Centre for
Climate Change
Economics and Policy

The Munich Re Programme: *Evaluating the Economics of Climate Risks and Opportunities in the Insurance Sector*

Grantham Research Institute on
Climate Change and
the Environment

A trend analysis of normalized insured damage from natural disasters

Fabian Barthel and Eric Neumayer

November 2010

Centre for Climate Change Economics and Policy
Working Paper No. 40

Munich Re Programme Technical Paper No. 5

Grantham Research Institute on Climate Change and the Environment

Working Paper No. 30

The Grantham Foundation for the Protection of the Environment
E·S·R·C Economic & Social Research Council
Munich RE
University of Leeds
LSE The London School of Economics and Political Science

The Centre for Climate Change Economics and Policy (CCCEP) was established by the University of Leeds and the London School of Economics and Political Science in 2008 to advance public and private action on climate change through innovative, rigorous research. The Centre is funded by the UK Economic and Social Research Council and has five inter-linked research programmes:

1. Developing climate science and economics
2. Climate change governance for a new global deal
3. Adaptation to climate change and human development
4. Governments, markets and climate change mitigation
5. The Munich Re Programme - Evaluating the economics of climate risks and opportunities in the insurance sector (funded by Munich Re)

More information about the Centre for Climate Change Economics and Policy can be found at: http://www.cccep.ac.uk.

The Munich Re Programme 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. The programme is exploring, from a risk management perspective, the implications of climate change across the world, in terms of both physical impacts and regulatory responses. The programme draws on both science and economics, particularly in interpreting and applying climate and impact information in decision-making for both the short and long term. The programme is also identifying and developing approaches that enable the financial services industries to support effectively climate change adaptation and mitigation, through for example, providing catastrophe insurance against extreme weather events and innovative financial products for carbon markets. This programme is funded by Munich Re and benefits from research collaborations across the industry and public sectors.

The Grantham Research Institute on Climate Change and the Environment was established by the London School of Economics and Political Science in 2008 to bring together international expertise on economics, finance, geography, the environment, international development and political economy to create a world-leading centre for policy-relevant research and training in climate change and the environment. The Institute is funded by the Grantham Foundation for the Protection of the Environment, and has five research programmes:

1. Use of climate science in decision-making
2. Mitigation of climate change (including the roles of carbon markets and low-carbon technologies)
3. Impacts of, and adaptation to, climate change, and its effects on development
4. Governance of climate change
5. Management of forests and ecosystems

More information about the Grantham Research Institute on Climate Change and the Environment can be found at: http://www.lse.ac.uk/grantham.

A Trend Analysis of Normalized Insured Damage from Natural Disasters

This version: 24 November 2010

Fabian Barthel* **and Eric Neumayer**

Department of Geography and Environment and The Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, Houghton Street, London WC2A 2AE, U.K.
Fax: +44 (0)20 7955 7412
Tel: +44 (0)20 7955 7598

---

[*] Corresponding author (email: f.barthel@lse.ac.uk). The authors acknowledge financial and other support from the Munich Re Programme "Evaluating the Economics of Climate Risks & Opportunities in the Insurance Sector" at LSE. All views expressed are our own and do not represent the views of Munich Re. We thank Eberhard Faust, Peter Höppe, Jan Eichner, Nicola Ranger and Bob Ward for many helpful comments. All errors are ours.

A Trend Analysis of Normalized Insured Damage from Natural Disasters

Abstract

As the world becomes wealthier over time, inflation-adjusted insured damages from natural disasters go up as well. This article analyzes whether there is still a significant upward trend once insured natural disaster loss has been normalized. By scaling up loss from past disasters, normalization adjusts for the fact that a disaster of equal strength will typically cause more damage nowadays than in past years because of wealth accumulation over time. A trend analysis of normalized insured damage from natural disasters is not only of interest to the insurance industry, but can potentially be useful for attempts at detecting whether there has been an increase in the frequency and/or intensity of natural hazards, whether caused by natural climate variability or anthropogenic climate change. We analyze trends at the global level over the period 1990 to 2008, over the period 1980 to 2008 for Germany and 1973 to 2008 for the United States. We find no significant trends at the global level, but we detect statistically significant upward trends in normalized insured losses from all non-geophysical disasters as well as from certain specific disaster types in the United States and Germany.

