Executive Summary

Climate change resulting from emissions of CO_2 and other greenhouse gases (GHGs) is widely regarded to be the greatest environmental challenge facing the world today. It also represents one of the greatest social and economic threats facing the planet and the welfare of humankind.

The focus of climate change mitigation policy to date has been on "*preventing dangerous anthropogenic interference with Earth's climate system*". There is no global agreement or scientific consensus for delineating 'dangerous' from 'acceptable' climate change but limiting global average temperature rise to 2 °C above pre-industrial levels has emerged as a focus for international and national policymakers.

The origin and selection of this 2 °C policy threshold is not entirely clear but its determination has been largely informed by assessments of impacts at different levels of temperature increase such as those of the UNFCCC Assessment Report 4 (AR4). With few exceptions, such assessments tend to present a gradual and smooth increase in scale and severity of impacts with increasing temperature. The reality, however, is that climate change is unlikely to be a smooth transition into the future and that there are a number of thresholds along the way that are likely to result in significant step changes in the level of impacts once triggered. The existence of such thresholds or 'tipping points' is currently not well reflected in mitigation or adaptation policy and this oversight has profound implications for people and the environment.

'Tipping element' – *a component of the Earth system that can be switched under particular conditions into a qualitatively different state by a small perturbation*

'Tipping point' - *the critical point (in forcing and a feature of the system) at which a transition is triggered for a given 'tipping element'*

The phrase 'tipping point' captures the intuitive notion that "a small change can make a big difference" for some systems (1). The term 'tipping element' has been introduced to describe those large-scale components of the Earth system that could be forced past a 'tipping point' and would then undergo a transition to a quite different state.

To formally qualify, **tipping elements** should satisfy the following conditions (7):

- *be components of the Earth system that are at least sub-continental in scale (~1000km); and*
- *the factors affecting the system can be combined into a single control; and*
- *there exists a critical value of this control (the tipping point) from which a small perturbation leads to a qualitative change in a crucial feature of the system, after some observation time.*

From the perspective of climate policy and this report we are most concerned with 'policy-relevant' tipping elements which might be triggered by human activities in the near future and would lead to significant societal impacts within this century.

Considering both the conditions for and likelihood of tipping a number of different elements, the report focuses on the following subset of phenomena and regions where passing tipping points might be expected to cause significant impacts within the first half of this century. Impacts have been explored and assessed in as much detail as possible within such a short study paying particular attention to economic costs and implications for the insurance sector.

The four tipping points that were chosen according to the above criterion are located in the USA (Combined sea level rise, Shift in aridity in Southwest North America), India (Indian Summer Monsoon) and Brazil (Amazon die-back).

Rather than just describing the tipping points as natural phenomena, the report also analyses the socio-economic consequences, i.e. the impact of Tipping Points on livelihoods, economies and the insurance sector.

For each tipping point, the report attempts to quantify the economic costs and the assets at risk and thereby underlines the relevance of tipping points for political and business decision makers. The figures derived do not represent a deterministic scenario but should rather be read as indicators of the scale of potential economic impacts in case the tipping points are triggered. The assumptions underlying the socio-economic impact assessment are made transparent in the report. All analyses of the tipping points themselves are based on the most recent scientific publications available and represent the latest scientific knowledge (climate modelling specific for tipping points).

Combined sea level rise - global sea level rise (SLR) of up to 0.5 m by mid century combined with localized sea level rise anomaly for the eastern seaboard of North America

Exposed assets in Port Megacities - A global sea level rise of 0.5 m by 2050 is estimated to increase the value of assets exposed in all 136 port megacities worldwide by a total of $US 25,158 billion to $US28,213 billion in 2050. This increase is a result of changes in socio-economic factors such as urbanization and also increased exposure of this (greater) population to 1-in-100-year surge events through sea level rise.

Exposed assets on NE coast of the US - The impact of an additional 0.15 m of SLR affecting the NE Coast of the US as a result of the localized SLR anomaly means that the following port megacities may experience a total sea level rise of 0.65 m by 2050: Baltimore, Boston, New York, Philadelphia, and Providence. 0.65 m of SLR is estimated to increase asset exposure from a current estimated $US 1,359 billion to $US 7,425 billion.

Insurance aspects - The critical issue is the impact that a hurricane in the New York region would have. Potentially the cost could be 1 trillion dollars at present, rising to over 5 trillion dollars by mid-century. Although much of this would be uninsured, insurers are heavily exposed through hurricane insurance, flood insurance of commercial property, and as investors in real estate and public sector securities.

Indian Summer Monsoon - shifts in hydrological systems in Asia as a result of hydrological disturbance of monsoon hydrological regimes (particularly Indian Summer Monsoon) combined with disturbance of fluvial systems fed from the Hindu-Kush-Himalaya-Tibetan glaciers (HKHT)

Overview - The impacts on hydrological systems in India under a 'tipping' scenario are expected to approximately double the drought frequency (2) and effects from the melting of the Himalayan glaciers and reduced river flow will aggravate impacts.

Drought costs - Extrapolating from the 2002 drought using a simple calculation would suggest that the future costs (in today's prices) might be expected to double from around $US 21 billion to $US 42 billion per decade in the first half of the century. However, a range of other factors are likely to act to increase these costs and consequences in the same period. The most significant of these are likely to be the combined effects of:

- decreasing probability of consecutive 'non-drought' years from which to accumulate surpluses (the probability of two consecutive 'non-drought' years is halved from 64% to 36% and for three consecutive years reduced from 51% to 22%);
- the pressures of increasing population on food and food surpluses (identified as equal to an increase in production by >40% by 2020 and continuing thereafter); and
- impacts of climate change on irrigation (with up to a 60% reduction in dry season river flows).

