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Centre for Climate Change Economics and Policy

INSURANCE INDUSTRY *brief*

The Munich Re Programme of the Centre for Climate Change Economics and Policy

TRENDS IN ECONOMIC AND INSURED LOSSES FROM WEATHER-RELATED EVENTS: A new analysis

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Summary

- Global economic losses from reported weather-related events increased between 1980 and 2009 by US$2.7 billion per year in real terms (when merely the effects of inflation are taken into account).
- Normalisation methods allow loss data to be adjusted for one or more components, such as population growth, increasing wealth or changes in vulnerability, so that any remaining trends can be studied.
- Conventional normalisation methods have explored the contribution of inflation, changes in wealth per capita, and changes in population over time to the trends in economic losses, but do not take into account variations in wealth per capita and population between locations.
- A new normalisation method has been devised by researchers in the Munich Re Programme at the Centre for Climate Change Economics and Policy which takes into account spatial variations in wealth per capita and population, although it suffers from greater problems than the conventional method in terms of practical application.
- The new normalisation method has been applied to economic losses from global weather-related events over the past 30 years, during a period when there appears to have been an increase in the reported number of weather-related loss events.
- The most likely explanation for the simultaneous findings of, on the one hand, the absence of upward trends in reported global losses (recorded by either the conventional or new method) and, on the other hand, the dramatic increase in recorded weather-related loss events, is the implementation of defensive mitigation measures, particularly in some developed countries, which has reduced vulnerability to weather-related damage.
- Other possible explanations for the absence of upward trends include data limitations, bias in the reporting of losses, problems in the measurement of the areas affected by loss events, or a decrease in the intensity of weather-related loss events over time.
- The first ever analysis of global insured losses has been carried out using the conventional normalisation method, but indicates no statistically significant trend for total weather-related events over the past 19 years.
- However, the new analysis shows that there has been a statistically significant increase in insured losses from weather-related events in the United States over the past 37 years, and in Germany over the past 29 years.
- Statistically significant upward trends in normalised insured losses are found for total weather-related events, convective events, flooding, all storm events, and tropical cyclones in the United States, and for total weather-related events, winter storms and all storm events in Germany.

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Introduction

One of the expected consequences of global warming caused by the rise in atmospheric concentrations of greenhouse gases is a change in the frequency and intensity of extreme weather events in many regions of the world. Such impacts have profound implications for society and for the insurance industry in particular. Changes in extreme weather events, in the absence of adequate adaptation by populations, could lead to large increases in uncertainty and risk, fundamentally affecting the provision of insurance coverage against damage to properties and businesses.

The insurance industry, and society in general, are obviously concerned about quantifying when and how these changes will manifest themselves, particularly in light of the very large increase in economic losses from weather-related events that has been recorded over the past few decades (see Box 1). This has led to efforts to investigate the factors that are driving trends in current and future losses.

Normalisation methods allow loss data to be adjusted for one or more components, such as population growth, increasing wealth or changes in vulnerability, so that any remaining trends can be studied. This insurance industry brief describes the role of normalisation studies in contributing to the understanding of trends in economic and insured losses from weather-related events, and outlines the results of new analyses carried out by researchers in the Munich Re Programme at the Centre for Climate Change Economics and Policy.

Box 1: Trends in global economic losses from weather-related events

Figure 1 shows annual economic losses from weather-related events worldwide between 1980 and 2009, as recorded in the Munich Re NatCatSERVICE database, after the effects of inflation are removed. It shows a strong upward trend that is statistically significant at the 1 per cent level. The trend is equivalent to an increase in losses of about US$2.7 billion per year ie more than tripling over the 30-year period between 1980 and 2009.

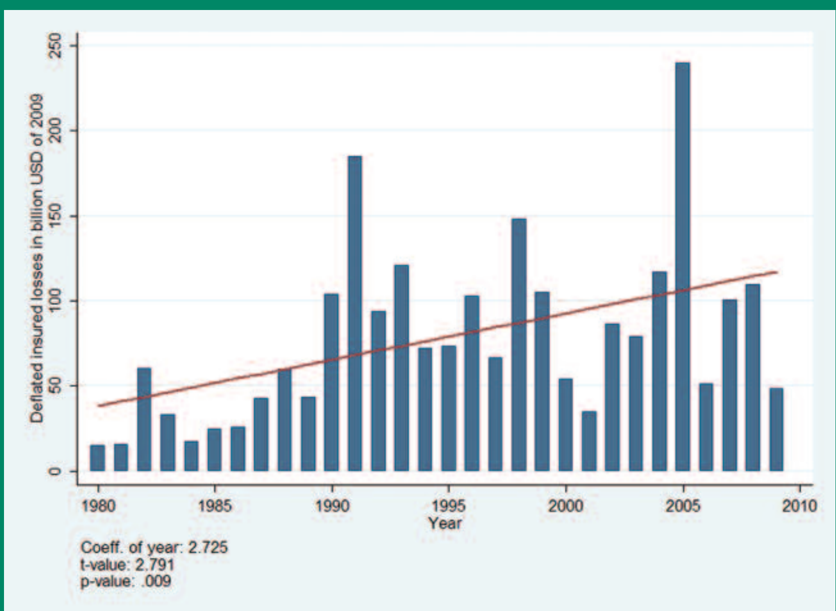

Figure 1: Annual losses from 15,963 weather-related events worldwide between 1980 and 2009, as recorded in the Munich Re NatCatSERVICE database, after the effects of inflation are removed.

Components of economic and insured losses from weather-related events

It is well-understood that the trend in annual economic losses from weather-related events shown in Box 1 could potentially result from changes in hazard, vulnerability and/or exposure. In order to prepare for future trends in losses, the insurance industry and society need to understand how these components of loss have been changing and how they might change in the future. The next few sections outline some of the main trends in exposure, vulnerability and hazard that have been directly investigated and described in relation to weather-related events.

Exposure

The global population grew by more than 50 per cent, from 4.4 billion to 6.8 billion, between 1980 and 2009 (United Nations 2008). In addition, gross domestic product (GDP), wealth per capita and the value of assets, increased significantly at a global level over this period. Such large increases in population and wealth have inevitably meant a growth in exposure to weather-related events, even if population increase had been directed into low-risk locations.

In addition, there is evidence of an increasing concentration of economic activities, assets and infrastructure in coastal regions and near large rivers, many of which are exposed to weather-related events (UNISDR 2009). For example, between 1980 and 2009, the total population of the United States increased at a rate of about 11 per cent per decade, while the population of Florida, a state prone to hurricanes, increased at a rate of 25 per cent per decade (United States Census Bureau 2009). It seems likely therefore that exposure to weather-related events, such as tropical cyclones, will continue to grow, and will perhaps increase disproportionately in high-risk locations, such as coastal urban areas that are close to sea level.

CHANGES IN EXTREME WEATHER EVENTS, IN THE ABSENCE OF ADEQUATE ADAPTATION BY POPULATIONS, COULD LEAD TO LARGE INCREASES IN UNCERTAINTY AND RISK, FUNDAMENTALLY AFFECTING THE PROVISION OF INSURANCE COVERAGE AGAINST DAMAGE TO PROPERTIES AND BUSINESSES.

