise or heat waves. Development can be predominantly an urban phenomenon or it can also benefit the rural population. The geography of growth is usually driven by economic opportunities, for example coastal cities develop around a port or trading hub. The geography of development will therefore drive both exposure and sensitivity to shocks.
2. *Sectoral patterns of development* refer to the parts of the economy that are growing and the ones shrinking. For instance, growth might be driven by improved productivity of the agriculture sector, a move to manufacturing, or development of the service sector. Different sectors and industries will vary in their exposure and sensitivity to climate hazards – for instance, through the extent to which they rely on the weather for productivity, how badly they will be affected by supply-chain disruptions, and how much they rely on well-functioning communication, IT, power and transport systems.

Some key factors that will affect the sensitivity of the sectoral pattern of development to climate hazards are:⁷

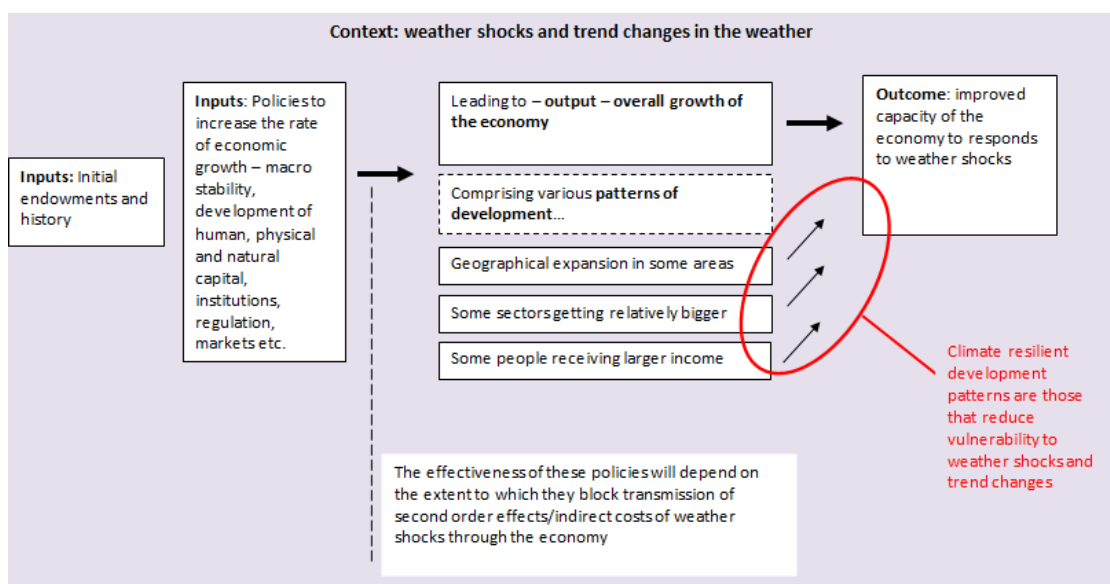
- **The degree of diversification or specialisation in production.** Specialisation in products or industries might lead to high growth (and so build capacity to respond to hazards) but if the economy relies on industries that are highly sensitive to hazards then this might increase vulnerability.
- **The extent to which investment is domestically financed or externally financed.** In theory, external finance could act as a buffer against climate hazards if domestic investors suffer a covariate climate shock that hinders their ability to finance investment. However, over-reliance on external finance might be dangerous if multiple climate shocks change the risk perception of external investors and cause finance to dry up.

⁷ The definitions below were those suggested by DFID.

- **Reliance on domestic vs. international markets for inputs to production.** Urban production that relies on domestic agricultural inputs might be vulnerable to shocks if those inputs are affected by climate hazards. On the other hand, over-reliance on international markets will make industries vulnerable to price increases that are the result of climate impacts overseas.
 - **The extent to which sectors and industries sell outputs to external markets.** An outward focus may act as a form of insurance, sharing the risks the country faces with its trading partners. However, as with the above, there is a risk that shocks elsewhere will be imported.
 - **How far industries that drive economic activity rely on transport, IT, communications, power and water systems.** Sectors with a high degree of connectivity are likely to be associated with more developed and complex economies. However, industries relying on the proper functioning of systems may experience significant output losses from climate hazards because of business interruptions and supply-chain failures.
3. *Distributional patterns of development* refer to the extent to which growth is inclusive or increasingly unequal. Inclusive growth should benefit the poorest – typically the most vulnerable – helping them build their resilience, but it might not be the fastest type of growth.

Figure 4.2 illustrates the link between development patterns and climate resilience. It shows how economic growth is determined by some exogenous factors (such as initial endowments) and other inputs (such as policies and institutions). Whether growth leads to an increase in resilience will depend on the specific patterns of a country’s development.

Figure 4.2. Development patterns and climate resilience



Source: discussions with DFID.

4.4 The existing evidence base

The extent to which economic development creates opportunities or constrains adaptation is dependent on the development pathway (IPCC, 2014). However, this area of research – aimed at understanding what climate-resilient patterns of growth and development are – is relatively underdeveloped. That said, there is nevertheless some evidence that we explore below.

The focus of literature has been on the prediction of the economic costs of climate change and shocks, and on estimating the potential costs (and benefits) of adaptation options that respond to these risks. Recent work by the UN University's World Institute for Development Economics Research (WIDER) estimates the total cost of climate change by adopting a multi-sectoral approach and considering the full range of climate projections over the period 2007–2050, comparing the reasonable baseline trajectory for growth and structural change (Arndt et al., 2012). According to their findings, climate change will have a modest negative impact on agriculture and roads, at least until 2050. Larger costs will be caused by rising sea levels and cyclone strikes. Overall, climate change is likely to reduce Vietnam's national income by between 1 and 2% by 2050 (relative to a historical baseline). These findings suggest that there are benefits from pre-emptive action, but also opportunity costs from precautionary adaptation investments.

In general, economic development is seen as being key to reducing vulnerability to climate change. By growing, economies generally become less dependent on climate-sensitive sectors such as agriculture, thus reducing their vulnerability. Through increasing levels of income, health and education, development can also reduce vulnerability by increasing the capacity to adapt and improving the capacity of governments to assist (Pye et al., 2010).

However, in certain cases, development can increase vulnerability. Development in locations that are more susceptible to climate risks or development around activities that will be affected by future climate change will increase future exposure potential. In addition, the more developed the country, the greater the value of infrastructure and property at risk from climate change and therefore the greater the absolute cost of climate protection (Pye et al., 2010). Economic development can also put pressure on natural resources and ecosystems in ways that can constrain their capacity to adapt (IPCC, 2014).

Therefore, growth and development are not sufficient to put countries on a climate-resilient pathway (Pye et al., 2010; WDR, 2010). There is a high level of confidence that the prospects for climate-resilient pathways for sustainable development are related to what the world accomplishes with climate change mitigation (IPCC, 2014). Moreover, even with mitigation there will still be significant potential impacts from climate change, and a need for adaptation (Pye et al. 2010).

We briefly illustrate the evidence base on these issues structured around geographical, sectoral, and distributional patterns of development.

4.4.1 Geographical patterns of development

As summarised by ODI (2013), disasters *'have a distinct geography ... poverty is concentrated in particular parts of the world and [...] climate change has an impact on extremes of heat, rainfall and droughts in many [of these] regions.'* (ODI, 2013, pg. vii)

Urban areas are now home to more than half the world's population and most of its built assets and economic activities. A high proportion of the population and economic activities at risk from climate change are in urban areas (IPCC, 2014).

IPCC (2014) reports that economic development and the urbanisation of hazardous landscapes may increase human exposure to extreme weather events and climate change, thus resulting in greater economic losses and risks to public health and safety (Baldassarre et al., 2010; IPCC, 2014). Economic development in hazardous zones (e.g. flood plains or low-lying coastlines) increases vulnerability (Vivid Economics, 2010). Intensive and unplanned human settlements in flood-prone areas appear to be playing a major role in increasing flood risk (Baldassarre et al., 2010), with an increasing preference for coastal and riverside development as income increases also increasing the exposure of assets to climate risks (OECD, 2013; Kellenberg and Mobarak, 2008).

There is some country-level evidence:

- Ethiopia's geographical location and topography in combination with low adaptive capacity entail a high level of vulnerability to the impacts of climate change (see Box 4.1 for more details). Around 45% of Ethiopia consists of a high plateau, with mountain ranges with elevations greater than 1,500 metres above sea level where almost 90% of the population resides (World Bank, 2010b).
- Ghana is also highly vulnerable due to its 565 kilometre coastline, which is inhabited by about a quarter of the population and is the location of significant physical infrastructure (World Bank, 2010c).
- About two-thirds of Bangladesh is less than five metres above sea level and is susceptible to river and rainwater flooding. The burden is likely to fall disproportionately on the rural poor in low-lying coastal areas (World Bank, 2010d).
- In Vietnam, exposure to the effects of climate change is highest in the Central Coastal regions and in the Mekong River Delta. On the other hand, sensitivity to the effects of climate change is highest in the North West and Central Highland regions. The only region with indices that are above the average on both measures is the Mekong River Delta, home to a large proportion of the population and to significant economic development (World Bank, 2010f).

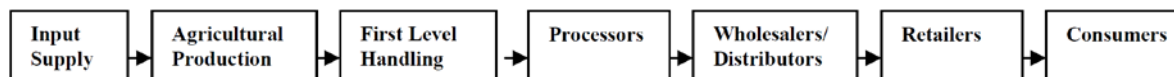
These examples show how, at a certain moment in time, vulnerability can be caused by the location of populations living in places at risk. We later explore in more detail the case of Ethiopia (see Box 4.1), with the aim of understanding how vulnerability changes as a result of changes in geography (and other variables).

4.4.2 Sectoral patterns of development

There is some evidence on the relationship between development patterns in terms of sectors and vulnerability or resilience. We take as our case study the agricultural sector. Agriculture is one of the economic sectors most vulnerable to the impacts of climate change because agricultural activities are by their nature prone to risks and uncertainties of various social, economic and environmental types (IIASA, 2002). Many of these risks have a climatic component and most of them will be affected by climate change, either in intensity, scope or frequency. The impact of a risk will depend on the shock itself and on the system to which it is applied. The system will be more or less affected by a particular shock depending on its vulnerability, and it will recover more or less easily depending on its resilience (Gitz and Meybeck, 2012).

When looking at a particular sector, one can represent it as a production supply. A shock to any part of this supply-chain will affect other connected sectors. This will change the relative price of final goods in any connected supply-chain and this will in turn change the composition of consumer demand, which will subsequently affect all sectors of the economy (Vivid Economics, 2013).

For example, if we assume that the value chain for the agricultural sector is the one depicted in Figure 4.3, a shock to any particular phase in the chain could have potential consequences in other phases in the chain, with the extent depending on the sector's vulnerability and resilience.

Figure 4.3. Example of value chain for agricultural products

Source: Smart Marketing (2005).

The economic vulnerability of agriculture is related to a number of interacting elements that include its importance in the overall national economy, trade and foreign exchange earnings, aid and investments, international prices of agricultural commodities and inputs, and production and consumption patterns (IIASA, 2002). Further research into how these processes take place would provide useful inputs to better understand the extent to which policies (including climate change ones) will be able to reduce vulnerability and increase resilience.