1. Introduction

Analyzing trends in natural disaster loss represents an important tool for attempts at detecting whether climate change has already started to have an effect on the frequency and/or intensity of natural disasters. Most of existing studies have looked at total economic loss (Pielke and Landsea 1998; Pielke et al. 1999, 2003, 2008; Brooks and Doswell 2001; Raghavan and Rajseh 2003; Nordhaus 2006; Vranes and Pielke 2009; Schmidt, Kemfert and Höppe 2009; Barredo 2009). Fewer studies have analysed insured losses and all of them are confined to a specific hazard type in one country (Changnon and Changnon 1992; Changnon 2001, 2009a, 2009b; Crompton and McAeneney 2008).[1] Yet, analyzing trends in insured losses is important for two reasons. First, insurance companies naturally worry most about insured losses and are interested in any trends in these losses quite independently of whether they are caused by natural climate variability or anthropogenic greenhouse gas emissions or other drivers. Second, insured losses are estimated with greater precision than total economic losses, which all other things equal should be beneficial since measurement error hampers statistical analysis and thus renders detecting statistically significant trends more difficult.

Existing studies of total economic and insured loss have typically found no increasing trend over time after loss has been subjected to what is known as “normalization”. Normalization adjusts for the fact that a disaster of equal strength will typically cause more damage in the current period than in the past because there is typically more wealth potentially destroyable in the present compared to the past. Normalization thus adjusts nominal economic loss from past disasters upwards by multiplying past damage with a factor for inflation, for population growth and for

---

[1] Hazards are events triggered by natural forces. They will turn into natural disasters if people are exposed to the hazard and are not resilient to fully absorbing the impact without damage to life or property (Schwab, Eschelbach and Brower 2007).

growth in wealth per capita, thus in effect estimating the damage a past disaster would have caused had it hit the same, but nowadays wealthier, area today. Without normalization, disaster loss is likely to trend upwards over time, not because disasters have necessarily become more frequent and/or more intensive, but simply because destroyable wealth has increased over time. For normalizaton of insured disaster losses, one additionally needs to adjust for changes in insurance penetration, i.e. the share of wealth covered by insurance, over time. The question, to be studied in this article, is therefore whether the results of existing studies which have analyzed trends in normalized *total* economic loss carry over to trend analysis in normalized *insured* losses.

To our knowledge, this is the first article systematically analyzing trends in insured natural disaster loss for more than one hazard type and for a larger country sample. We do so at the global level, for developed countries, for specific types of disasters as well as for specific country/disaster type combinations. Section 2 explains the methodology of normalizing natural disaster loss. Section 3 describes our empirical research design and reports results from the analysis. Section 4 concludes.

2. Normalizing natural disaster loss

The conventional approach to normalizing natural disaster loss can be credited to Roger Pielke Jr. and co-authors (see Pielke and Landsea 1998, Pielke et al. 1999, 2003, 2008; Vraines and Pielke 2009). The typical equation to compute normalized damage according to this approach is as follows:

$$Normalized\ Damage_t^s = Damage_t \cdot \frac{GDPdeflator_s}{GDPdeflator_t} \cdot \frac{Population_s}{Population_t} \cdot \frac{Wealth\ per\ capita_s}{Wealth\ per\ capita_t} \quad (1)$$