Vulnerability

It is difficult to measure trends in vulnerability to weather-related events at a regional scale because extreme events occur relatively infrequently. For example, UNISDR (2009) reported that of the 2.3 million people who lost their lives in natural disasters (geophysical and weather-related, excluding epidemics) between 1975 and 2008, 1.8 million were killed in 23 'mega-disasters'. That is, 78% of fatalities occurred in just 0.3% of events recorded. This indicates that vulnerability is disproportionately higher for severe loss events.

Vulnerability is linked with development, with the poorest people being most vulnerable to the impacts of extreme weather events. Economic and human development in many poor countries over the past few decades has been accompanied by reductions in vulnerability to disasters in many regions. However, UNISDR (2009) warned: "As countries develop, and both economic conditions and governance improve, vulnerability decreases, but not sufficiently rapidly to compensate for the increase in exposure".

To carry out a more effective evaluation of changes in vulnerability, detailed comparative analyses would be required for cases in which hazard was unchanged. There are very few studies that have evaluated trends in vulnerability to weather-related disasters at a global or regional scale. Several studies have been based on modelling of the effects of risk mitigation investments, using engineering data. These have suggested that there have been significant reductions in vulnerability. However, there is an absence of research on changes in vulnerability based on observational evidence collected after disasters. UNISDR (2009) reported modelling of the factors responsible for losses and fatalities between 1990 and 2007. The analysis suggested that the increase of 13 per cent in fatalities from flooding over this period was driven by a combination of a rise in exposure of 28 per cent and a decrease of 11 per cent in vulnerability. Similarly, the 33 per cent increase in losses from flooding was driven by the combination of a 98 per cent increase in exposure and a 33 per cent decrease in vulnerability.

There are many difficulties in detecting and quantifying changes in weather-related hazards. The scarcity of robust and reliable long-term observational records, particularly at local level, limits the level of confidence in the detection and attribution of trends. Globally-consistent satellite observations have only been available since the 1980s, and 30 years is a short time period over which to detect trends in extreme weather events at a local level because, by definition, these are rare events.

Global studies of daily temperature and precipitation extremes over land suffer from a scarcity of data for many regions. In many parts of the world there are few homogeneous observational records, having a daily resolution and covering multiple decades, within integrated and digitised data sets. Observed changes in extreme weather events are often more sensitive to inhomogeneous climate monitoring practices than changes in mean climate.

The rarer the event, the more difficult it is to identify long-term changes, simply because there are fewer cases to evaluate compared with indicators of mean climate. Bender *et al*. (2010) projected that the frequency of category 4 and 5 hurricanes in the Atlantic could increase by 81 per cent over the next 80 years, but that it would take 60 years for this signal to be detectable from the background variability.

The most comprehensive survey of research on trends in extreme weather was published by the Intergovernmental Panel on Climate Change (2007a) and is summarised in Table 1. A likely or very likely increase in the frequency and/or intensity over the 20th century has been reported for some types of extreme weather events in many parts of the world.

A LIKELY OR VERY LIKELY INCREASE IN THE FREQUENCY AND/OR INTENSITY OVER THE 20TH CENTURY HAS BEEN REPORTED FOR SOME TYPES OF EXTREME WEATHER EVENTS IN MANY PARTS OF THE WORLD.

Phenomenon and direction of trend	Likelihood that trend occurred in late 20th century (typically post-1960)[a]	Likelihood of a human contribution to observed trend	D	Likelihood of future trend based on projections for 21st century using SRES[b] scenarios
Warmer and fewer cold days and nights over most land areas	Very likely[c]	Likely[e]	*	Virtually certain[e]
Warmer and more frequent hot days and nights over most land areas	Very likely[d]	Likely (nights)[e]	*	Virtually certain[e]
Warm spells/heat waves: Frequency increases over most land areas	Likely	More likely than not		Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	More likely than not		Very likely
Area affected by droughts increases	Likely in many regions since 1970s	More likely than not	*	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970	More likely than not		Likely
Increased incidence of extreme high sea level (excludes tsunamis)[f]	Likely	More likely than not[g]		Likely[h]

Notes:

[a] The following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: Virtually certain > 99% probability of occurrence, Extremely likely > 95%, Very likely > 90%, Likely > 66%, More likely than not > 50%, Unlikely < 33%, Very unlikely < 10%, Extremely unlikely < 5%

[b] SRES refers to the IPCC Special Report on Emission Scenarios. The SRES scenario families and illustrative cases are summarised in a box at the end of the Summary for Policymakers.

[c] Decreased frequency of cold days and nights (coldest 10%)

[d] Increased frequency of hot days and nights (hottest 10%)

[e] Warming of the most extreme days/nights each year

[f] Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

[g] Changes in observed extreme high sea level closely follow the changes in average sea level. It is very likely that anthropogenic activity contributed to a rise in average sea level.

[h] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Table 1: Recent trends, assessment of human influence on trends, and projections of extreme weather and climate events for which there is evidence of an observed late 20th-century trend. An asterisk in the column headed 'D' indicates that formal detection and attribution studies were used, along with expert judgement, to assess the likelihood of a discernible human influence. Where this is not available, assessments of likelihood of human influence are based on attribution results for changes in the mean of a variable or changes in physically related variables and/or on the qualitative similarity of observed and simulated changes, combined with expert judgement. Source: IPCC (2007a).

Analysis of loss trends and their components through normalisation methods

While trends in exposure, vulnerability and hazard provide useful information, they do not give a direct indication of their contributions to loss trends, such as those illustrated in Box 1. However, the relative influence of some of the components can be assessed through normalisation methods. To date, these normalization methods have focused on removing the impacts of changes in exposure only.

Pielke and Landsea (1998) proposed a method for exploring how inflation and changes in population and wealth per capita had influenced economic losses from hurricane damage in the United States. They normalised losses that occurred between 1925 and 1995 in order to estimate the impact each historical storm in terms of the loss it would have created if it had made landfall in 1995.

Based on the results of their analysis, Pielke and Landsea (1998) concluded that while losses from hurricane damage during the 1990s were much higher than in the 1970s and 1980s, they were comparable with losses during the 1940s and 1960s. Although the authors did not independently verify the contributions of hazard and vulnerability to losses, they claimed that "a climate signal is present in the normalized data, and this is of *decreased* impacts in recent decades".

The method of Pielke and Landsea (1998) has now been applied in many other studies for economic losses from weather-related events and other perils in regions across the world. For instance, Schmidt *et al*. (2009) applied a modified version of the Pielke and Landsea (1998) method to normalise economic losses from tropical cyclones in the United States with respect to changes in capital stock and found a statistically significant increase of 4 per cent per year over the period between 1971 and 2005. However, in almost all cases, the normalisation for inflation and changes in wealth per capita and population has removed any trends in economic losses (see Bouwer 2010). Some authors have applied more or less ad hoc adjustments to normalised loss results to take account of changes in vulnerability due to, for instance, the implementation of building codes (eg Crompton and McAneney 2008; Vranes and Pielke 2009).

WHILE TRENDS IN EXPOSURE, VULNERABILITY AND HAZARD PROVIDE USEFUL INFORMATION, THEY DO NOT GIVE A DIRECT INDICATION OF THEIR CONTRIBUTIONS TO LOSS TRENDS.