Climate change is likely to harm developing economies, which tend to generate a major portion of their GDP from climate-sensitive sectors (Mideksa, 2009). Benson and Clay (1998) argue that there is a U-shaped relationship between development and vulnerability to climate change, drawing on evidence from the consequences of the 1991/92 southern African drought. They state that the economic impact of climate-related shocks such as drought was higher for economies that had moved from a 'simple stage' of water-intensive agriculture and subsistence toward a more 'intermediate stage' of development, with labour-intensive low-technology manufacturing. Vulnerability was lower where economies had become more diversified and developed (Vivid Economics, 2010).

Countries that reach the middle of the 21st century with large shares of their populations engaged in subsistence agriculture will be particularly vulnerable to the effects of climate change (World Bank, 2010). Adaptation requires sectoral shifts away from climate-sensitive activities (Pye et al., 2010), and agricultural expansion that increases reliance on scarce water resources potentially increases vulnerability (Vivid Economics, 2010). Furthermore, shrimp farming and the conversion of coastal mangroves, while profitable in an economic sense, can exacerbate vulnerability to sea-level rise (Agrawala et al., 2005 in Adger et al., 2007). Diversification away from agriculture into manufacturing is likely to reduce the severity of climate change impacts (Vivid Economics, 2010). Developing countries are also more vulnerable than developed countries because they are characterised by a high reliance on physical infrastructure for GDP creation and have a lower share in services (Benson and Clay, 2004; Ghesquiere and Mahul, 2010; OECD, 2013). A step forward in this analysis would be to better understand the paths that can make this transformation happen. For instance, is there any particular sector that has the characteristics to build resilient development? The answer is still not clear as this is a relative new area of research. Further work in this area would help respond to these questions.

Vulnerability extends beyond subsistence farmers or those who produce for their own or local consumption. Farmers growing predominantly cash crops are also very vulnerable. Some crops like coffee are particularly sensitive to temperature (IPCC, 2014). For many crops, the effects of temperature will depend on the stage at which the crop is. For instance, rice is most sensitive to high temperatures at heading and wheat is more sensitive to high temperatures in the period during which its flower is fully open and functional (Luo, 2011).

There is some country-level evidence:

- In Mozambique, agriculture employs over 70% of the population, and the most vulnerable sectors are agriculture, energy (particularly hydropower generation, which is dependent on water runoff), transport infrastructure (notably roads), and coastal areas (World Bank, 2010a).

- Ethiopia is heavily dependent on rain-fed agriculture, which combined with other factors makes it highly vulnerable to the impacts of climate change (World Bank 2010b).
- Ghana also is highly vulnerable to climate change and variability because it is heavily dependent on climate-sensitive sectors such as agriculture (which is largely rain-fed with a low level of irrigation development), forestry, and hydropower (World Bank, 2010c).
- Although Bolivia's main economic sectors are minerals and gas, which are relatively insensitive to climate change, most people are engaged in small-scale agriculture, a sector that is quite vulnerable to the effects of a changing climate (World Bank, 2010e).

A more detailed example is analysed in Box 4.1 for Ethiopia.

In terms of the structure of markets and economic sectors, there is generally a high level of agreement and medium-strength evidence that well-functioning markets provide an additional mechanism for adaptation and therefore tend to reduce the negative impacts for any specific sector or country. However, as was demonstrated earlier, climate impacts in one country on one sector of the economy in turn affect other sectors and other countries through product and input markets. Although markets increase overall welfare, they do not necessarily increase welfare in every sector and every country (IPCC, 2014).

A higher level of connectedness between economic sectors can increase indirect impacts and thus the total economic cost of a disaster (OECD, 2013; Okuyama, 2009; Benson and Clay, 2004; Ghesquiere and Mahul, 2010). Also, vulnerability increases in the presence of limited flexibility of productive factors such as labour in the presence of high growth rates (OECD, 2013; Hallegatte and Ghil, 2008).

Dercon (2012) argues that growth that is less labour-intensive will slow the labour absorption from agriculture. Moreover, inputs into agricultural growth – such as fertiliser, water or transport – will become more expensive.

4.4.3 Distributional patterns of development

Does growth combined with or characterised by a reduction in inequality lead to more resilient economies? The intuitive answer is yes, given that the poor are disproportionately affected by shocks. However, the evidence from the literature is more complex than one might expect.

Chapter 13 of the Fifth Assessment Report of the IPCC (IPCC, 2014) on Poverty and Livelihoods indicates that the complex interactions among weather events and climate, dynamic livelihoods, multidimensional poverty and deprivation, and persistent inequalities (including on gender) create a shifting context of risk. Climate change, climate variability, and extreme events synergistically add on to and often reinforce other environmental, social, and political calamities (IPCC, 2014; Field et al., 2012). The IPCC (2014), however, also reports that, despite this recognition, there is no single conceptual framework in the literature that captures them concurrently, and few studies exist that overlay gradual climatic shifts or rapid-onset events onto livelihood risks.

Countries that reach the middle of the 21st century with substantial illiteracy and lethargic or inept institutions will be particularly vulnerable to the effects of climate change (World Bank, 2010). There is a medium to high level of confidence that the risks for disproportionately affected people and communities are generally greatest in low-latitude, less-developed areas, and are moderate at recent temperatures because of regionally differentiated climate change impacts on food production (IPCC, 2014).

There is further evidence from case studies that poverty tends to exacerbate the costs of climate change (Vivid Economics, 2010; Bowen et al., 2009; O'Brien et al., 2008). Economic growth has the potential to increase resilience by removing poverty-related gaps in adaptive capacity – the

poorest within a country are the least able to adapt. For example, based on an analysis of Malawi's famines in 2001/02 and then in 2005 it was found that, because of deep structural poverty over the years, farming households had contributed to the deterioration of soil by failing to invest in land inputs (Vivid Economics, 2010; Menon, 2007).

From studies on the economics of adaptation at the country level we learn that:

- Ghana is highly vulnerable to climate change impacts and real household consumption is expected to decrease by 5 to 10% by 2050 (with rural households suffering greater reductions) due to the country's reliance on agriculture and therefore exposure to the negative impacts of a changing climate on agricultural production (World Bank, 2010c).
- In 1998, Hurricane Mitch affected poor households in Honduras proportionally more than other groups; among affected households, the poor lost 15 to 20% while the richest lost only 3% (WDR, 2010).

4.5 Recommendations for further research

As acknowledged by the IPCC (2014), **the question of whether there are some patterns that lead to climate-resilient development has been not addressed in detail by the academic literature**. However, there are learnings from other strands of the literature (see Section 4.4) that can be applied in some cases to the case of climate change. This is partly due to the fact that this is a new area of research. We recommend that more research in this area should be conducted.

1. Given the very wide scope of this question, our suggestion is to begin by **focusing on particular case studies**, which can offer a good starting point. The case studies should look into how the vulnerability of a country (or region) has been affected by particular patterns, and how weather variability is likely to affect those. In this section we looked into the case of Ethiopia, and found evidence of how some particular patterns of development are affected by climate change. A more detailed study of this case study could lead richer findings that can contribute to the understanding of this question.
2. Most examples in the literature look at a particular point in time. For this reason, case studies should have **a particular emphasis on understanding the dynamics** of how a country (or a region) has moved to more climate-resilient development. Again, by focusing on some particular countries to start with, will allow us to improve the quality of the findings that provide answers to this questions.

Box 4.1 Ethiopia's vulnerability to climate change

Most existing evidence on how geographical, sectoral and distributional patterns of development affect resilience refer to countries or regions that are highly vulnerable because of where people live or what sectors drive the economy (see examples in this section), while there is limited systematic evidence on how this has changed due to changes in their geography of population or sectoral composition of growth. The case study below provides more detail on how Ethiopia's vulnerability has been affected by these patterns, and how projections expect these to change.

Ethiopia is one of the most vulnerable countries in the world to the impacts of climate change. It is ranked 11th of 233 countries in terms of vulnerability to physical climate impacts and 9th in terms of overall vulnerability, defined as physical impacts adjusted for coping ability (CGD, 2011).

The country has a long history of being prone to extreme weather variability, often suffering floods and droughts. Rainfall is characterised by its high intensity and degree of variability in both when and where it falls. Since the early 1980s, Ethiopia has experienced seven major droughts – five of which have led to severe food insecurity – and several other local droughts (World Bank, 2010). As temperatures will continue to rise, a correspondingly likely increase in the areas affected by drought and desertification is expected (Ethiopia Synthesis Report, ACCRA, n.d).

There are two main reasons for Ethiopia's vulnerability.

1. **Geographical patterns of development:** its geographical location and topography make Ethiopia highly prone to climate-related disasters. Approximately 90% of the population lives in the highlands (above 1,500 metres above sea level), while the lowlands are dominated by groups of mobile pastoralists (Ethiopia Synthesis Report, ACCRA, n.d).

Despite numerous efforts from the government, NGOs and donors, this development pattern is unlikely to change in the short run due to the fact that Ethiopia remains vulnerable to chronic food insecurity, which affects approximately 7.5 million people. This is because agriculture is primarily rain-fed, subsistence-oriented and characterised by low levels of both inputs and outputs. In addition, 72% of the population lives in areas subject to land degradation. Population growth is 2.5% per annum, resulting in a doubling of the population in less than 30 years, and this growth is mainly in rural areas.

The above evidence shows that there has been little change in the geography of the population in Ethiopia, keeping the country highly vulnerable to the impacts of climate change.

2. **Sectoral patterns of development:** most of the population is highly dependent on crop farming, making them vulnerable to climate and weather variability. The majority of Ethiopia's population is in fact mainly rural (83%) and depends on agricultural income. The dominant structure of the agricultural sector in the highlands is household-based, small-scale and subsistence-oriented. Ninety-five percent of Ethiopia's agricultural output and 95% of the total area under crops is small-scale subsistence farming (about 8 million peasant households). Chronic food insecurity affects 10% of the population (Ethiopia's Climate Resilient Green Strategy, 2011).

The World Bank (2010b) identifies three main sectors (called 'channels') through which climate vulnerability affects the Ethiopian economy and that are likely to be of major significance under the climate of the future. These are agriculture, transport (roads) and energy (dams). Agriculture is highly sensitive to seasonal variations in temperature and moisture, roads are often hit by floods (causing serious damage to infrastructure and disruptions to supply chains) and dams that provide hydropower are affected by large precipitation changes.

Despite a reduction in Ethiopia's dependency on agriculture, this sector remains the main source of income for most households in the country. For this reason, its population is and will remain highly vulnerable to climate change.

Mideksa (2010) computes the economy-wide impact of climate change and its distributional consequence with a sector-disaggregated general equilibrium model for Ethiopia. The results suggest that climate change will make economic development harder in at least two ways: first, by reducing agricultural production and output in the sectors linked to the agricultural sector, which is likely to reduce Ethiopia's GDP by about 10% from its benchmark level, and, second, by raising the degree of income inequality in which the Gini coefficient increases by 20%, which is likely to further decrease economic growth and fuel poverty. Thus, climate change is expected to increase the fraction of people in poverty by 'reducing the size of the total pie and redistributing it more unevenly'.

5 Is it possible to shape patterns of development using particular policies?

This section begins with the introduction of the research hypothesis and its rationale, followed by the explanation of the approach we follow. It then discusses two case studies – on Ethiopia and Bangladesh – before moving to the conclusions and further research recommendations.