where s is the (chosen) year one wishes to normalize to, t is the year in which damage occurred, the Gross Domestic Product (GDP) deflator adjusts for inflation (i.e., change in producer prices), while the remaining two correction factors adjust for *changes in* population and wealth per capita. In theory, the population and wealth changes should be based on data from the exact areas affected by the natural disaster in question. However, in practice it is often impossible to determine the exact areas or information on these areas is difficult or impossible to get, so scholars typically resort to using data from the country or, if they can, from sub-country administrative units known to be affected (e.g., counties or states). Studies differ with respect to how wealth per capita is measured. Some use data on the value of capital stocks (e.g., Pielke and Landsea 1998; Brooks and Doswell 2001; Vranes and Pielke 2009; Schmidt, Kemfert and Höppe 2009) or the value of dwellings (Crompton and McAneney 2008), others, often for lack of data, simply use GDP per capita (e.g., Raghavan and Rajseh 2003; Pielke et al. 2003; Nordhaus 2006; Miller et al. 2008; Barredo 2009). With more than one disaster per year, the measure of disaster loss per year is the sum of normalized damages from each disaster as per equation (1).

Neumayer and Barthel (2010) have criticized conventional normalization methodology on the grounds that it adjusts for differences in wealth over time, but not for differences in wealth across space at any point of time. Conventional normalization adjusts for the fact that a disaster like, say, the 1926 Great Miami hurricane would have caused far more damage if it hit Miami nowadays since the value of what can potentially become destroyed has tremendously increased over this time period (Pielke et al. 1999). At the same time, however, a hurricane that hits Miami in any year will cause a much larger damage than a hurricane that hits in the same year rural parts of Florida with much lower population density and concentration of wealth. Conventional normalization accounts for the former effect, but not for the latter. It makes Miami in 1926 comparable to Miami in 2010, but fails to make Miami in whatever year comparable to rural Florida or other areas affected by a particular natural disaster in that same year. Neumayer and Barthel (2010) have therefore developed an alternative normalization methodology that additionally adjusts for differences in space. However, for this method to be applied in empirical analysis, one would need information on the value of *insured* wealth potentially destroyable in any given area. Since this information is typically not available, we follow the conventional normalization methodology in this paper.

3. Research Design

Contrary to Neumayer and Barthel (2010), in which we could study trends of all economic losses over the period 1980 to 2009, poor availability of data during the 1980s on insurance premia needed for normalization in terms of insurance penetration means that our statistical tests are restricted to the period 1990 to 2008 for all analyses but those for the United States and Germany, for which we have data from 1973 and 1980, respectively, onwards. The disadvantage of being compelled to use a relatively short time period is that, ceteris paribus, the shorter the time series of annual loss data the less likely any trend will be detected as statistically significant (the smaller N, the number of observations, the higher the standard error of the estimate). Also, the IPCC (2007a: 942) defines climate in a narrow sense “as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities” over a period of 20 to 30 years, so our study period of 1973, 1980 or 1990 to 2008 may be too short to identify changes in climate.

Data on insured loss from natural disasters in nominal USD comes from Munich Re's NatCat database. Munich Re also supplied us with data on insurance premia in a country. The NatCat database provides the highest quality data currently available, but it is of course not perfect. Smaller disasters may be somewhat under-reported in the early periods relative to later periods. At Munich Re, several members of staff scan daily international and regional sources to compile information about disaster events. Data are collected from a variety of sources including government representatives, relief organisations and research facilities. Information on insured losses is based on information of insurance associations and insurance services as well as on claims made by Munich Re's customers, which provide the best approximation to the actual damage. Initial reports on insured losses, which are usually available in the immediate aftermath of a disaster, are often highly unreliable. Therefore, data in the NatCat database is updated continuously as more accurate information becomes available, which might be even years after the disaster event. Our analysis ends in 2008, since these cases are closed to the largest extent (Munich Re, personal communication).