Only one previous study has used this conventional normalisation method in an attempt to assess loss trends from all weather-related events at a global level. The results of this study of losses between 1950 and 2005 from weather-related events in a group of developed (Australia, Canada, Europe, Japan, South Korea, United States) and developing (Caribbean, Central America, China, India Philippines) countries were published first as an extended abstract from a workshop (Muir-Wood *et al.* 2006) and then as a book chapter (Miller *et al.* 2008).

Muir-Wood *et al.* (2006) acknowledged that their database of losses before 1970 was incomplete for many regions, but they concluded: "After 1970 when the global record becomes more comprehensive we find evidence of an annual upward trend for normalized losses of 2% per year that corresponds with a period of rising global temperatures". However, they warned that "the significance of the trend in global normalized losses is dominated by the affect [sic] of the 2004 and 2005 Atlantic hurricane seasons as well as by the bias in US wealth relative to other developing regions". The results of Muir-Wood et al. (2006) have been widely cited, including by Stern (2007; see Box 2) and IPCC (2007b), although this has been criticised (eg Pielke 2007).

Miller et al. (2008) presented the results in more detail, and concluded: "After 1970, when the global record becomes more comprehensive, we find evidence of an annual upward trend for normalized losses of 2% per year. Conclusions are heavily weighted by US losses, and their removal eliminates any statistically significant trend."

In contrast to Pielke and Landsea (1998), Miller et al. (2008) acknowledged that "without fully controlling for other factors that could affect the trend in losses, we can not draw any firm conclusions about the role of climate change in loss trends". However, they carried out a simple test for a correlation between annual global temperature anomaly and annual normalised losses between 1950 and 2005. They found that the temperature anomaly was statistically significant at the 1 per cent level for normalised losses, but that this significance disappeared when the losses from hurricane damage in the United States in 2004 and 2005 were excluded.

A new normalisation method for economic losses

Neumayer and Barthel (2010) identify a number of shortcomings of the method first put forward by Pielke and Landsea (1998). Their primary criticism is that although it normalises across time, it does not do so across space. Hence it implicitly assumes a homogeneous geographical distribution of potential losses, and does not distinguish between, for instance, events that by chance affect wealthy built-up cities instead of sparsely-populated poor rural areas, and vice versa.

Box 2: Use of normalisation results by Stern (2007)

Stern (2007) cited Muir-Wood *et al.* (2006) to support the following statement: "New analysis based on insurance industry data has shown that weather-related catastrophe losses have increased by 2% each year since the 1970s over and above changes in wealth, inflation and population growth/movement."

Stern (2007) continued:

"If this trend continued or intensified with rising global temperatures, losses from extreme weather could reach 0.5-1% of world GDP by the middle of the century."

An explanatory footnote stated:

"Based on simple extrapolation through to the 2050s, the lower bound assumes a constant 2% increase in costs of extreme weather over and above changes in wealth and inflation. The upper band assumes that the rate of increase will increase by 1% each decade, starting at 2% today, 3% in 2015, 4% in 2025, 5% in 2035, and 6% in 2045. These values are likely underestimates: (1) they exclude 'small-scale' events which have large aggregate costs, (2) they exclude data for some regions (Africa and South America), (3) they fail to capture many of the indirect economic costs, such as the impacts on oil prices arising from damages to energy infrastructure, and (4) they do not adjust for the reductions in losses that would have otherwise occurred without disaster mitigation efforts that have reduced vulnerability."

Finally Stern (2007) stated: "If temperatures continued to rise over the second half of the century, costs could reach several percent of GDP each year, particularly because the damages increase disproportionately at higher temperatures (convexity in damage function)." This statement referenced a chapter in Stern (2007) which pointed out: "Basic physical and biological principles indicate that impacts in many sectors will become disproportionately more severe with rising temperatures".

Hence Stern (2007) was primarily concerned about the most appropriate basis for estimating future losses from changes in weather-related loss events with rises in global average temperature, rather than quantifying the contribution of climate change to past losses. He noted that past trends are unlikely to provide a good indication of future trends due to climate change as they do not reflect the likely convexity of the damage function (eg damage to property increases as a cube function of tropical cyclone windspeed).

Neumayer and Barthel (2010) point out that a normalisation methodology must produce results that satisfy two criteria:

- *Criterion 1:* all other things being equal, the normalised loss total in year 2 must be higher than the total in year 1 if more loss events of the same intensity occur ie greater frequency of loss events leads to higher loss total.
- *Criterion 2:* all other things being equal, the normalised loss total in year 2 must be higher than the total in year 1 if the same number of loss events occur but they are of greater intensity ie greater intensities of loss events lead to higher loss total.

Neither criterion is necessarily fulfilled by results obtained from the method devised by Pielke and Landsea (1998); if more loss events of the same magnitude, or the same number of loss events with higher magnitude, strike less wealthy areas in year 2 compared with year 1, then the normalised loss calculated by the Pielke and Landsea (1998) method for year 2 may well be less than that for year 1.

This introduces potential bias in the results generated by the Pielke and Landsea (1998) method. There would not be any bias if there are a large numbers of loss events in each year, as there is no reason to suppose that the events would be more likely to systematically hit low-density poor areas rather than high-density rich areas, or vice versa, in the distant past compared with the recent past. However, if the analysis is carried out for low-frequency loss events, in relatively small areas over short periods of time, the volume of data may be too small to invoke the law of large numbers, and the analysis may be biased by the variability in the distribution of population and wealth.

Therefore, Neumayer and Barthel (2010) propose a new method for normalising loss data to take into account differences in wealth and population between locations, as well as changes of wealth and population across time.

Their method differs from that of Pielke and Landsea (1998) by calculating relative, rather than absolute, loss. Neumayer and Barthel (2010) describe this as the ‘actual to potential loss ratio’ (APLR). For any single loss event, the APLR must vary between 0 (no loss of wealth) and 1 (total loss of wealth). For any year, the aggregate total loss is expressed as the sum of the APLRs for each loss event that occurred during that year.

As this new method calculates relative loss, it does not need to be adjusted for inflation across time. It also does not need the selection of a particular base year against which losses from other years are measured. Most importantly, the results from this method satisfy both Criterion 1 and Criterion 2 that are set out by Neumayer and Barthel (2010) as necessary for any normalisation procedure.

Neumayer and Barthel (2010) recognise practical limitations to their proposed new method. One problem is that there are no reliable measures of wealth that are consistent and available across the world. However, gross domestic product (GDP) can be used as a proxy for wealth.

Neumayer and Barthel (2010) point out that GDP typically understates wealth and is a relatively poor proxy for the wealth of the physical stock that may be damaged or destroyed by a loss event. Furthermore, GDP is only correlated with the physical capital stock that is used for the production of consumption goods and services, but not the value of other wealth held in, for instance, residential property. In addition, intangible components, such as services, are contributing an increasing proportion of GDP in many, but not all, countries. This means that the growth rate of GDP possibly overestimates the growth rate of the wealth held in physical stock, and so may bias the result of the proposed normalisation method as loss events from past years will tend to be scaled up too strongly.