5.1 The hypothesis and rationale

This section explores the following hypothesis:

‘It is possible to shape patterns of development using policy levers. Some policy levers are more effective than others in shaping patterns toward resilience building’

Many countries are currently integrating climate resilience into their development planning. However, given that this is somewhat novel, there is still no answer as to what the best way is to make this transition. We consider this question to be the most fundamental one for policy-makers that is addressed in this report. However, given that we are in the early stages of the implementation of these policies, there is still no evidence in the literature gathering findings and recommendations for ways to make this process successful and/or to identify potential bottlenecks.

In this section we aim to provide some very preliminary thoughts to help with the understanding of this question, i.e. whether more climate-resilient patterns of development could be shaped through climate change policies, and whether these policies may be effective or not overall. However, it is not within the scope of this study to provide an in-depth analysis.

5.2 Our approach

Policy responses intended to reduce vulnerability to climate change focus on either strengthening the adaptive capacity of the economic system (climate-resilient development) or on reducing the potential impacts of climate change by tackling exposure and/or sensitivity.

As mentioned above, there is very limited progress in the literature in relation to this research question and, for this reason, we take a different approach to this hypothesis here in comparison to the one used in previous sections.

A case study approach has been considered because it can provide some initial insights. In fact, every country exhibits a different pattern of development. It is of course not practical to analyse all the patterns of all the countries in the world. Clustering is also potentially challenging and not useful. For example, while some South Asian countries may exhibit similar geographic characteristics, they would have differing sectoral characteristics. We investigate patterns of development with relation to climate resilience in Bangladesh and Ethiopia. While their geography is very different, they are also exposed to a wide variety of disasters and are both among the 11 countries most at risk of disaster-induced poverty (ODI, 2013).

We have reviewed selected documents to assess the relationship between the patterns of development and increased resilience or vulnerability and in particular identified and analysed a few selected programmes on climate resilience in both countries. By looking at these interventions, we will attempt to provide some initial thoughts with the intention of understanding whether the patterns of development have been beneficial or not, and if there are important lessons to be drawn. However, much more research and analysis is needed in order to gather comprehensive learnings for this research question.

For each of the case studies we briefly summarise their main national development policies and climate change policies, after which we present a succinct analysis, followed by some general conclusions.

5.3 Ethiopia

As was highlighted in Box 4.1, Ethiopia is one of the countries most vulnerable to the impacts of climate change. The country is, however, moving forward in terms of the inclusion of climate change on the development agenda. The transformation includes integrating adaptation to climate change, green growth and disaster risk management into development planning.

5.3.1 Development priorities and policies

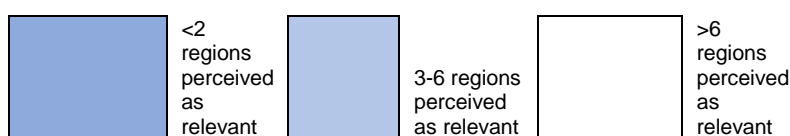
The main development agenda of the Ethiopian government is poverty eradication, and broad-based, accelerated and sustained growth is aimed at achieving this goal (Ethiopian ATA, 2014). Plans, policies and programmes of relevance in the area of climate change and social protection are: the Climate Resilient Green Economy (CRGE), the National Growth and Transformation Plan, and the Productive Safety Net Programme (PSNP).

The CRGE

The CRGE is Ethiopia’s development vision to gain middle-income status by 2025 through climate-resilient green growth, climate change adaptation and disaster risk management (see Federal Democratic Republic of Ethiopia, 2011). The most vulnerable economic sectors have been identified and prioritised for regional adaptation action (see Table 5.1).

Table 5.1. Sectors identified as most vulnerable to climate change hazards

Climate change hazards	Sector						
	Agriculture	Health	Water and energy	Buildings	Transport	Industry	Service
Flooding							
Droughts							
Diseases (human, animal, and crop)							
Wind damage							
Earthquakes							



Source: Federal Democratic Republic of Ethiopia (2011)

The green economy strategy is based on four pillars:

1. Improving crop and livestock production practices to increase food yields – and thus food security and farmer income – while at the same time reducing emissions;
2. Protecting and re-establishing forests for their economic and ecosystem services, including as carbon stocks;
3. Expanding electric power generation from renewable sources of energy fivefold for markets in Ethiopia and in neighbouring countries; and
4. Leapfrogging to modern and energy-efficient technologies in transport, industry, and buildings.

Wider socioeconomic benefits are expected and include the following:

- Public health is expected to improve with better water and air quality;
- Rural development will accelerate through reductions in soil erosion and increased soil fertility, thus helping the country's food security and rural employment; and
- Households will benefit from more efficient cooking/baking and transport, thereby increasing domestic savings and thus the capacity to invest in improving labour and land productivity and to participate more profitably in domestic and export markets.

The National Growth and Transformation Plan

The National Growth and Transformation Plan was established by the Government of Ethiopia as a strategic framework for the agricultural sector from 2011 to 2015 (see Ethiopian ATA, 2014). The overall target is to achieve at least 8.1% annual agricultural growth over the five-year period through:

- Enhancement of productivity and production of smallholder farmers and pastoralists;
- Strengthening of marketing systems;
- Improvement of participation and engagement of the private sector;
- Expansion of the amount of land under irrigation; and
- Reduction of the number of chronically food-insecure households.

The PSNP

The PSNP is the largest safety net in Africa. The programme aims at reducing household vulnerability, improving resilience to shocks and promoting sustainable community development in food-insecure areas of rural Ethiopia (World Bank IDA, 2012). It is recognised that the emergency in the Horn of Africa reflects a convergence of factors that are broader than drought alone, and include record high food prices and a humanitarian crisis aggravated by conflict in Somalia.

Every year for over two decades (1986–2006) the Ethiopian government launched international emergency appeals for assistance to meet the consumption needs of the country's food-insecure households. Despite the assistance being substantial, it has not provided a stable solution to planners, and consequently was not very effective in protecting livelihoods, preventing environmental degradation, generating community assets, or preserving physical or human household assets. This situation led to chronic food insecurity in a period of repeated droughts.

The project has two components. The first is characterised by sub-projects, determined locally by beneficiary communities, with the aim of sustainably rehabilitating the highly degraded environments that are one of the causes of food insecurity. The second component of the

programme is Direct Support, which provides grants to households who are labour-poor and cannot undertake public works.

It is anticipated that the PSNP will have reached in total 8.3 million people by 2015.

5.3.2 Brief analysis

Ethiopia has made big steps in proposing the CRGE, which is a development vision to gain middle-income status that starts from the acknowledgement and inclusion of climate change as a fundamental variable in what is a transformational path. As a complement, the National Growth and Transformation Plan identifies the agricultural sector as being key for the development of the country within the next five years. The strong dependency of the Ethiopian economy on agriculture has been identified as one of the main reasons why the country remains highly vulnerable to climate change (see Box 4.1). At the same time, according to the CRGE, the agricultural sector has only been identified as being particularly relevant for less than two regions in the country, while other sectors such as services and industry seem to be relevant for more than six regions. It appears that the Government of Ethiopia recognises the need to diversify away from the country's high dependency on agriculture. In summary, Ethiopia has both acknowledged the need to include climate change in development plans and has also recognised the need to diversify away from sectors that are particularly vulnerable to climate change. To complement such efforts, the PSNP has provided strong support to those households that are particularly vulnerable to food insecurity.

5.4 Bangladesh

5.4.1 Vulnerability and development context

Bangladesh is one of the most vulnerable countries in the world to the impacts of climate change (World Bank, 2010). Two-thirds of the nation is less than five metres above sea level, and the country is at the tail end of the delta of three main rivers, making Bangladesh extremely susceptible to river and rainwater flooding, especially during the monsoon season. Once every three to five years, up to two-thirds of Bangladesh is inundated by floods that cause substantial damage to infrastructure, housing, agriculture, and livelihoods. Low-lying coastal areas are also at very high risk from tidal floods and cyclones. On average once every three years, Bangladesh is heavily hit by a cyclone around the monsoon season, creating extremely high storm surges. In addition, the north western region is occasionally hit by seasonal droughts.

Most rural households depend on weather-sensitive sectors – such as agriculture, fisheries, and other natural resources – for their livelihoods. Crops and the livelihoods of the rural poor in low-lying coastal areas are also affected by saline water intrusion into aquifers and groundwater and land submergence.

These damages and losses are geographically concentrated in areas that also have higher concentrations of the poor, thus affecting this group disproportionately.

5.4.2 Development priorities and policies

Addressing the impacts of climate and non-climate natural disasters has been an integral part of Bangladesh's development plans. Investments made over the past 50 years have made the country more resilient to climate-related hazards, but additional steps are necessary to reduce potential damages from both existing and future climate-related hazards (World Bank, 2010).

Progress has been seen through the following:

- Switching from low-yielding deep water rice to high-yielding rice crops has increased agricultural productivity;
- Higher incomes have also enabled an increasing proportion of households to live in homes that are more resilient to natural disasters; and
- The government has made very large investments in disaster-reduction measures.

The National Sustainable Development Strategy (NSDS) and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) are of particular relevance when seeking to understand the country's direction in regard to sustainable development.

The NSDS

Bangladesh's main priority is slowing down the growth of the country's population, while also addressing other sustainable development challenges including poverty and inequality, unplanned urbanisation, energy security, inefficient water resources management, natural disasters and climate change.

The NSDS (2010–2021) has identified five strategic priority areas along with three cross-cutting areas with a view to achieving its stated vision (see NSDS, 2013). These strategic areas are: (i) sustained economic growth; (ii) development of priority sectors (agriculture and rural development, industry, energy, transport and human resources development); (iii) urban environment (urban housing, management of urban slums, water supply and sanitation, pollution management, urban transport and urban risk reduction); (iv) social security and protection; and (v) environment, natural resources and disaster management (water resources, forestry and bio-diversity, land and soil, coastal and marine resources, natural disasters and climate change). The three cross-cutting themes are good governance, gender, and disaster risk reduction and climate change.

The BCCSAP

Before the BCCSAP, climate change was poorly reflected in national policies and programmes in Bangladesh. The country launched the National Adaptation Programme of Action (NAPA) in 2005, which identified 15 priority activities that were subsequently updated to 45 programmes in 2009. The Coastal Zone Policy and the National Water Management Plan have also been subsequently produced.

The BCCSAP, which was prepared by the Ministry of Environment and Forest in 2009, is the country's guiding document to address climate change and to achieve sustainable development (see World Bank, 2010). The strategy identifies three main climate hazards – tropical cyclones/storm surges, inland flooding, and droughts.

The strategy is implemented through an Action Plan of 44 programmes based on six pillars:

1. Food security, social protection and health
2. Comprehensive disaster management
3. Infrastructure development
4. Research and knowledge management
5. Mitigation and low carbon development
6. Capacity building and institutional development

Thirty-four programmes listed under five themes are wholly or partially focused on adaptation.

5.4.3 Brief analysis

Bangladesh has made considerable progress in recognising that climate change is both one of the strategic priority areas and one of the cross-cutting areas in their NSDS. Climate change is therefore fundamental within their national development strategy. In addition, the BCCSAP provides guidance to address climate change and achieve sustainable development. Bangladesh has decades of experience dealing with disaster risk reduction and management, and is clearly integrating climate change into its agenda.