Since we study trends in insured rather than total economic losses, we need to adjust the conventional normalization methodology represented by equation (1) by adding an additional factor to control for changes in the insurance penetration as a proxy for the share of wealth covered by insurance policies:

$$Norm.Ins.Loss_t^s = Loss_t \cdot \frac{GDPdefl_s}{GDPdefl_t} \cdot \frac{Pop_s}{Pop_t} \cdot \frac{Wealth\ pc_s}{Wealth\ pc_t} \cdot \frac{Ins.\,penetration_s}{Ins.\,penetration_t} \qquad (2)$$

For our global analysis, we use GDP per capita as a proxy for wealth as there is no other measure of wealth available for all countries in the world. This is not unproblematic. GDP has the advantage that it captures well potential economic loss due to the interruption of economic operations as a result of a natural disaster, but it is a relatively poor proxy for the physical wealth stock potentially destroyable by disasters.[2] Whereas economic wealth is a stock, GDP is a flow of economic activity. Fortunately, despite GDP consisting in part of intangible components such as services with scant correspondence to the value of the physical wealth stock, on the whole GDP is highly correlated with it. But GDP can only function as a proxy for wealth and typically understates it. Economists estimate the ratio of the value of the physical man-made or manufactured capital stock to GDP to lie somewhere in between 2 and 4 for a typical macro-economy (D'Adda and Scorcu 2003). But this ratio will differ from country to country and, more importantly, is a national macro-economic average, which can differ more drastically across sub-country units.[3] It also only captures the value of the physical capital stock used for the production of consumption goods and services, but not the value of other wealth held in the form of, for example, residential property. Moreover, the increasing share of GDP consisting of intangible components such as services, which is observed in many, but not all, countries implies that the growth rate of GDP possibly over-estimates the growth rate of the physical wealth stock. This will bias the results against finding a positive trend since disasters from past periods are scaled up too strongly as a result of normalization.

---

[2] GDP might also be positively affected by large disasters as repair and reconstruction increase GDP.

[3] It has also changed over time (see D'Adda and Scorcu 2003), but Krugman (1992: 54f.) concludes that "there is a remarkable constancy of the capital-output ratio across countries; there is also a fairly stable capital-output ratio in advanced nations. These constancies have been well known for a long time and were in fact at the heart of the famous Solow conclusion that technological change, not capital accumulation, is the source of most growth."

Keeping in mind that, for our global analysis, we use GDP per capita as a proxy for wealth and that the product of population and GDP per capita equals total GDP, equation (2) modifies to:

$$Norm.Ins.Loss_t^s = Loss_t \cdot \frac{GDPdefl_s}{GDPdefl_t} \cdot \frac{GDP_s}{GDP_t} \cdot \frac{Ins.\,penetration_s}{Ins.\,penetration_t} \tag{3}$$

Regrettably, there is no data available on insurance penetration as such for our global analysis. For our global analysis, we use data on property and, where available, also engineering insurance premia, which, if expressed relative to GDP, can function as a proxy for insurance penetration.. For Germany and the US, however, we have data, including data for a longer time-series, on a subset of property and engineering premia as well as premia on motor physical damage, which relate more directly to insured values that can potentially be destroyed by natural disasters and which we therefore take in lieu of all property and engineering insurance premia.[4]

One problem with using insurance premia relative to GDP is that these can change even if the share of insured wealth among all wealth remains the same and vice versa. Insurance premia can, for example, change in response to changes in insurance pay-outs resulting from changes in the frequency and/or intensity of insured loss events, constituting the requirement of "risk adequate pricing" in the insurance industry. For example, premia have increased following the 2004/05 hurricane seasons in parts of the US. But on the whole, changes in property and engineering

---

[4] Only for the normalization of damage from temperature highs and temperature lows do we exclude motor physical damage premia since vehicles can not normally be damaged by these hazards. A full list of the detailed types of insurances, for which premia are included in the analysis for Germany and the US, is available from the authors on request.

premia relative to GDP should in the long run by and large represent an acceptable proxy for changes in insurance penetration (Munich Re, personal communication).[5]