A NEW METHOD FOR NORMALISING LOSS DATA TO TAKE INTO ACCOUNT DIFFERENCES IN WEALTH AND POPULATION BETWEEN LOCATIONS, AS WELL AS CHANGES OF WEALTH AND POPULATION ACROSS TIME.”

Another problem is that it is difficult to define the area that could have been potentially affected by a loss event, which should determine the area within which wealth should be taken into account and compared with losses. Few loss events affect an entire country, and could therefore justify the use of a whole country GDP value. This means that an assumption must be made about the size of area affected. This introduces some measurement error and potentially some bias which might not be random if, for instance, there is a systematic under- or over-estimation of the true affected area for events in earlier years compared with later years.

Neumayer and Barthel (2010) acknowledge that these two problems also affect the normalisation method of Pielke and Landsea (1998), but to a lesser extent because it measures changes in wealth over time, rather than levels of wealth across both time and space. Neumayer and Barthel (2010) conclude that while their proposed new method is theoretically better than that of Pielke and Landsea (1998), the much greater problems involved in its practical application mean that both methods should be considered to have strengths and weaknesses. As a result, the new method should be considered complementary to that of Pielke and Landsea (1998). Recognising this, Neumayer and Barthel (2010) use both their new proposed method and that of Pielke and Landsea (1998).

The two normalisation methods are applied to the data contained in Munich Re's NatCatSERVICE database, containing information about loss events from around the world. This database is the world's most comprehensive database of information about losses from natural catastrophes, and includes information about both insured and non-insured losses, together contributing to overall economic losses from the full range of events. It should be noted, however, that there remain some significant problems with the accuracy and reliability of records of economic losses, which, in many cases, are compiled by using insurance claims as the main source and estimating uninsured damages.

The analysis carried out by Neumayer and Barthel (2010) is restricted to loss events that occurred during the 30-year period between 1980 and 2009. For their alternative method, they assume that each loss event affected an equal-sized area of 100 km by 100 km (i.e an area of 10,000 km2). This assumption introduces some measurement error which, if it is non-random, could result in some bias.

Neumayer and Barthel (2010) aggregate the weather-related loss events by year (based on the onset date) to arrive at annual sum total APLRs. These figures are then tested for the presence of a trend. The method of Pielke and Landsea (1998) is also applied to the same data for the period from 1980 to 2009.

Results for economic losses from the application of the methods of Neumayer and Barthel (2010) and Pielke and Landsea (1998)

Figure 2 shows the results for the analysis of global annual losses from weather-related events over the period between 1980 and 2009 using the method of Pielke and Landsea (1998) and Neumayer and Barthel (2010).

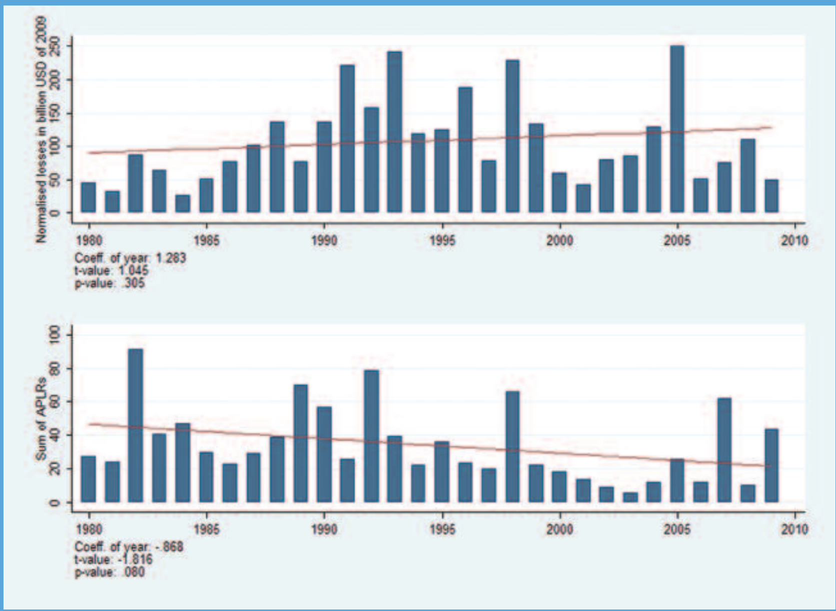

Figure 2: Results for 16,546 weather-related loss events worldwide using the method of Pielke and Landsea (top) and Neumayer and Barthel (bottom).

The results of applying the method of Pielke and Landsea (1998) show a slight upward trend over time that is not statistically significant, while the results from Neumayer and Barthel (2010) show a downward trend over time that is marginally significant.

The loss events are also analysed separately in terms of whether they occurred in developed (members of the OECD and other high-income) or developing (middle- and low-income) countries. Figure 3 shows the results for loss events in developed countries.

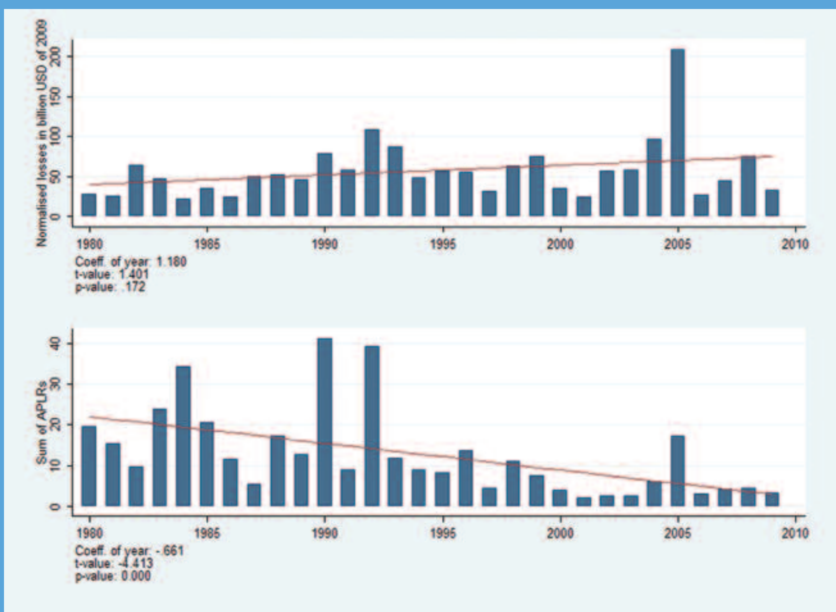

Figure 3: Results for 8,307 weather-related loss events in developed countries using the method of Pielke and Landsea (top) and Neumayer and Barthel (bottom).

The results for the Pielke and Landsea (1998) method show a slight upward trend that is not statistically significant, whereas the results of the Neumayer and Barthel (2010) method show a relatively strong negative, which is statistically significant. For developing countries, no significant trend is detected using either normalisation method.

Neumayer and Barthel (2010) also analyse the data according to region. No significant trends are found using either normalisation method for any region except the United States and Canada. The results for loss events in the US and Canada that are analysed using the Pielke and Landsea (1998) method show a slight upward trend that is not statistically significant, while the method of Neumayer and Barthel (2010) yields a downward trend with time that is statistically significant.