5.5 Some preliminary considerations

Despite the fact that both Ethiopia and Bangladesh appear to be undertaking considerable efforts to make their development plans climate-resilient, at this stage it is difficult to reach conclusions regarding the success of these policies and programmes. There are a number of considerations that can be made in this sense:

- Through a brief overview of two countries it is difficult to make very meaningful comparisons. Every country is different, and while there is some scope for sharing of lessons, policies and policy levers need to be very country-specific.
- It is difficult to assess whether policies and policy levers have been successful due to the fact that most climate change policies are recent and that climate change effects will be mostly felt in the future.
- For these reasons, it is challenging to at this stage make specific recommendations for particular regions of the world based on preliminary findings of two case studies (for instance drawing conclusions from the experience of Bangladesh to South Asia or from the experience of Ethiopia to Sub-Saharan Africa).
- However, it is clear that climate change has to be mainstreamed into national development planning (as has been done in both Ethiopia and Bangladesh) and supported by specific climate changes plans and policies.
- Climate change policies need to incorporate both mitigation and adaptation aspects, and be complemented with other policies such as those on disaster risk management, social protection, health, etc.
- It is expected that climate change adaptation policies have been developed on one side through a participative approach, therefore leading to actions that are felt to be necessary by relevant stakeholders, and on the other side are based on the most rigorous evidence available.

5.6 Recommendations for further research

As already mentioned, we consider this question to be the most fundamental facing policy-makers. At present there are many examples of countries that are integrating climate resilience into their development planning, but it is still too early to provide conclusions on how specific approaches have been more or less successful.

1. **We propose that this area should be the particular focus of work for coming years** as answers to these questions are fundamental and urgent.
2. Once again, **a starting point can be to look at case studies** in more detail in order to start gathering common findings and conclusions. We understand that DFID has a particular interest in South Asia and Sub-Saharan Africa. We suggest that further studies should continue to focus in these particular regions.
3. The analysis should then move into **identifying common patterns and providing guidance to countries on how to design and implement policies** that support the transformation toward climate-resilient development.
4. **We propose to focus on two or three case studies** (Ethiopia and Bangladesh could be part of this sample). A first step would be to **concentrate the research to the third and fourth hypotheses of this study**. After a thorough review of the literature and the development plans (including policies, action plans, etc) of each country, a field visit should follow where findings of key informant interviews would allow deepening the understanding of the preliminary findings of the research phase.

6 Conclusions

This report investigates four research hypotheses that aim to improve understanding of patterns of climate-resilient development. It is part of broader work by DFID in moving toward the adoption of resilience as a core approach that combines different but complementary areas of work, including adaptation to climate change, disaster risk management, social protection and others.

The scope of this study is extremely broad, as providing answers to each of the questions involved has been a focus of a great deal of research over several decades. This study had two main methodological goals:

1. To identify recent evidence in the literature to support or refute each of these hypotheses.
2. To identify gaps in the literature related to evidence and actual practise of climate-resilient development. This will help in the identification of areas for further research.

We found a broad body of evidence looking into the first hypothesis (with mixed findings), but very limited work done addressing the second, third and fourth hypotheses. We present the more detail the main conclusions for each of the four hypotheses with specific recommendations for further research below:

6.1 Hypothesis 1. Weather changes and climate shocks have a negative impact on economic growth in both the short and the long run.

Addressing this area will help DFID to make the case as to why policy-makers should be interested in moving toward patterns of development that help build resilience to a changing climate.

Our literature review identifies a broad body of academic work studying this hypothesis. In addition, related questions have also been addressed in major development and climate reports from donors and by the grey literature. Key findings are:

1. Climate shocks and natural disasters are generally found to affect economic growth in developing countries more strongly than in developed countries.
2. Economic growth is more vulnerable to natural disasters in small economies or countries where there are only a few large sectors. There is some discussion about whether it is the physical shocks (damages to capital) or the human shocks (through lives lost and affected) that cause a lowering of economic growth.
3. There is contrasting evidence as to whether disasters commonly cause a short-term decline in economic growth or not. In the case of the latter, in fact there is evidence that smaller but still large natural disasters have no discernible effect on output in the short or in the long run.
4. Socially and economically disadvantaged and marginalised people are disproportionately affected by climate change, and climate change generally contributes to increased poverty and inequality.

Despite the fact that there is broad research done in this area, we have identified two main gaps in the literature:

1. Most studies focus on the short run, and **there is little evidence of the impacts of climate weather variability in the long run (at least, based on historical data).**

2. Most evidence looks at the direct impacts of climate shocks on the economy. However, **measuring the indirect impacts has been less explored and is also much more challenging**. This may lead to underestimated findings.

6.2 Hypothesis 2. Weather-related shocks and trend changes that have an impact on the micro-economy can add up to macroeconomic impacts (and vice versa) because the economy is full of interlinked systems and networks.

Although findings related to Hypothesis 1 show that there is a broad body of literature pointing at a negative relation between weather variability and economic growth and poverty, the evidence is not always clear and it is often mixed. From an intuitive perspective, it is also puzzling that, although there is evidence of impacts of weather variability at the microeconomic level, these impacts are not always reflected at the macroeconomic level (and vice versa).

Despite it seemingly being intuitive, there is practically no empirical evidence in the literature to support or refute Hypothesis 2. However, without looking into the transmission from the macro to the micro level and vice versa per se, there is a strand of work that conceptually looks into other reasons why the impacts of disasters and climate shocks seem to be often underestimated. This body of literature identifies methodological challenges that should be further studied to improve the understanding of both the impacts of weather variability and also the transmission from micro to macro effects and vice versa.

This body of literature also proposes a conceptual framework to study the welfare impact of a disaster as a function of three main factors (see Figure 3.3):

- (i) the direct impacts of the disaster;
- (ii) the macroeconomic resilience; and
- (iii) the microeconomic resilience.

This conceptual framework can be used to better understand this research hypothesis from a conceptual perspective, as it does identify the way in which both macroeconomic and microeconomic variables are determinants in understanding the welfare impact of a disaster.

Hypothesis 2 is an area that would particularly benefit from further work. Here are some specific gaps:

1. **We found very little empirical evidence that micro effects add to the macro level.**
2. **Most empirical evidence looking at the long-term impacts of uninsured risk on the poor is at the micro level**, and there is very little work that quantifies the overall impact on growth and poverty.
3. **We did not find empirical evidence that macro impacts translate into micro impacts.**
4. **Most existing studies fail to take into account output losses** when looking at the impacts of disasters.

6.3 Hypothesis 3. There are some patterns of development that increase the vulnerability of an economy to climate shocks, and there are some that build resilience to deal with shocks (and, potentially, future trends). What are they?

This hypothesis is important in helping DFID to better identify ways to support countries moving to more resilient patterns of development. However, this hypothesis poses a challenge as it is a very new area of research and is therefore understudied. Nonetheless, there are relevant learnings that can be drawn from other areas of research. As agreed with DFID, our literature review was narrowed down to three particular patterns of development: geographical, sectoral and distributional patterns of development.

Geographic patterns of development refer to where in a country or area development is taking place in a physical sense. The geography of growth is usually driven by economic opportunities; for example, coastal cities develop around a port or trading hub. The geography of development will drive both exposure (the value of assets and number of people physically exposed to climate hazards) and capacity of people and firms to respond to shocks (it will influence how rich they are and what they do for a living).

Sectoral patterns of development refer to the parts of the economy that are growing and that are shrinking. Different sectors and industries will vary in their exposure and sensitivity to climate hazards.

The distributional impacts of development address the extent to which growth is inclusive or increasingly unequal. Inclusive growth should benefit the poorest, who are typically the most vulnerable, helping them build their resilience. However, it might not be the fastest type of growth.

There are examples where we find evidence that countries' vulnerability is affected by these patterns. The case of Ethiopia is very clear; the country's development is affected by its geography (which makes the country highly prone to climate change disasters), the high dependence of its economy on agriculture (which is very vulnerable to the impacts of climate change and to disasters), and exposure to distributional impacts (there is evidence that climate change is likely to raise the country's inequality).

The following gaps were identified and recommendations for further research made:

1. Given the very wide scope of this question, our suggestion is to begin by **focusing on particular case studies**, which can offer a good starting point. The case studies should look into how the vulnerability of a country (or region) has been affected by particular patterns, and how climate change is likely to affect those.
2. Most examples in the literature look at a particular point in time. For this reason, case studies should have a **particular emphasis on understanding the dynamics** of how a country (or a region) has moved to more climate-resilient development.

6.4 Hypothesis 4. It is possible to shape patterns of development using policy levers. Some policy levers are more effective than others in shaping patterns toward resilience building.

Exploration of this research hypothesis will help DFID to start to form ideas about what policy advice can help countries develop in a more resilient way. This is a fundamental question for policy-makers. There is, however, very limited progress in the literature in studying this research question. We propose that this area of research should be the main focus of future work. We look into what two countries – Ethiopia and Bangladesh – are currently doing in order to shift toward more climate-resilient patterns of development. However, it is still too early to know whether these programmes have been successful.

Our main findings in this vein are as follows:

1. It is difficult to make very meaningful comparisons through a brief overview of two countries. Every country is different, and while there is some scope for sharing of lessons, policies and policy levers need to be very country-specific.
2. It is difficult to assess whether policies and policy levers have been successful due the fact that most climate change policies are recent and that climate change effects will be mostly felt in the future.
3. However, it is clear that climate change has to be mainstreamed into national development planning (as both Ethiopia and Bangladesh have done) and supported by specific climate changes plans and policies.
4. Climate change policies need to incorporate both mitigation and adaptation aspects, and be complemented with other policies such as those on disaster risk management, social protection, health, etc.
5. It is expected that climate change adaptation policies have been developed on one side through a participative approach, therefore leading to actions that are felt as necessary by relevant stakeholders, and on the other side are based on the most rigorous evidence available.

We propose the following approach to strengthen research in this area:

1. **We firmly believe that this area should be the particular focus of work for coming years**, as answers to these questions are fundamental and urgent.
2. Once again, **a starting point can be to look at case studies** in more detail in order to start gathering common findings and conclusions. Given the particular interests of DFID, we recommend to particularly focus on countries in South Asia and Sub Saharan Africa.
3. The analysis should then move onto **identifying common patterns and providing guidance to countries as to how to design and implement policies** that support the transformation toward climate-resilient development.
4. **We propose to focus on two or three case studies** (Ethiopia and Bangladesh could be part of this sample). After a thorough review of the literature and the development plans of each country, a field visit should follow where findings of key informant interviews would allow deepening the understanding of the preliminary findings of the research phase.

6.5 Further reflections

6.5.1 Learn from Political Economy Analysis

Although this study did not look into political economy analysis, we consider that it will play a central role in enabling us to understand where there is space for reform and the incentives required to gain support from key, high-level stakeholders. For this reason, we propose that the study of Hypothesis 4 (in particular) is closely linked with research on the political economy of climate change.

We are aware of some literature that directly comments on the political economy of climate change and disaster management, including responses by international, national and subnational bodies. From a preliminary glance, this literature appears to be highly varied, ranging from international negotiations to national government policy responses to the role of ideology and discourse.

6.5.2 Learning from other relevant projects

There are many other projects under way that will undoubtedly provide insights into Hypotheses 2, 3 and 4. For instance, we recommend to follow up on the work currently done by the Pilot Program for Climate Resilience (PPCR) providing funds for technical assistance and investments to support countries' efforts to integrate climate risk and resilience into core development planning and implementation. Learnings from these programs will provide inputs for Hypothesis 4. Other examples of relevant projects currently taking place are the work by the OECD on Integrating Climate Resilience into Development; by GFDRR and DFID on the Impact Appraisal for Sovereign Disaster Risk Financing and Insurance; by the World Bank on Financial Innovations for Social and Climatic Resilience: Establishing an Evidence Base; and by the World Bank on Climate Change and Poverty.