The effect of all of the variables is to increase the likelihood, severity and exposure of populations and the economy to potentially devastating conditions within the first half of this century with implications for water resources, health, and food security, and major economic implications not only for India but for economies regionally and worldwide.

Insurance aspects - The potential scale of drought losses could abort the initiatives to extend insurance more widely into the rural sector. The wider repercussions of drought through an economic slow-down and deterioration in public finances would impact insurers strongly, through the liquidation of private savings and the impairment of investments in public sector securities.

Amazon die-back and drought - committed die-back of the Amazon rainforest and a significant increase in the frequency of drought in western and southern parts of the Amazon basin

Amazon die-back - Several model studies have now shown the potential for significant die-back of the Amazon rainforest by late this century and into the next century and that ecosystems can be committed to long-term change long before any response is observable. Any estimate of the cost of Amazon die-back is likely to fall far short of true costs but an indication of costs has been derived by application of the UK shadow price of carbon approach (using UK values and approaches). This suggests that

- the significant increase in committed die-back that occurs between 1 and 2 °C results in incremental NPV costs of carbon approaching $US 3,000 billion;
- policies aimed at stabilization at 2 °C result in net present value (NPV) costs of the order of $US 3,000 billion from carbon lost through committed forest die-back (some 1.6 million km^2 of Amazon rain forest); and
- beyond ~2 °C the costs of committed die-back rise very rapidly and more than double to around $US 7,800 billion and $US 9,400 billion NPV for 3 °C and 4 °C respectively (with forest area losses of circa 3.9 and 4.3 million km^2).

The loss of very substantial areas of forest will result in the release of significant quantities of CO_2 and stabilization at 2 °C results in GHG emissions from Amazon die-back equivalent to ~20% of the global historical emissions from global land use change since 1850. This has the potential to interfere very significantly with emissions stabilization trajectories in the latter half of the century and moving forward into the future.

Amazon drought - In 2005, large sections of the western Amazon basin experienced severe drought. Recent studies (*3*) suggest that droughts similar to that of 2005 will increase in frequency from 1-in-20yr to 1-in-2yr and above by between 2025 and 2050 if stabilization at 450 to 550 ppmv CO_2e is achieved (with a higher probability if not). The drought of 2005 resulted in a range of impacts including increases in wildfire (with knock-on effects including human health and closure of airports, schools and businesses), interference with navigation (and therefore trade), reductions in agricultural productivity (with knock-on effects to industries servicing agribusinesses and food shortages) and impacts on hydroelectric power generation (which supplies 85% of Brazil's electricity). These impacts reduced contribution to

Brazilian GDP in affected regions including Mato Grosso do Sul, Santa Catarina, Paraná and Rio Grande do Sul.

Insurance aspects - Insurers would be directly affected by the economic effects of drought in the region i.e. an economic slow-down, and deterioration in public finances. The impacts on natural forests would be less material, since markets in natural carbon and biodiversity are unlikely to be significant for some time, and the drought risk will become evident during that period. In a broader sense, drought could incentivize investment into other forms of energy, e.g. solar power.

Shift in aridity in Southwest North America (SWNA) - a significant shift to a very arid climatology in Southwest North America (SWNA)

Overview - Aridity in Southwest North America is predicted to intensify and persist in the future and a transition is probably already underway and will become well established in the coming years to decades, akin to permanent drought conditions (*4*). Levels of aridity seen in the 1950s multiyear drought or the 1930s Dust Bowl are robustly predicted to become the new climatology by mid-century, resulting in perpetual drought. In California alone this will result in a number of impacts including on water resources, agriculture, and wildfire.

Wider impacts - Besides South-western North America, other land regions to be hit hard by subtropical drying include southern Europe, North Africa and the Middle East as well as parts of South America. If the model projections are correct, Mexico in particular faces a future of declining water resources that will have serious consequences for public water supply, agriculture and economic development and this will (and already has) affected the region as a whole, including the United States.

Insurance aspects - Insurers are now alert to wildfire risk in the region. The most serious aspects of the tipping point for insurers would therefore be the indirect ones, i.e. economic and labour market disruption and a deterioration of public finances. On the positive side, investment in water management and alternative energy could provide opportunities for fund managers.

Take home message

Historical GHG emissions have already 'committed' us to at least 0.6 °C of further warming. The lack of determined action to reduce GHG emissions means that a warming almost certainly in excess of 2 °C and probably in excess of 3 °C sometime in the latter half of the 21st century is likely unless extremely radical and determined efforts towards deep cuts in emissions are put in place in the short term (by 2015). Alarmingly, this means that, conceivably, there could be tipping elements that have not been triggered yet but which we are already committed to being triggered and/or have already been triggered, but we have yet to fully realize it because of a lag in the response of the relevant system.

Although having the potential to affect very significant numbers of people and assets, such elements are virtually absent from policy and decision contexts concerning what changes in temperature or other variables constitute 'dangerous climate change'. Work to provide early warning of such tipping elements could provide information to facilitate adaptation or mitigation but, at the same time, getting to the point where action is taken on the basis of such early warnings is, arguably, the greater challenge.