Neumayer and Barthel (2010) analyse the global data for loss events according to peril type. Neither normalisation method produces a statistically significant trend for convective events (flash flood, hail storm, tempest storm, tornado and lightning), storm events or tropical cyclones. For precipitation-related loss events, the results of applying the method of Pielke and Landsea (1998) show no significant trend, but the Neumayer and Barthel (2010) method shows a downward trend with time that is statistically significant.

Neumayer and Barthel (2010) also consider the results for loss events by peril and region together. For convective events in Europe, no significant trend is found using either normalisation method. A separate analysis for the United States was carried out, using information from the Munich Re NatCatSERVICE database that extended back to 1970 ie a 40-year period. For convective loss events, the Pielke and Landsea (1998) method yields an upward trend with time of US$0.20 billion per year on average that is statistically significant, whereas the Neumayer and Barthel (2010) method yields a small positive trend that is not statistically significant. For tropical cyclones, the Pielke and Landsea method (1998) results in a small positive trend that is not significant, while the Neumayer and Barthel (2010) method also shows no significant trend.

Interpretation of results

As pointed out in Box 1, annual inflation-adjusted economic losses from reported weather-related events increased between 1980 and 2009 by about $US2.7 billion per year on average, thus tripling over the 30-year period. However, when these losses are normalised using the method of Pielke and Landsea (1998) there is no significant trend over time, while the method of Neumayer and Barthel (2010) shows a downward trend over time that is marginally significant. Hence the rise in economic losses of US$2.7 billion per year can be attributed to the increase in population and wealth per capita that is exposed to weather-related events.

This conclusion is consistent with other evidence that shows a combination of factors has been increasing the size of total assets exposed to weather events. Hence this increasing accumulation of exposure is the most significant driver of rising risk and losses. It is not clear how this trend might develop into the future, nor whether its continuation will be considered socially or politically acceptable.

Neumayer and Barthel (2010) urge caution in interpreting the trends (or lack of) that emerge after normalisation. They point out that a number of factors, other than changes in population and wealth, contribute to normalised losses. In particular, the normalisation methods of both Pielke and Landsea (1998) and Neumayer and Barthel (2010) do not independently take into account changes in vulnerability that may have taken place over time through the implementation of defensive mitigating measures such as flood barriers and building codes. There is some evidence that disaster risk reduction measures are more likely to be introduced as populations become more wealthy, which would tend to reduce losses over time. This may explain the downward trend recorded in losses for developed countries, which are more able to fund and implement such mitigating measures (Figure 3; see Box 3 for a case study for Hamburg).

As a result, it is not possible to draw any firm conclusions about the extent of any changes in hazard, nor about any potential trend due to climate change. It is important to note that during the period between 1980 and 2009 which Neumayer and Barthel (2010) consider, global average temperature increased at a rate of 0.15°C per decade on average ie by about 0.45°C over 30 years. It is not clear to what extent a change in extreme weather events worldwide occurred over this time period, or whether any change would be detectable in data for loss events. In order to make some assessment of this, Neumayer and Barthel (2010) analyse the annual frequency of geophysical and weather-related loss events recorded in the Munich Re NatCatSERVICE database between 1980 and 2009.

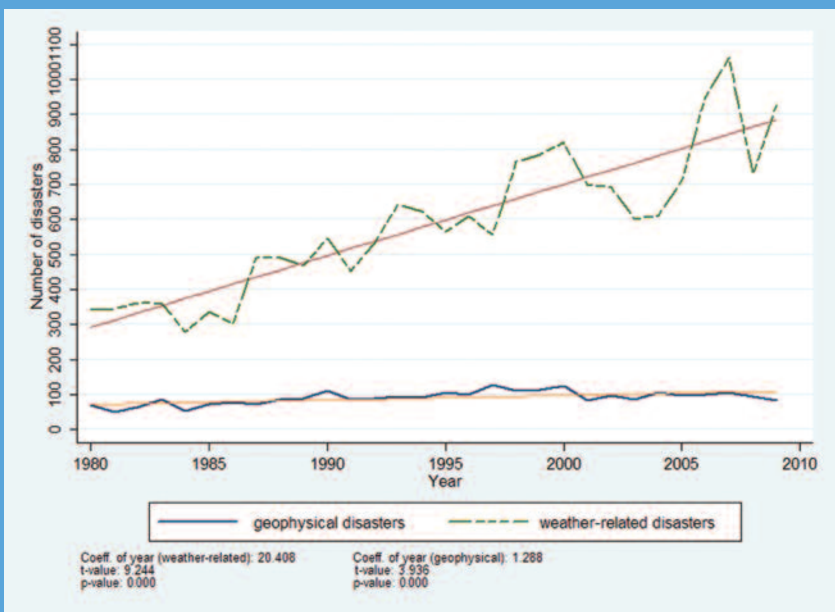

Figure 4: Annual frequency counts of recorded geophysical and weather-related loss events worldwide between 1980 and 2009.

Figure 4 shows that the number of recorded weather-related loss events more than doubled in the period between 1980 and 2009. Such a trend may be due to increased awareness and reporting of weather-related loss events over time, or by human populations moving into previously uninhabited areas where loss events would not have been recorded in earlier years. However, such factors should also have an impact on geophysical events, such as earthquakes, but Figure 4 shows only a small positive trend for them. A similar picture emerges from an analysis of major loss events, for which increased awareness or movement into previously uninhabited areas should not have as much of an impact.

Neumayer and Barthel (2010) suggest three potential explanations for the apparent mismatch of, on the one hand, the lack of trend or negative trend in losses from weather-realted events resulting from analyses with their normalisation method, and, on the other, the strong increase in the frequency of recorded weather-related events.

First, there could be a bias in the reporting of losses that lead to overestimates for earlier years and underestimates in later years. Second, weather-related loss events may have become less intensive over time. Or third, and most plausible, the intensity of weather-related events has not decreased over time, but increasing development of defensive mitigating measures have stopped any increase in losses.

Whatever the reason, one thing is clear: any adaptive response which may be limiting losses by reducing vulnerability is being completely outpaced by the massive increase in exposure. Even if defensive mitigating measures have been implemented over the past 30 years, economic losses from reported weather-related events have been increasing, in real terms by US$2.7 billion per year. Given that further climate change is inevitable, and it is not clear that defensive mitigation measures will keep pace, the combination of the likely increase in hazard and increasing exposure will provide a severe test for society in general, and the insurance industry in particular, over the next few decades.

EVEN IF DEFENSIVE MITIGATING MEASURES HAVE BEEN IMPLEMENTED OVER THE PAST 30 YEARS, ECONOMIC LOSSES FROM REPORTED WEATHER-RELATED EVENTS HAVE BEEN INCREASING, IN REAL TERMS BY US$2.7 BILLION PER YEAR.

Box 3: Munich Re case study on Hamburg

Munich Re has assessed, in a study to be submitted to a journal, how flood mitigation measures have reduced economic losses in Hamburg, Germany. The city is located on the Elbe River, roughly at the point where it passes into an estuary, about 100 km from the North Sea. About 40 per cent of the Hamburg area is prone to flooding from an extreme storm surge, including residential properties that are home to 200,000 people and workplaces for 165,000 more.