Annex A Methodology used for Hypothesis 1

Our literature review for Hypothesis 1 comprised three parallel phases: one was to consult with widely recognised sources, the second to conduct a semi-systematic review of the academic literature, and the third to complement our findings with grey literature. We describe the three processes below.

A.1 Consulting widely recognised sources

We looked at most widely recognised reports and academic journals on relevant topics for this study. In particular, we carefully revisited Chapter 1 of the World Development Report 2010 on Development and Climate Change; Chapter 2 of the World Development Report 2014 on Risk and Opportunity; Chapter 2 of Natural Hazards, Unnatural Disasters; the IPCC Fifth Assessment Report; the forthcoming paper by Dell, Jones and Olken in the *Journal of Economic Literature*, 'What Do We Learn from the Weather? The New Climate-Economy Literature'; the paper by Kousky (2013), 'Informing Climate Adaptation: A Review of the Economic Costs of Natural Disasters'; and the paper by Cavallo and Noy (2010), 'The Economics of Natural Disasters: A Survey'. In addition, we complemented our search with papers and literature suggested during key informant interviews.

Our selection of the most relevant papers was based on those papers quoted by these sources and was complemented with the findings of our semi-systematic search and the grey literature. We believe this methodology allowed us to identify the most relevant papers in this body of literature.

A.2 Academic papers – semi-systematic review

Through an internal process within the team, a list of search terms was created to address the research questions proposed by DFID. These questions are included in the second column of Table A.1 below.

These terms were then entered into Scopus, which is a widely used search engine for social science papers. Singular words were used, since this would allow the singular and plural form of the word to appear as part of the search results. Asterisks were utilised when needed. For instance, labo* was entered as it would thus reveal 'labour' (UK spelling) and 'labor' (US spelling). Since the Terms of Reference asked for 'recent papers' we limited the search to papers that were published in 2004 or afterwards, thus allowing us to get a review of the literature within the past 10 years. We also limited our search to papers that came under the social science and humanities subject area. Table A.1 illustrates the search terms that were used for each research question and the number of papers that came up for each of the searches carried out.

A.3 Grey literature

The websites of the World Bank, Organisation of Economic Co-operation and Development, Provention, United Nations Office for Disaster Risk Reduction and the Stockholm Environmental Institute were searched for post-2003 papers that related to the first two research questions (this list was agreed with DFID). Most of the literature that could be found on these websites related to adaptation and mitigation measures and was therefore not relevant. However, more than 20 documents were found to be useful and were later read. In addition, during the main review phase, we also looked at the reports and documents recommended by DFID staff after our scoping phase presentation.

Table A.1: Results from the literature search

No.	Research question	Search terms	No. of results
1	Evidence of macro impacts of natural disasters (including weather-related shocks) and trend changes in the weather on macroeconomic variables, including GDP levels and (short- and long-term) growth rates	macroeconomic OR growth OR gdp OR price OR national income OR national investment OR multiplier effect OR poverty OR unemployment OR labo* AND disaster OR climate OR weather OR global warming OR greenhouse gas OR ghg OR drought OR flood OR storm OR sea level rise AND impact OR effect AND shock OR trend	461
2	Evidence of direct (first-round) micro impacts, distinguishing shocks from trends (to the extent the literature allows)	microeconomic OR household OR firm OR community OR supply chain OR value chain OR industry OR market AND disaster OR climate OR weather OR global warming OR greenhouse gas OR ghg OR drought OR flood OR storm OR sea level rise AND impact OR effect AND shock OR trend	454
3	Evidence of micro-transmission mechanisms (assessing second and subsequent round effects) distinguishing shocks from trends (to the extent the literature allows)	transmission OR pathway OR second round effect AND microeconomic OR household OR firm OR community OR supply chain OR value chain OR industry OR market AND impact OR effect AND shock OR trend	317
4	Evidence of macro-transmission mechanisms, including: evidence on what determines the size of any multiplier effect and how this may change the longer it is after a shock; and what institutions seem to matter for containing transmission mechanisms, again distinguishing shocks from trends (how either may affect a country's comparative advantage)	macro-transmission OR multiplier OR institution OR quantifying impact AND macroeconomic OR growth OR gdp OR price OR national income OR national investment OR multiplier effect OR poverty OR unemployment OR labo* AND impact OR effect AND shock OR trend	370
5	Studies, particularly in developing countries, which have sought to evaluate the effectiveness of measures to avoid a shock or trend change, contain	government OR policy OR adaptation measure OR adaptation response OR disaster risk management OR aid program* OR reform OR contribution OR recovery OR NAPA OR National Adaptation Plan of	92,344

	its impact or speed the recovery	Action AND effectiveness OR impact OR measurement OR trade-off OR evaluate OR evaluation	
6	Studies into the behavioural issues in promoting more resilient systems, be they barriers or opportunities at household, firm or more macro levels	government OR policy OR adaptation measure OR adaptation response OR disaster risk management OR aid program* OR reform AND political economy OR behavio* change OR institutional incentive OR power OR barrier	41,968
7	Trade-offs between existing patterns of growth and more climate-resilient patterns, noting both those envisaged and those for which there is evidence	(See points five and six above)	

A.4 Mapping of literature search

We used Table A.2 to map the findings of our search. This table was originally presented to DFID during the kick-off meeting as an initial attempt from the research team to re-interpret the seven questions included in the Terms of Reference. The columns in this table represent areas of research that are addressed in each of the seven research questions. The boxes marked with an X represent areas of research addressed in each question, whereas empty boxes represent areas not covered. The initial goal of this table was to show and map the very broad area of work that was covered by the seven questions. During the kick-off meeting, it was agreed with DFID that one of the goals of the scoping phase would be to narrow down the Terms of Reference so that the team could make the best use of their resources.

As can be seen in Table A.1 above, the results for questions 5 and 6 gave an extremely large number of search results. Therefore, because of time constraints in the scoping phase we decided to limit the readings of abstracts and papers for questions 1, 2, 3 and 4. This was agreed in a phone call with DFID on 25 November 2013.

For the first four questions, the abstracts, keywords and titles of all the papers were downloaded using Endnote and read. Those that were not relevant to any of the research questions were crossed off. Where a paper was relevant to a research question, it was noted down using the mapping matrix in Table A.2. It was the case that even though a paper came up in the search results for question 1, for example, it may have been relevant to another research question as well. Abstracts that were relevant for questions 5 and 6 were also noted, as these would be useful during the main review phase later in the assignment.

Table A.2: Literature review mapping matrix

Research questions	Study area	Macro level	Micro level	Shocks	Trends
1 and 2	Evidence impacts / effects	X	X	X	X
3 and 4	Transmission mechanisms	X	X	X	X
5	Effectiveness of measures to avoid shocks and trends			X	X
6	Behavioural issues promoting resilient systems	X	X		
7	Trade-offs growth/climate resilience				

Those papers that were *especially* relevant to a research question were highlighted, thereby creating a shortlist from the larger number of papers for a research question. For questions 3 and

4, of these shortlisted papers, those that were related to climate change or disasters were prioritised.

Annex B Annotated bibliography of papers reviewed for Hypothesis 1

This annex presents summaries of 34 empirical papers recently published looking at the links between weather variability and economic growth. The selection was made using the papers mostly quoted by widely recognized reports and authors and was complemented with the semi-systematic search conducted by our team. They are presented in alphabetical order.

1. Auffret, P. (2003) High Consumption Volatility: The Impact of Natural Disasters? World Bank Policy Research Working Paper 2962

The paper conducts an empirical analysis of the impact of natural disasters on 16 countries (six from the Caribbean region and 10 from Latin America) for the period 1970–1999. Natural disasters that are covered are earthquakes, tsunamis, slides, lahars, volcanic eruptions, hurricanes and tropical storms, floods, droughts and forest fires. The impact of catastrophic events on macroeconomic variables (production, public and private consumption, investment and external balance) is estimated using dynamic panel data models based on generalised methods of moments (GMM). Catastrophic events are proxied by a variable (Cat) which takes the value of the costs of the damage (as percentage of GDP) in the year when the catastrophic events occur and zero otherwise. Additionally, changes in (log) income Dy , (log) consumption Dc and (log) investment $Dinv$ are modelled as autoregressive processes. The results show that catastrophic events lead to: (i) a substantial decline in the growth of output; (ii) a substantial decline in the growth of investment; (iii) a more moderate decline in consumption growth (most of the decline is in private consumption while public consumption declines moderately); and (iv) a worsening of the current account of the balance of payments.

2. Barrios Cobos, S., Bertinelli, L. and Strobl, E. (2008) Trends in Rainfall and Economic Growth in Africa: A Neglected Cause of the Growth Tragedy, Proceedings of the German Development Economics Conference, Zurich 2008, No. 41, pp. 1–45

The authors use a new cross-country panel climatic data set in an empirical economic growth framework to investigate the role of rainfall trends in the poor growth performance of sub-Saharan African (SSA) nations relative to other developing countries. Annual rainfall data for 289 ‘countries’ (comprised of 188 states and 101 islands and territories) from 1901 to 2000 is used and GDP per capita data from 1960 to 2000 is proxied as a measure of economic performance. Rainfall is treated as a strictly exogenous factor. The main finding is that rainfall has been a significant determinant of poor economic growth for SSA but not for other countries in the Global South. The direct impact under the scenario of no decline in rainfall would have resulted in a reduction of between around 15 and 40% of today’s gap in SSA GDP per capita relative to the rest of the developing world. The authors argue that policy-makers should take specific steps to lower African countries’ sensitivity to rainfall variations.

3. Benson, C. and Clay, E. J. (2004) Understanding the economic and financial impacts of natural disasters, Disaster Risk Management Series No. 4, The World Bank, Washington DC

The study uses a mixture of formal quantitative and qualitative analysis to examine the short- and long-term economic impacts of natural disasters. It relies in part on in-depth case studies of Dominica, Bangladesh, Malawi and southern Africa. The quantitative investigations are partial, involving a combination of regression analysis, the use of charts to examine movement around trends, and ‘before-and-after’ comparison of disaster impacts and of forecast and actual economic performance. If impacts are not apparent at an aggregate level (in terms of GDP performance), the analysis moves on to consider possible effects within the composition of the relevant economic

indicator. A qualitative political-economic analysis is also employed in a complementary way to place quantitative results within the specific economic and social policy context of each case study country. For each case study, a country visit was made to collate data and conduct interviews with key informers.

Some of the findings include that disasters commonly cause a short-term decline in GDP. Long-term impacts are that capital assets and other resources can be severely damaged, and the productivity of undamaged capital and labour can be reduced by associated disruptions of infrastructure and markets. Except in the case of drought, significant direct capital losses can result. All major types of disaster can disrupt longer-term investment plans for both physical and human capital. Governments may divert resources away from planned investments to fund relief and rehabilitation. Disasters contribute to economic instability and to an atmosphere of uncertainty, deterring potential investors.