Using insurance premia in a given year relative to total GDP in the same year as a proxy for insurance penetration in equation (3), total GDP drops out and using 2008 as our chosen base year for normalization, we can write:

$$Norm.Ins.Loss_t^{2008} = Loss_t \cdot \frac{GDPdefl_{2008}}{GDPdefl_t} \cdot \frac{Insurance\ premia_{2008}}{Insurance\ premia_t} \quad (4)$$

Normalization equation (4) is the one we use in our global analysis. The loss data in the NatCat database and the data on insurance premia are in USD. We converted them into local currencies applying exchange rate data provided to us by Munich Re to ensure we use the same exchange rates Munich Re uses to convert from local currency values into USD. With all data in local currency, we therefore also use the GDP deflator of the country itself for our normalization purposes. Since for an aggregate analysis of more than one country one needs to make normalized insured loss comparable across countries, in the final step we then re-converted the normalized insured losses from local currencies into USD.[6]

For Germany and the US, not only do we have a longer time-series of data on insured losses, but also GDP or income data are available for sub-national

---

[5] For Germany, researchers at Munich Re undertook an analysis of the relationship between premia and total sum of insured values and found the two to be very highly correlated over time. For the US, due to lack of data no similar analysis could be undertaken. Most likely, if data had been available such an analysis would have shown a lower correlation because of market cycles and premia adjustments after large disasters (Munich Re, personal communication).

[6] Alternatively, one can keep all values in USD and then apply the US GDP deflator for normalization purposes. The two approaches lead to practically identical results.

administrative units, i.e. on a more fine-grained spatial resolution.[7] The NatCat database provides a geo-reference of the disaster center which allows us to match each disaster with the sub-national administrative unit in which it occurred. For Germany, our spatial resolution is on the NUTS3 level (corresponds to ‘Landkreise’ and ‘Kreisfreie Städte’). Total GDP in constant Euros is provided by Cambridge Econometrics (2010). We converted insured losses into Euro using the exchange rate used by Munich Re. Since the analysis for Germany is thus in local currency units, we also used the GDP deflator for Germany and normalized damage is expressed in Euros.[8]

For the US, we have access to two alternative measures of wealth. Our first measure is personal per capita income data taken from BEA (2010), at the county level.[9] Our second measure is a combination of information on the number and value of housing units, with data at the state level. Data on housing units up to year 2000 are taken from the National Historical Geographical Information System (NHGIS 2010), estimates for later years are obtained from the US Census Bureau (2010a). Median home value data is available until 2000 and taken from the US Census Bureau (2010b). Both data on housing units and median house values are available on a decadal basis for earlier years. Linear interpolation was used to fill the gaps. Values on median home values for years after 2000 are obtained by linear extrapolation of all

---

[7] GDP growth on a country level can be a poor approximation for changes in wealth in the affected area of a disaster. For instance, while GDP in Germany grew over the whole study period, GDP actually decreased in some parts of Eastern Germany after reunification.

[8] Since we use GDP at different levels of spatial resolution for calculating insurance penetration on the one hand and for wealth adjustment on the other for Germany and the US, GDP does not drop out of equation (3). As a consequence, equations (2) and (3) rather than equation (4) are used for normalizing insured losses in Germany and the US.

[9] Personal income is defined as the income received by all persons from all sources before the deduction of personal taxes (BEA 2010) and reported in current USD and converted into constant values with the US GDP deflator. Results are almost identical if we use GDP data at the state level from the same source instead

previous values. To adjust losses both to the changes in the number and the median value of housing units, the following equation is used:

$$Norm.Ins.Loss_t^s = Loss_t \cdot \frac{GDPdefl_s}{GDPdefl_t} \cdot \frac{Units_s}{Units_t} \cdot \frac{MedVal_s}{MedVal_t} \cdot \frac{Ins.\,penetration_s}{Ins.\,penetration_t} \qquad (5)$$

In line with existing normalization studies, to test for the existence of a trend, the annual sum of normalized disaster losses from each year is regressed on a linear year variable and an intercept:

$$Normalized\ Insured\ Loss_t^{2008} = \alpha_0 + \beta_1 \mathrm{year}_t + \varepsilon_t \qquad (6)$$

A trend is statistically significant if the null hypothesis that β_1 is equal to zero can be rejected at the ten percent level or lower. Robust standard errors are employed in all estimations.