In 1962, Hamburg was flooded by a storm surge that was more than 3.5 m above mean high-tide water levels. Old and weak dykes around the city were breached at several locations. The flood killed 347 people and caused €1.56 billion (adjusted for inflation to 2009 Euros) in economic losses.

A major construction programme was undertaken after the 1962 tragedy to re-build and improve flood defences, with more than €2 billion invested up to 2009. Dykes were reinforced and re-shaped to withstand breaches, and flood walls were built, strengthened and raised.

Over the past 48 years, water levels along the Elbe River in Hamburg have exceeded those of the 1962 flood on seven occasions, but losses in the city have been negligible. An analysis by Munich Re has calculated that on four occasions, water levels were high enough to have potentially caused losses higher than those experienced in 1962. If no additional flood mitigation levels had been undertaken, losses in Hamburg would probably have shown a significant increase over the past four decades (see Figure 5). Instead, losses have decreased over this period.

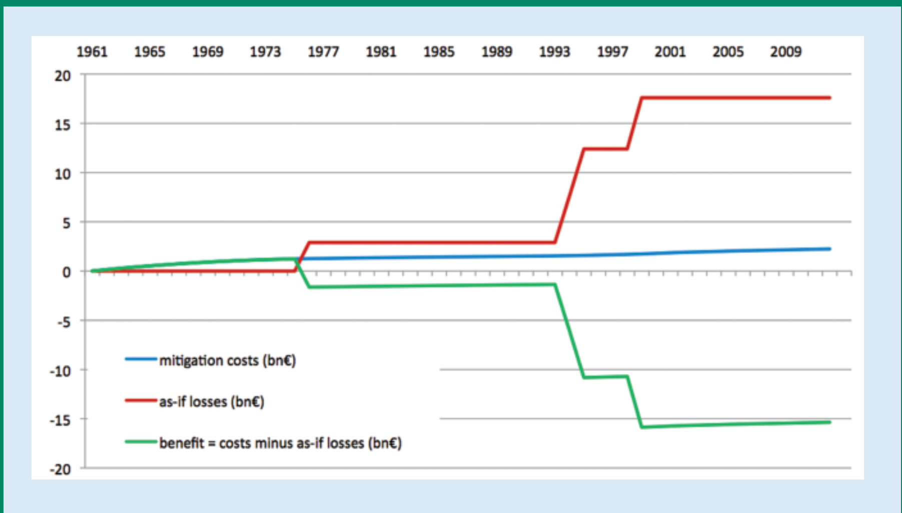

Figure 5: Munich Re analysis for Hamburg showing flood mitigation costs and projected 'as-if' cumulative losses that would have occurred without mitigation.

A new normalisation analysis for insured losses

The analysis of Neumayer and Barthel (2010), which has been accepted for publication in the peer-reviewed journal *Global Environmental Change*, has been expanded in a further study by Barthel and Neumayer (2010) that focuses on insured losses from weather-related events. It should be noted that while the analysis of Barthel and Neumayer (2010) has been submitted to a journal for publication, it has not yet undergone formal peer review and so these results should be regarded as provisional.

Barthel and Neumayer (2010) point out that applying the new method of Neumayer and Barthel (2010) to insured losses would require information about the value of insured wealth that could potentially be affected in an area experiencing a loss event. As this is not currently available, Barthel and Neumayer (2010) only apply a modified version of the method of Pielke and Landsea (1998) to the analysis of insured losses, by adding an additional factor to take into account changes in insurance penetration as a proxy for changes in the proportion of wealth that is covered by insurance policies. For a global analysis of insured losses, Barthel and Neumayer (2010) use GDP per capita as a proxy for wealth per capita.

There is no suitable information available about insurance penetration on a worldwide basis. Therefore, Barthel and Neumayer (2010) use property insurance premia and, where available, engineering insurance premia, expressed relative to GDP, as a proxy for insurance penetration. However, the authors acknowledge that the ratio of insurance premia to GDP can change over time even if the proportion of wealth that is insured remains the same, and vice versa. For instance, insurance premia may increase following significant pay-outs from claims, as was seen in Florida for homeowner policies against wind damage following the hurricane seasons of 2004 and 2005, and similarly, insured wealth may outpace premia due to, for example, market or regulatory conditions. In theory, for risk-based pricing, insurance premia should change over time if there is any change in the hazard that is covered, which would result in no trend if losses were normalised with respect to premia. However, Munich Re indicates that changes in property and engineering premia relative to GDP should in the long run serve as an acceptable proxy for changes in insurance penetration.

Reliable data for insurance premia on a worldwide basis are only available for the period from 1990. Therefore, Barthel and Neumayer (2010) carry out a global analysis for the 19-year period between 1990 and 2008. They note that the data on insured losses should be more robust than that for economic losses. However, the availability of data for such a relatively short period means the standard errors will be higher, and the chances of finding statistically significant trends are reduced.

This modification of the Pielke and Landsea (1998) method allows Barthel and Neumayer (2010) to carry out the first global analysis of normalised insured losses.

Results for global insured losses from the application of the modified method of Pielke and Landsea (1998)

To provide a comparison with the normalised economic losses, Figure 6 shows the results of removing the effects of inflation from the record of global annual insured losses from weather-related events.

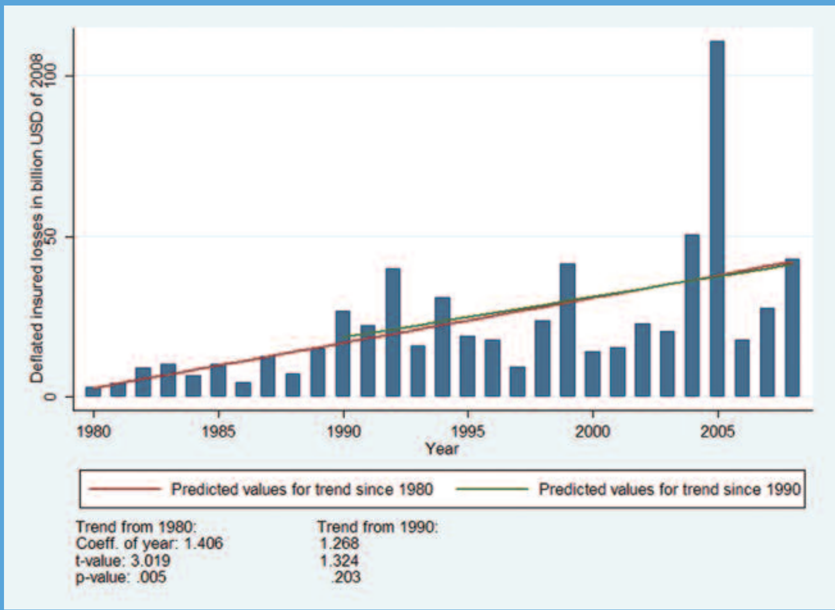

Figure 6: Global deflated insured losses from 2477 weather-related events between 1980 and 2008

It shows a strong upward trend in insured losses that is statistically significant for the period between 1980 and 2008, and is consistent with the trend in total inflation-adjusted economic losses shown in Figure 1. However, the upward trend in insured losses between 1990 and 2008 is not statistically significant due to the shorter time period, and hence lower number of data analysed.