4. Blanco, J. T. and Hernández, D. (2009) *The Potential Costs of Climate Change in Tropical Vector-Borne Diseases- A Case Study of Malaria and Dengue in Colombia* in W. Vergara (ed.) *Assessing the Potential Consequences of Climate Destabilization in Latin America*, Sustainable Development Working Paper 32, World Bank: Latin America and Caribbean Region, Washington DC

The study uses a statistical-empirical approach to estimate the impact of climate change on malaria and dengue epidemics in Colombia. With the statistics of the number of cases of malaria and dengue reported by 715/716 municipalities between 2000 and 2005 and the climate change variables from 1995 to 2005, the study tests two types of models (inter-temporal and cross-sectional) to find the relationship between epidemics and climate change variables (temperature and precipitation).

In the cross-sectional analysis, the model's dependent variable was constructed as the rate of morbidity during the 2000–2005 period, whereas the independent variables comprise the monthly mean temperature and the average annual precipitation during the 1995–2005 period. The model also includes a socioeconomic variable. A significant relation was discovered; an increase in the level of annual rainfall will generate an increase of the rate of malaria incidence in the municipalities. For dengue, the temperature variable was significant but precipitation was not.

In the inter-temporal analysis, the dependent variable was constructed as the difference between the rates of morbidity of the 2000–2002 period and the 2003–2005 period, and the variance was calculated as the difference between the maximum and minimum average of the monthly temperature from 1995 to 2005, and between the maximum and minimum total annual precipitation, both from 1995 to 2005. A socioeconomic variable was also included. None of the inter-temporal models were significant enough to explain the variation of the incidence rate within municipalities.

The direct and indirect unit costs of malaria and dengue cases was calculated to estimate the total costs of climate change i.e. US\$ 2.5 million and US\$ 7.6 million for 50- and 100-year scenarios respectively. The burden will be borne mainly by the low-income population, and the additional cases represent an increase of 11% and 35%, for 50 and 100 years respectively, compared to the 2000–2005 period.

5. Brown, C., Meeks, R., Ghile, Y. and Hunu, K. (2010) *An Empirical Analysis of the Effects of Climate Variables on National Level Economic Growth*, Policy Research Working Paper 5357, The World Bank, Washington DC

The authors use a precipitation index that preserves the spatial and temporal variability of precipitation maximums and minimums. A year and country fixed regression model is developed to test the influence of climate variables (independent variables) on measures of national-level economic growth and activity (dependent variables) for 133 countries. Climate variables are temperature and precipitation for 1901 to 2003 and economic growth is proxied by GDP growth, agricultural GDP value added, industrial GDP value added and poverty headcount ratio at national poverty line, covering the period 1961–2003. The main findings are that precipitation extremes (such as floods and droughts) are the dominant climate influence on economic growth and the effects are significant and negative. Droughts are associated with highly significant negative influences on growth of GDP and floods are associated with a negative influence of GDP and lagged effects on growth. Temperature has little significant effect. The authors use this evidence to conclude that adaptation strategies should give new importance to water resources.

6. Cavallo, E., Galiani, S., Noy, I. and J. Pantano (2011) *Catastrophic Natural Disasters and Economic Growth*, Mimeo, Inter-American Development Bank, Washington, DC

The paper uses a quasi-experimental design to examine the short (less than five years) and long run (five years or more) average causal impact of pre-2000 catastrophic natural disasters on economic growth. It does this by combining information from cross-country case studies in a comparative event study approach, using a dataset of 196 countries covering the period 1970–2008. The data on real GDP per capita at purchasing power parities comes from the World Bank World Development Indicators and the data on natural disasters and their economic impacts comes from the EM-DAT database. The magnitude of the disaster is defined by the variable ‘number of people killed’ divided by the total population. The study assesses the counterfactual of the cases studied by constructing synthetic control groups, taking advantage of the fact that the timing of large sudden natural disasters is an exogenous event. The authors find that only extremely large disasters have a negative effect on output both in the short and long run. However, this results from two events where radical political revolutions followed the natural disasters. Once the authors control for these political changes, even extremely large disasters do not display any significant effect on economic growth. They also find that smaller but still large natural disasters have no discernible effect on output in the short run or in the long run.

7. Confalonieri, U., Menne, B., Akhtar, R., Elbi, K.L., Hauengue, H., Kovats, R. S. Revich, B., Woodward, A. (2007) Human Health, in M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.) *Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pp. 391–431

Climate change is contributing, both directly and indirectly, to the global burden of disease and premature deaths, and predictions are that the impact is likely to intensify. The authors use confidence levels to assess the direction and magnitude of change of selected health impacts of climate change at the global scale, taking into account the likely numbers of people at risk and potential adaptive capacity. Projected trends in climate change-related exposures of importance to human health will increase malnutrition and consequent disorders (high confidence); increase the number of people suffering from death, disease and injury (high confidence); continue to change the range of some infectious disease vectors (high confidence); have mixed effects on malaria (very high confidence); increase the burden of diarrhoeal diseases (medium confidence); increase cardio-respiratory morbidity and mortality associated with ground-level ozone (high confidence); increase the number of people at risk of dengue (low confidence); and bring some benefits to health, including fewer deaths from cold, although it is expected that these will be outweighed by the negative effects of rising temperatures worldwide, especially in developing countries (high

confidence). Adverse health impacts will be greatest in low-income countries and, for all countries, the urban poor, the elderly, children, traditional societies, subsistence farmers and coastal populations will be at greater risk (high confidence). Adaptive capacity needs to be improved; even high-income countries are ill-prepared to cope with extreme weather events (high confidence). Economic development will be an important component of adaptation, but on its own will not insulate the world's population from disease and injury due to climate change (very high confidence). Critically important will be the manner in which economic growth occurs, the distribution of the benefits of growth, and factors that directly shape the health of populations, such as education, health care, and public health infrastructure.

8. Cunado, J. and Ferreira, S. (2011) *The macroeconomic impacts of natural disasters: new evidence from floods*, Agricultural and Applied Economics Association's 2011 AAEA and NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania

The study compiles an unbalanced panel with annual data on the number and physical intensity of floods, and macroeconomic variables, to analyse the long-run economic impacts of floods. Data on 3,184 large flood events in 118 countries between 1985 and 2008 is utilised. The authors use panel vector auto-regressions, in the presence of endogenous variables and exogenous shocks, to trace the dynamic response of output to three types of flood shocks. Flood shocks are defined by experiencing an additional 'typical' large flood event, experiencing an exogenous increase in the magnitude of the average flood, and an increase in the death toll. The main variables used in the paper are divided into three groups: growth variables (growth rate of real per capita GDP, growth rate of real per capita value added in the agricultural and the non-agricultural sectors), flood event variables (total number of floods, average magnitude and total number of deaths) and institutional/macro-economic variables (to control for country differences: corruption and ethnic tensions, domestic credit to private sector and gross fixed capital formation). Observations from the countries are pooled over time to arrive at average responses of growth to major flood events. The results indicate that flood shocks tend to have a positive average impact on GDP growth, that this impact is limited to developing countries, that the effect is not confined to the agricultural sector, and that it is stronger when it is accompanied by an increase in gross fixed capital formation.

9. Dell, M., Jones, B. F. and Olken, B. A. (2009) *Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates*, *American Economic Review: Papers and Proceedings*, 99, 2, pp. 198–204

The authors analyse climate data from 12 countries in the America, which has been averaged over the 1950–2000 period, with country-level climate variables aggregating the municipal-level variables, weighting by 2000 municipal population. This paper offers two main findings. First, cross-sectional evidence is provided to explore the temperature–income relationship, using cross-country and subnational data at the municipal level. Variables used include municipal-level and national-level labour income data, mean temperature, mean precipitation levels and geography data to control for elevation, slope and distance from the municipality to the sea. It is found that there is a significant negative relationship between income and temperature when looking between countries and within countries, although the relationship is substantially smaller in magnitude within countries than across countries. The second finding is the provision of a theoretical framework that emphasises adaptation and convergence, to reconcile the strong cross-sectional effects of temperature with the even stronger short-run effects of temperature shown in panel models in the authors' previous work. Using equations with parameters that capture the degrees of adaptation and convergence over the long run to average temperature levels, estimates suggest that in the cross-country context adaptation offsets approximately a half of the negative effects of higher temperatures.

10. Dell, M., Jones, B. F. and Olken, B. A. (2012) Temperature Shocks and Economic Growth: Evidence from the Last Half Century, *American Economic Journal: Macroeconomics* 2012, 4, 3, pp. 66–95

The paper analyses the historical relationship between weather fluctuations and economic growth. The authors construct annual mean temperatures and precipitation panel data for 125 countries from 1950 to 2003 to identify its effects on the dependent variable: aggregate log per capita GDP in the year 2000. There are four main findings. First, changes in precipitation have relatively mild effects on national growth in rich and poor countries. Second, there is cross-sectional correlation: higher temperatures substantially reduce economic growth in poor countries. Third, higher temperatures may reduce growth rates, not just the level of output. Last, higher temperatures reduce agricultural output, industrial output and political stability, thus underscoring the breadth of mechanisms underlying the climate–economy relationship.

11. Dercon, S. (2004) Growth and shocks: evidence from rural Ethiopia, *Journal of Development Economics*, 74, pp. 309–329

Using panel data from 350 households in six villages in rural Ethiopia, the article discusses the determinants of consumption growth (1989–1997), based on a microgrowth model, controlling for heterogeneity. Growth is measured using the growth rates in food consumption. Measured recent and past shocks are directly introduced in the regressions, and their cumulative impact is quantified. Data from 1989 and from the revisits during four rounds in 1994 to 1997 is used. The results indicate that consumption grew substantially, but with diverse experiences across villages and individuals. Rainfall shocks have a substantial impact on consumption growth, which persists for many years. Indicators of the severity of the famine in 1984/85 are significant to explain growth in the 1990s, as well as substantial externalities from road infrastructure. Estimates suggest a substantial impact of about a 16 percentage point lower growth in the 1990s, when comparing groups that suffered substantially compared to those only moderately affected. The evidence suggests that a 10% lower rainfall about 4–5 years earlier had an impact of one percentage point on current growth rates. The persistent effects of rainfall shocks and the famine crisis imply that welfare losses due to the lack of insurance and protection measures are well beyond the welfare cost of short-term consumption fluctuations.

12. Ding, Y., Hayes, M. J., Widhalm, M. (2011) Measuring economic impacts of droughts: a review and discussion, *Disaster Prevention Management*, 20, 4, pp. 434–446

The objective of this literature review is to increase the understanding of the full scope of drought economic impacts and the associated quantitative assessment methodologies. It reviews studies in both agricultural and non-agricultural sectors, summarises the methods and data employed, compares the various results, and investigates the problems and limitations of previous studies. When assessing economic impacts, it is important to establish the geographical coverage and timeframe, to quantify overall drought impacts and identify the losses borne by different stakeholders. The direct economic impacts of droughts are in production, sales and business operations while indirect economic impacts of drought stem from the interactions and transactions among industries and sectors. Drought-induced losses are borne by farmers and a portion is passed on to consumers. Drought also causes significant economic impacts in non-agricultural sectors through its effects on water supplies. These non-agricultural sectors include tourism and recreation, public utilities, horticulture and landscaping services, navigation and other industries/businesses that have significant water consumption. The secondary impacts of drought are attributed to the upstream or downstream interactions and transactions among industries and sectors. Outputs from one industry/sector become inputs into other industries/sectors. Approaches used to estimate the secondary effects from an exogenous change such as drought are the Input-Output model and the Computable General Equilibrium Model. Although drought impacts exist in a variety of sectors, most impact studies are focused on the agricultural sector or sub-sectors. Most

drought impact studies were ad hoc, following a specific drought disaster. Many drought impact estimates were focused on short-term losses of production and income, while the lagged or dynamic impacts of drought were less investigated. The paper concludes with a discussion of the challenges and directions of future improvement on drought economic impact assessment.