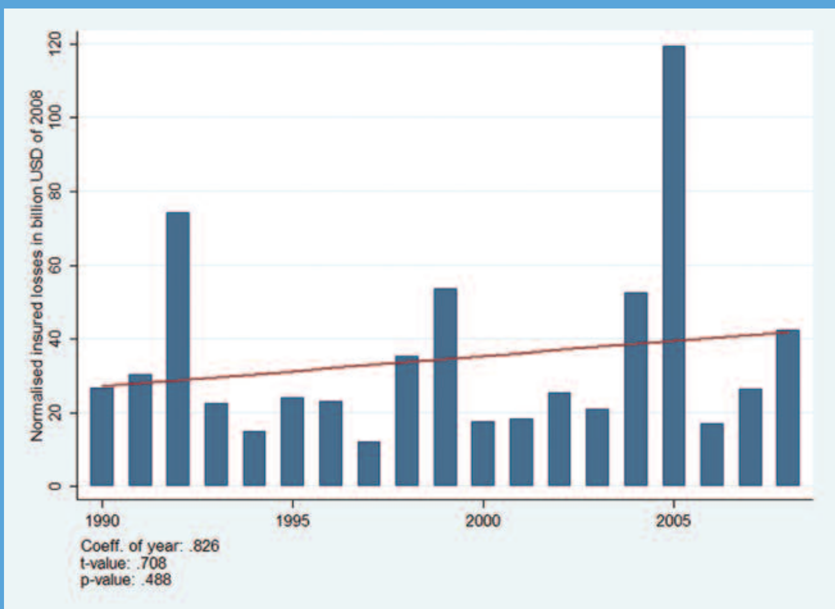

Figure 7: Results for global normalised insured losses from 1,531 weather-related events using the modified method of Pielke and Landsea (1998).

Figure 7 shows that the modified normalisation method of Pielke and Landsea (1998) yields an upward trend in global insured losses, but it is not statistically significant. Limiting the analysis to developed countries (members of the OECD and high-income) also produces no statistically significant trend. Unsurprisingly separate analyses for convective events, storm events, tropical cyclones and precipitation-related events also yield no statistically significant trends.

Interpretation of results

Barthel and Neumayer (2010) note that the lack of statistically significant trends in the deflated global insured losses from 1990 onwards and all of the normalisation analyses is perhaps to be expected for such a short time period of 19 years. It is also possible that the lack of trends represents the opposing influences of an increase in the frequency and/or intensity of extreme weather events, and increasing implementation of defensive mitigation measures, which would tend to reduce vulnerability over time and therefore limit any potential increases in insured losses.

Results for insured losses in the United States and Germany from the application of the modified method of Pielke and Landsea (1998)

Barthel and Neumayer (2010) are also able to apply their modified version of the method of Pielke and Landsea (1998) to insured losses in Germany and the United States over longer periods than for the global analysis.

Munich Re provided information about relevant premia for Germany between 1980 and 2008, and for the United States between 1973 and 2008. This included a sub-set of property premia and engineering premia, as well as premia for coverage of physical damage to vehicles, which related more directly to insured values that could potentially be lost through damage by weather-related events. In addition, Barthel and Neumayer (2010) are able to use GDP and wealth data for areas that are smaller than the country-scale, and thus more closely correspond to changes in wealth in the affected areas.

For Germany, Barthel and Neumayer (2010) use changes in GDP at the local level as a proxy for changes in wealth, while for the United States, they make use of two databases, one recording changes in personal income at the country level, and the other showing changes in the value of housing units at the state level.

Figure 8 shows the results of applying the modified normalisation method of Pielke and Landsea (1998) to insured losses in the United States.

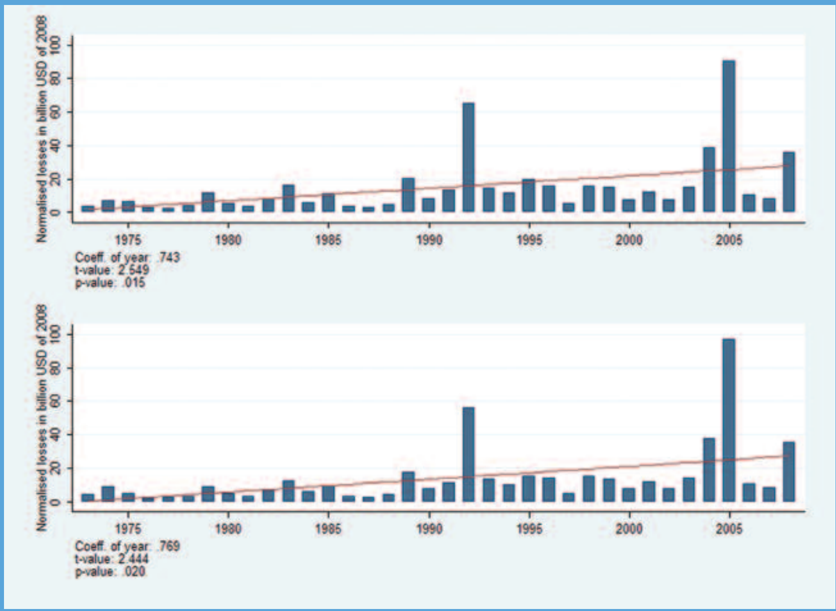

Figure 8: Results for insured losses from 1,277 weather-related events in the United States using the modified method of Pielke and Landsea (1998), taking into account changes in personal income (top) and changes in the value of housing units (bottom).

The results obtained by using changes in personal income as a proxy for changes in wealth are almost identical to those from using changes in the number and value of housing units as a proxy. In both cases the upward trend with time is statistically significant even if the results from 2005 (which include losses from Hurricane Katrina) are excluded. Using personal income, the upward trend in normalised insured losses is US$0.74 billion per year, and using housing units, the trend is US$0.77 billion per year.

Other analyses show statistically significant upward trends in normalised insured losses for convective events (US$0.1 billion per year for both measures of wealth per capita; see also Box 4), flood (flash and general; US$0.15 billion per year for personal income and US$0.14 billion per year for housing units), and all storm events (convective storm, winter storm, sand storm and storm surge; US$0.13 billion per year for both measures of wealth per capita) in the United States. Normalised insured losses from tropical cyclone events in the United States also display a positive trend (US$0.56 billion for personal income and US$0.59 for housing units) that is statistically significant. Analyses of losses due to temperature highs, temperature lows, and winter storms yield results that show no statistically significant trend.