13. Fomby, T., Ikeda, Y., and Loayza, N.V. (2013) *The Growth Aftermath of Natural Disasters*, *Journal of Applied Econometrics*, 28, pp. 412–434

This paper looks at the yearly response of GDP growth (both aggregated and disaggregated into agricultural and non-agricultural components) to four types of natural disasters (droughts, floods, earthquakes, and storms). It uses annual panel data for 84 countries between 1960 and 2007. Data on natural disasters come from the Centre for Research and Epidemiology of Disasters (CRED) and on macroeconomic variables comes from the World Development Indicators of the World Bank. The authors find heterogeneous effects: (i) the impacts of natural disasters are stronger on developing than on developed countries; (ii) the growth response induced by natural disasters is different, and can in some cases be positive; (iii) severe disasters tend to carry stronger effects; and (iv) the timing of growth response varies both with the type of disaster and with the sector of economic activity.

14. Heger, M., Julca, A. and Paddison, O. (2008) *Analysing the Impact of Natural Hazards in Small Economies: The Caribbean Case*, UNU-WIDER Research Paper 2008/25

This paper analyses the impact of natural disasters in 16 Caribbean states over 1970 to 2006. Natural disasters analysed are hurricanes, windstorms, earthquakes, droughts, epidemics, extreme temperature events, floods, famines, (mud) slides, waves, wildfires and volcanic eruptions. Simple OLS estimation and panel data are used, and interaction terms are investigated. A number of disaster variables are used: dummy disaster, count disaster, deaths, injured, homeless, affected and damage. Data used to calculate the Herfindahl-Hirschman index were drawn from the United Nations ComTrade database whereas economic indicators, which form our outcome variables, are taken from the World Development Indicators of the World Bank's 2006 edition. Among them are mainly measures of economic performance and trade of interest. Social and demographic variables are used as either control or as intermediating variables. The economic impact of natural disasters in the region has been significant, resulting in widespread destruction of the productive economy. This paper presents the main macroeconomic impact of disasters, including a collapse of growth, as a consequence of damage resulting from the event. A disaster negatively affects GDP per capita not only through its mere incidence but also through the impact on the victims that it causes (the deaths variable is significant). Interruption of production of goods and services can be particularly devastating in an environment where a few large sectors (e.g. agriculture or tourism) dominate the economic landscape.

15. Hochrainer, S. (2009) *Assessing the macroeconomic impacts of natural disasters: are there any?* Policy Research Working Paper 4968, The World Bank, Washington DC

This paper uses time series models to assess whether and by what mechanisms disasters have the potential to cause significant GDP impacts. Natural disasters that are considered are floods, storms, earthquakes, drought, volcanic eruptions, slow mass movements, tropical cyclones, winter storms, droughts and desertification. The sample consists of 225 large natural disaster events during 1960 to 2005 for various countries. The analysis first studies the counterfactual versus the observed GDP. The autoregressive integrated moving average model (ARIMA) is used, and the Box-Jenkins methodology is applied for determining the components of the ARIMA process. Forecasts into the future are performed with the selected econometric models and then compared to the observed variables. Second, the analysis assesses disaster impacts as a function of hazard,

exposure of assets, and vulnerability. In a medium-term analysis (up to five years after the disaster event), comparing the counterfactual with observed GDP, the author finds that natural disasters on average can lead to negative consequences, leading to a median reduction of GDP of about 4% points (of baseline GDP) in year 5 after the event. Although the negative effects may be small, they can become more pronounced depending mainly on the size of the shock. Using multivariate and general linear regression models, the author tests a large number of economic predictors that explain potential impacts to projected and observed GDP in year 5 post event. They find that greater aid and inflows of remittances reduce adverse macroeconomic consequences, and that direct losses appear most critical.

16. Hsiang, S. M. (2010) Temperatures and Cyclones Strongly Associated with Economic Production in the Caribbean and Central America, Proceedings of the National Academy of Sciences, 107, 35, pp. 15376–15372

Annual longitudinal data from 1970 to 2006 from 28 Caribbean and Central American countries are analysed with multiple regression analyses that control for rainfall, average country-level differences in production for each industry, country–industry time trends in production and year-level shocks to regional–industry production. Variables used are surface temperature and economic output and the impact of cyclones is measured through wind-field histories for every storm passing through the region, with energy dissipation per square metre then being computed for each location in the region and spatially averaged over each country for every year. The paper concludes that the response of economic output to increased temperature is similar to the response of labour productivity to high temperatures. Output losses in non-agricultural production are higher than in agricultural production. The author argues that models of the economic costs of climate change need to include the response of workers to thermal stress as well as the agricultural impacts.

17. Hsiang, S. M. and Jina, A. S. (2013) *The causal effect of environmental catastrophe on long-run economic growth*, Working Paper

Reconstructing every country's physical exposure to the universe of tropical cyclones during 1950 to 2008 (4,174 events in total), the paper exploits year-to-year variation in cyclone strikes to identify the effect of disasters on long-run growth. Eleven economic variables (including variables on agriculture, industry and services) and four physical characteristic variables are used. The authors find robust evidence that national incomes decline, relative to their pre-disaster trend, and do not recover within 20 years. This result is globally valid, holding for countries of all types, and is supported by non-income variables as well as global patterns of climate-based adaptation. National income loss arises from a small but persistent suppression of annual growth rates spread across the 15 years following disaster, generating large and significant cumulative effects: a 90th percentile event reduces per capita incomes by 7.4% two decades later, effectively undoing 3.7 years of average development. The gradual nature of these losses render them inconspicuous to a casual observer, but simulations indicate that they have dramatic influence over the long-run development of countries that are endowed with regular or continuous exposure to disaster. Linking these results to projections of future cyclone activity, the study estimates that under conservative discounting assumptions the present discounted cost of 'business as usual' climate change is roughly US\$ 9.7 trillion larger than previously thought.

18. Hsiang, S. M. and Narita, D. (2012) Adaptation to Cyclone Risk: Evidence from the Global Cross-Section, *Climate Change Economics*, 3, 2, pp. 1–28

Using a global cross-section of countries, the authors estimate the extent of adaptation to tropical cyclones. Every tropical cyclone that occurred in the world during 1950 to 2008 is reconstructed to parameterise 233 countries' tropical cyclone climate and annual cyclone exposure. Evidence of

adaptation is sought by comparing deaths and damages from physically similar cyclone events across countries with varying cyclone climatologies. Variables used are annual economic losses, annual deaths, wind speed, energy, climatological wind speed 1950–2008 and climatological energy 1950–2008. The main findings from the physical model are that countries with more intense cyclone climates suffer lower marginal losses from an actual cyclone event, suggesting that adaptation occurs but that it is costly. Adaptation to cyclones is feasible and cost-effective for countries with intense cyclone climatologies, but marginal changes from countries' current cyclone climates generate persistent losses.

19. Jaramillo, C. R. (2009) *Do natural disasters have long-term effects on growth?* Documentos CEDE, Universidad de los Andes, Bogota

Using panel data and macroeconomic variables of 113 countries and data from 1960 to 1996, Jaramillo examines the relationship between different measures of natural disaster impact and long-run GDP growth. The disaster events that are studied are earthquakes, floods, wild fires, wind storms, waves and surges, extreme temperatures, volcano episodes and slides. The sample is partitioned in two separate ways: according to the amount and type of disasters that countries have experienced and to the size of those disasters. For each partition, the author presents two sets of econometric estimations. The first regressions identify short-run (two years) and longer-lasting (five years) effects of large natural disasters. However, these first estimations do not distinguish between temporary but persistent effects and truly permanent ones. He thus estimates a structural model that allows him to identify permanent changes. The results of the first regressions show that for some of the groups of countries the disaster impact persists beyond the 2–5 years in which reconstruction and adaptation are expected to have an effect on the economy. However, the estimates using the structural model show that only for a very small number of countries which share a history of highly devastating natural disasters are the negative effects truly permanent.

20. Lanzafame, M. (2012) *Temperature, Rainfall and Economic Growth in Africa*, Empirical Economics, DOI 10.1007/s00181-012-0664-3

This study examines the aggregated effects of temperature and rainfall on economic growth in Africa. The dataset is for the period between 1962 and 2002 for 36 African countries. Economic variables come from the Penn World Tables Version 6.3 and rainfall and temperature variables come from the Terrestrial and Air Temperature and Precipitation: 1900–2006 Gridded Monthly Time Series Version 1.01. According to their findings, there is evidence of short and long-run relations between temperature and per capita GDP growth. On the contrary, rainfall appears to be less important. Far from adapting quickly to weather shocks, the paper concludes that African economies are significantly damaged by them.

21. Lecoq, F. and Shalizi, Z. (2007) *How Might Climate Change Affect Economic Growth in Developing Countries?* World Bank Policy Research Paper, 4315

This paper reviews both the theoretical and empirical literature on economic growth with the aim of studying how climate change affects growth. In particular it looks how at mitigation, proactive ex-ante adaptation, reactive ex-post adaptation and climate change damage impact growth. The authors conclude that the growth literature rarely addresses climate change. However, they identify some findings that are relevant for the discussion: (i) the destruction of production factors or the reduction in factor productivity may have a strong effect on the long-run equilibrium growth; (ii) climatic shocks have had large impacts on growth in developing countries because of rigidities; and (iii) the introduction of increasing returns has a big impact of growth dynamics. The paper also identifies gaps in the literature such as a lack of understanding of channels by which shocks affect economic growth and of lock-ins.

22. Loayza, N., Eduardo, O., Rigolini, J. and Christiaensen, L. (2009) *Natural Disasters and Growth: Going beyond the Averages*, Policy Research Working Paper, 4980, The World Bank

This paper explores the effects of droughts, floods, earthquakes and storms on growth separately by disaster and economic sector (agriculture, industry and services). This is consistent with the insights from traditional models of economic growth, where production depends on total factor productivity, the provision of intermediate outputs, and the capital–labour ratio, as well as the existence of important intersector linkages. The share of the population affected by a specific disaster over a given period of time is taken as measure of natural disaster. A dynamic GMM panel estimator is applied to a 1961–2005 pooled cross-country and time series panel of 94 developing and developed countries. The data are organised in non-overlapping five-year periods, with each country having at most nine observations. Four dependent variables are considered. Regressions are first run using the growth rate of real per capita GDP as dependent variable. Subsequently measures of the growth rate of real per capita value added in the three major sector of the economy are used. All of them are measured as the five-year average of the log differences of per capita output (in 2000 US dollars). Per capita output is obtained by dividing the value added of each sector by the total population. Three major insights emerge: first, disasters affect economic growth—but not always negatively, and differently across disasters and economic sectors; second, although moderate disasters can have a positive growth effect in some sectors, severe disasters do not; and third, growth in developing countries is more sensitive to natural disasters—more sectors are affected and the magnitudes are non-trivial.

23. Mechler, R. (2009) *Disasters and Economic Welfare: Can National Savings Help Explain Post-disaster Changes in Consumption?* Policy Research Working Paper 4988, The World Bank

A global sample of 99 large disaster losses over the 30-year period from 1971 to 2000 is used in this paper. Floods, storms, earthquakes, droughts, mass movements, wildfires and extreme temperatures are all covered. Regressions are run to examine whether traditional and alternative national savings measures combined with adjustments for the destruction of capital stocks may contribute to better explaining post-disaster changes in consumption expenditure. The analysis is based on observed and calculated savings and the present value of consumption per capita from the disaster year into the future up to 2005, the last year with almost complete information. Disaster losses are from the EM-DAT and the Munich Re, and the saving measures and socioeconomic information are taken from the World Bank Development Indicators. Consumption changes are analysed from a minimum of five years to a maximum of 33 years into the future. The author concludes that including disaster asset losses may help to better explain variations in post-disaster consumption, albeit almost exclusively for the group of low-income countries. The observed effect is rather small and in the range of a few percent of the explained variation. For low-income countries, capital stock and changes therein, such as forced by disaster shocks, seem to play a more important role than for higher-income economies, where human capital and technological progress become crucial. There are important data constraints and uncertainties, particularly regarding the quality of disaster loss data and the shares of capital stock losses therein. Another important challenge potentially biasing the results is the lack of data on alternative savings measures for many disaster exposed lower-income countries and small island states.

24. Mideksa, T.K. (2010) *Economic and Distributional Impacts of Climate Change: The Case of Ethiopia*, *Global Environmental Change*, 20, pp. 278–286

This study computes the economy-wide impacts of climate change and its distributional impacts for Ethiopia. It uses data from the World Bank social accounting matrix (2005) on production, the use of inputs, consumption and trade. The data are aggregated at the national level in three production sectors (agriculture, manufacturing and services). Projections for climate shocks cause a reduction

of output in sectors with a strong linkage to the rest of the economy and redistribute income by altering the returns to inputs. According to these results, climate change will complicate economic development in the following ways: (i) it will reduce agricultural production and output in the sectors linked to the agricultural sector; and (ii) it will raise the degree of income inequality. The first result is likely to reduce Ethiopia's GDP by about 10% and the second result is likely to further decrease economic growth and increase poverty.

25. Nordhaus, W. D. (2006) Geography and Macroeconomics: New Data and New Findings, Proceedings of the National Academy of Sciences of the United States of America, 103, 10, pp. 3510–3517

Data on global economic activity, the G-Econ database, is utilised for all 'large countries' measured at a 1° latitude and 1° longitude scale. Variables for economic data include gross regional product, regional income by industry, regional employment by industry and regional urban and rural population or employment along with aggregate sectoral data on agricultural and non-agricultural incomes. Geographical factors included are exogenous and large-scale attributes that are largely unaffected by human activities on decadal time scales, either non-stochastic (such as latitude, distance from coastlines, or elevation) or stochastic (such as climate and soils). Important geographic data are collected on a geographic (gridded) basis rather than based on political boundaries. There are three main results. First, there is a negative relationship between temperature and output per capita, but a strongly positive relationship between temperature and output per area. Second, geography is an important source of income differences in Africa relative to high-income regions, but Africa's geography is only marginally disadvantageous relative to other low-latitude regions. Third, it is found that an equilibrium doubling of carbon dioxide-equivalent greenhouse gas concentrations will have significantly more negative economic impacts than was found in earlier studies.

26. Noy, I. (2009) The Macroeconomic Consequences of Disasters, *Journal of Development Economics*, 88, pp. 221–231

This is one of the first studies specifically looking at the ex-post impact of disasters on the macro-economy. It uses data on disasters from CRED and on macroeconomic variables (GDP growth, per capita income levels, CPI inflation, unemployment rate and population) from the World Bank's World Development Indicators for 109 countries. The paper concludes that natural disasters have an impact on the macro-economy when measured as the amount of property damage. On the other hand, when disasters are measured as population indicators (lives lost and affected) there is no evidence of macroeconomic costs. Macroeconomic impacts of disasters of similar magnitude affect much harder developing than developed countries. Small economies are also more vulnerable than large ones.

27. Noy, I. and Nualsri, A. (2007) *What do Exogenous Shocks tell us about Growth Theories?* University of Hawaii Working Paper 07-28

In this paper, the focus is on the dynamics of growth following external exogenous shocks (natural disasters). Natural disasters are defined as hydro-meteorological disasters (for example, floods, wave surges, storms, droughts, landslides, and avalanches), geophysical (such as earthquakes, tsunamis, and volcanic eruptions) and biological disasters refer to epidemics and insect infestations. The study uses panel fixed-effects and GMM estimation methods. Panel data from 98 countries, both developed and developing, is drawn upon in which the entire sample period is divided into several five-year intervals: 1975–79, 1980–84, 1985–89, 1990–94, and 1995–99. The study constructs two different measures of exogenous shocks: human and physical capital shocks. The data series on human capital shocks originates from compiled data on disaster-related deaths. For physical capital shocks, data on reported property damages from natural disasters is used. The dependent variable in the growth regression is the five-year average growth rate of real GDP per

capita. The set of explanatory variables consist of measures of exogenous shocks along with other standard growth determinants that are grouped into two categories: initial condition and control variables. The authors argue that the data analysis they present suggests that the neoclassical model does not accord very well with the growth experience of developing countries. They find that a negative shock to the stock of human capital results in a decreased growth rate (with no eventual return to the previous growth trajectory) while negative shocks to the stock of physical capital do not seem to have much statistically observable effect.

28. Noy, I and Vu, T.B. (2010) The Economics of Natural Disasters in a Developing Country: The Case of Vietnam, *Journal of Asian Economics*, 21, pp. 345–354

This paper studies the macro impact of disasters on the economy in Vietnam. It uses data from the CRED International Disaster Database for primary and secondary industries for 61 provinces between 1995 and 2006. The authors conclude that more fatal disasters (lives lost and affected) cause lower output growth. On the other hand, more costly disasters (higher damages to capital) boost the economy in the short run. This last finding is confirmed when looking at the data at the regional level.

29. Potter, S. (2008) The Sting of Climate Change: Malaria and Dengue Fever in Maritime Southeast Asia and the Pacific Islands, Lowry Institute for International Policy, Sydney

Malaria and dengue fever are already major public health concerns in the Indonesian archipelago and the Pacific Islands. There is some uncertainty over how much of the observed and predicted increases in malaria and dengue can be directly linked back to climate change but many experts agree that early warning signs exist. In the future northern Australia may be more at risk to outbreaks. Climate change and extreme weather events increase the number of displaced people, who are a high risk group for malaria and dengue that can cause the diseases to spread. The author provides three recommendations for what should be done to combat both diseases. First, to improve predictive modelling capacity to better gauge where and by how much malaria and dengue will spread because of climate change. Policy interventions can be based on the results. Second, to prepare the affected health systems so that there is better prevention, treatment and management of the diseases. Third, to tighten quarantine and border screening processes.

30. Raddatz, C. (2007) Are External Shocks Responsible for the Instability of Outputs in Low-Income Countries? *Journal of Development Economics*, 84, pp. 155–187

The author studies the contribution of various external shocks including natural disasters in explaining output fluctuations for low-income developing countries. The paper finds that natural disasters have a negative impact on output fluctuations in the short run. Floods, droughts, extreme temperatures, and wind storms result in reductions to the real per capita GDP of 2%. Changes in commodity price are the most important exogenous source of fluctuations (explaining 37% of the 11% explained by all external shocks), followed by aid shocks (25%), climatic disasters (14%), humanitarian crises (12%), and fluctuations in the GDP of high-income countries and the international interest rate (10% and 3%, respectively). Data for disasters comes from CRED and for macroeconomic variables comes from Penn World Tables (version 6.1).

31. Raddatz, C. (2009) *The Wrath of God: Macroeconomic Costs of Natural Disasters*, Manuscript

This paper uses panel time series techniques to estimate the short- and long-run impact of climatic and other disasters on a country's GDP. The global sample is restricted to the post-Bretton Woods, 1975–2006 period and because of the short time-dimension of the series available, most of the analysis uses panel autoregressive distributed lags and panel vector autoregression models that

restrict the response of various groups of developing countries to be identical. Macroeconomic variables are average growth rate, average growth terms of trade, average aid/GNI and average real exchange rate appreciation, and disasters are classified as geographical, climatic or belonging to a residual category. The results indicate that a climate-related disaster reduces real GDP per capita by at least 0.6%. Therefore, the increased incidence of these disasters during recent decades entails important macroeconomic costs. Among climatic disasters, droughts have the largest average impact, with cumulative losses of 1% of GDP per capita. Across groups of countries, small states are more vulnerable to windstorms than other countries, but exhibit a similar response to other types of disasters, and low-income countries respond more strongly to climatic disasters, mainly because of their higher responsiveness to droughts. However, a country's level of external debt has no relation to the output impact of any type of disasters. The evidence also indicates that, historically, aid flows have done little to attenuate the output consequences of climatic disasters.

32. Rasmussen, T. N. (2004) *Macroeconomic Implications of Natural Disasters in the Caribbean*, IMF Working Paper WP/04/224

This paper compares the incidence of natural disasters from 1970 to 2002 across various Caribbean countries along four dimensions: the number of events divided by land area; the number of events divided by population; the number of affected persons divided by total population; and damage divided by GDP. Natural disasters that occurred in this timeframe are droughts, hurricanes, floods, storms, landslides and volcanic eruptions. The dependent variables are the affected as a percentage of the population and damage as a percentage of GDP. The author runs correlations between measures of proneness to natural disasters and selected macroeconomic variables, 1970–2002. The 12 large natural disasters in the Eastern Caribbean Currency Union were associated with a median reduction in same-year real GDP growth of 2.2 percentage points, as well as with a large decline in agricultural production and an offsetting increase in investment. On average, natural disasters cause damage amounting to well over one-half of 1% of GDP. The paper finds that the relative costs tend to be far higher in developing countries than in advanced economies.

33. Schlenker, W. and Lobell, D. B. (2010) *Robust Negative Impacts of Climate Change on African Agriculture*, *Environmental Research Letters*, 5, 1, pp. 1–8

This paper uses panel analysis of crop production and weather data to model the yield response to climate change for several staple sub-Saharan African crops. The dependent variables are country-level yields for five key crops, with data on yields and the total harvested area being used from 1961 to 2006. Crop productions were matched with various weather measurements (temperature and precipitation) for 1961 to 2002, with all other variables unchanged. It is estimated that, by 2050, the mean estimates of aggregate production changes in sub-Saharan Africa are -22%, -18%, -17%, -17% and -8% for maize, groundnut, sorghum, millet and cassava respectively. In all crops except cassava, there is a 95% probability that damages exceed 7%, and a 5% probability that they exceed 27%. Countries with the highest average yields have the largest projected yield losses, indicating that well-fertilised modern seed varieties are more susceptible to heat related losses.

34. Vu, T. B. and Hammes, D. (2010) *Dustbowls and High Water, the Economic Impact of Natural Disasters in China*, *Asia-Pacific Journal of Social Sciences*, Special Issue No. 1, pp. 122–132

This paper investigates the consequences of natural disasters on annual output and output growth over the period 1995 to 2007 in China. Using data on gross regional product values, the authors follow the Blundell-Bond System GMM procedure to control for the presence of lagged dependent variables. Variables used include the damage from the disaster, number of people killed, number of people affected, output values, output growth, initial output values, freight traffic, domestic trade,

school enrolment rate and health care. The results show that the impacts of number of people killed on annual output and output growth are both negative. However, the impacts of the number of people affected and amount of direct damage on annual output differ from those on output growth and are different for different regions.

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