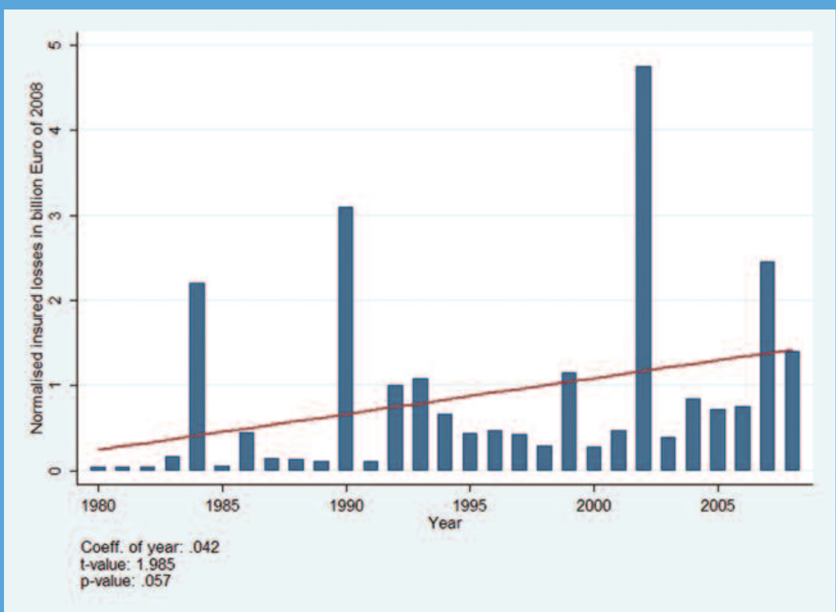

Figure 9: Results for insured losses from 268 weather-related events in Germany using the modified method of Pielke and Landsea (1998).

Figure 9 shows a positive trend of €0.04 billion per year in insured losses from weather-related events in Germany, which is statistically significant. Normalised insured losses from convective events display an upward trend that is not statistically significant. Normalised insured losses from winter storm events show a positive trend of €0.03 billion per year that is statistically significant at the 10 per cent level. There is also a statistically significant trend of €0.03 billion per year for normalised insured losses from all storm event types. However, no statistically significant trend is observed for flood events.

Box 4: Munich Re case study on convective event losses

In an analysis that is due to be submitted for publication in a journal, researchers at Munich Re have investigated trends in economic and insured losses, normalised using the method of Pielke and Landsea (1998), from convective events (flash flood, hail storm, tempest storm, tornado and lightning) between 1973 and 2008. However, the Munich Re analysis attempts to reconstruct the truly affected area at the local and regional level and uses changes in wealth from these affected areas. In contrast, Neumayer and Barthel (2010) simply use the data at the country level, and while Barthel and Neumayer (2010) use spatially disaggregated data, they use county or state level data from the centre of the reported disaster centre instead of trying to reconstruct the truly affected area. As a proxy for wealth, the Munich Re analysis uses the capital stock of buildings, calculated from county-level records of the number of housing units and state-wide median house values, for the affected area.

Neumayer and Barthel (2010) and Barthel and Neumayer (2010) find statistically significant upward linear trends for, respectively, economic and insured losses from convective events in the United States. Munich Re finds statistically significant upward exponential trends in both normalised economic losses and normalised insured losses from convective events in the United States.

In addition, Munich Re divide convective events according to whether they caused losses of more or less than US$500 million. They find a steeper upward trend in normalised insured losses for the large loss events (see Figure 10) than for the small ones.

The Munich Re findings may be due to insurance factors, such as the expansion of the scope of policy coverage over time, or changes in the handling procedures for claims. However, the trends may reflect a change in the occurrence of severe convective events, which has been observed, although it is not possible to tell whether this might be due to natural variability or anthropogenic climate change.

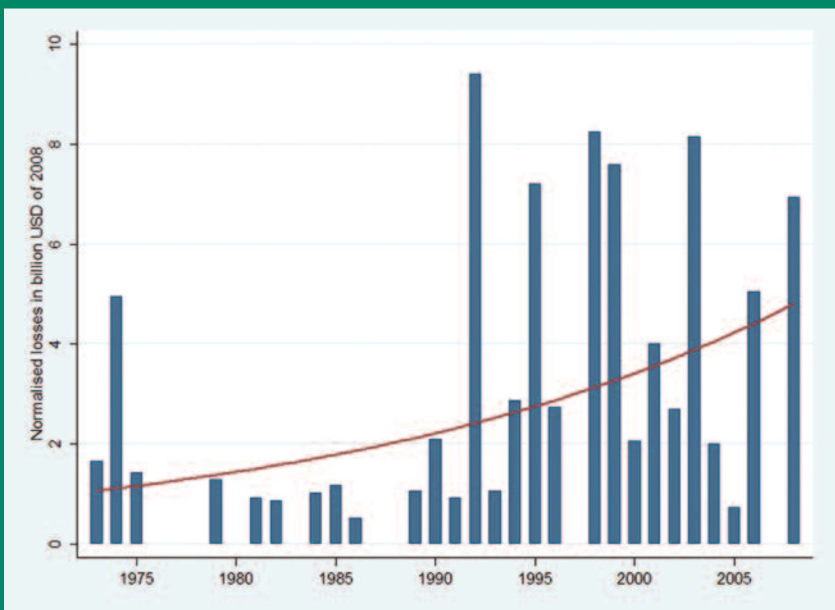

Figure 10: Munich Re analysis of normalised insured losses from convective events in the United States between 1973 and 2008 that caused damage of more than US$500 million (2008 prices). The trend is 4 per cent per year ($p = 0.026$).

Barthel and Neumayer (2010) note a difference in their results for normalised insured losses. They detect statistically significant trends in normalised insured losses for weather-related loss events in the United States and Germany over periods of, respectively, 37 years and 29 years. However, no trends are found in global insured losses for weather-related events over a 19-year period. This may indicate that the shorter period does not provide sufficient data to detect statistically significant trends in insured losses.

Barthel and Neumayer (2010) warn against the inference that the detection of statistically significant trends for normalised insured losses for total weather-related events and specific event types in the United States and Germany provides conclusive evidence for changes in hazard driven by climate change in those countries. They note for instance that the increase in insured losses from tropical cyclone events in the United States may relate to changes in hurricane activity in the North Atlantic that are the result of natural climate variability rather than anthropogenic climate change. However, this is less likely to be an explanation for the trends detected in convective events and flooding.

In addition, the upward trends may result from biases due to insurance premia being a poor proxy for insurance penetration and for the proportion of wealth that is insured in an area that could be affected by a loss event.

The influence of other factors is difficult to quantify. For instance, insured losses may be affected by changes in the handling procedures for insurance claims. Or the trends may be driven by a bias if insured losses are systematically under-reported in earlier years and therefore under-represented in the data analysed by Barthel and Neumayer (2010). This may not be a source of strong bias in the losses for Germany and the United States which have had well-established insurance markets for a relatively long period.

Barthel and Neumayer (2010) point out that before any firm conclusions can be drawn from their interesting and novel findings, more research is needed to analyse which of these potential factors drive the observed upward trends in normalised insured losses in the United States and Germany.

Further reading

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The Centre for Climate Change Economics and Policy was established in 2008 to advance public and private action on climate change through rigorous, innovative research. The Centre is hosted jointly by the University of Leeds and the London School of Economics and Political Science. It is funded by the UK Economic and Social Research Council and Munich Re. More information about the Centre can be found at: **www.cccep.ac.uk**

The Munich Re Programme of the Centre for Climate Change Economics and Policy is evaluating the economics of climate risks and opportunities in the insurance sector. It is a comprehensive research programme that focuses on the assessment of the risks from climate change and on the appropriate responses, to inform decision-making in the private and public sectors. This programme is funded by Munich Re and benefits from research collaborations across the industry and public sectors.

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