4. Results from an Analysis of Trends in Normalized Insured Losses

In this section, we present the results from our analysis of trends in normalized insured losses. We start with our global analysis, before analyzing in more detail insured losses in the US and Germany. Figure 1 displays the non-normalized, i.e. merely deflated annual insured losses caused by all types of natural disasters from 1980 to 2008. The analysis covers 19,367 disasters, of which 2,553 resulted in a known insured loss. Over the whole period, there is a positive and statistically significant trend. The coefficient indicates an average annual increase of 1.4bn USD. However, while the size of the coefficient is hardly affected if the sample is restricted to start from 1990, the trend loses its significance. As mentioned already, shorter time-series make the detection of a statistically significant trend less likely.

There is no statistically significant trend if we adjust insured losses for the changes in potentially destroyable insured losses, i.e. if we normalize insured disaster loss (Figure 2). Losses before 1990 are not shown since we have data on insurance premia only for few countries before 1990. The analysis still covers 11,988 disasters, with 1,636 of them resulting in a known damage claim to insurance companies.

Some natural hazards will be practically unaffected by climate change and are therefore irrelevant if one wants to detect whether a potential climate change already has lead to increased insured damages. In Figure 3, we therefore excluded geophysical disasters (earthquakes, land slides, rock falls, subsidence, volcanic eruptions, and tsunamis) and only include the following disaster types: blizzards, hail storms, lightning, local windstorms, sandstorms, tropical cyclones, severe storms, tornados, winter storms, avalanches, flash floods, general floods, storm surges, cold and heat waves, droughts, winter damages, and wildfires. As before, no significant trend is discernible. Similarly, we do not find a significant trend if we constrain our analysis to non-geophysical disasters in developed countries, which cover Organisation of Economic Co-operation and Development (OECD) and other high-income countries, according to World Bank classification (Figure 4).[10]

Convective events, i.e. flash floods, hail storms, tempest storms, tornados, and lightning, deserve closer attention since these are possibly affected by global warming (Trapp et al. 2007, 2009; Kuntz et al. 2009). Figure 5a shows that there is no significant trend in global insured losses for these peril types. Similarly, there is no

---

[10] We show no graphs for developing countries separately as insurance penetration is very low and insurance coverage is typically restricted to major cities in middle- and upper middle-income developing countries.

significant trend in insured losses for storm events (Figure 5b), tropical cyclones (Figure 5c) or precipitation-related events (Figure 5d).

As mentioned already, a statistically significant trend is harder to establish for a shorter time-series. Hence, we separately analyzed in some detail natural disasters occurring in the two countries for which data on insured losses and insurance premia are available for the longest time period, namely the United States and Germany, which are also major insurance markets of course. Figure 6a illustrates normalized insured losses from non-geophysical disasters that occurred in the United Stated over the period 1973 to 2008. Losses normalized using changes in personal income as a proxy for changes in wealth are shown in the upper panel, while we used the alternative proxy of changes in the number and value of housing units to adjust losses in the lower panel. The results for both approaches are virtually identical. Moreover, in non-reported analysis we found that results are very similar if we use GDP changes at the country rather than at the state level. We take this as evidence for the robustness of the results in our global analysis for which we had to resort to changes in GDP at the country level as a proxy for changes in wealth. We find a positive trend in normalized insured losses from non-geophysical disasters in the US, which is statistically significant at the 5 percent level. This remains true if the large outlier due to hurricane Katrina in 2005 is excluded.

In the remaining analysis of insured losses in the US, we examine specific subsets of the non-geophysical disasters. Figure 6b shows that there is also a statistically significant upward trend if the analysis is restricted to convective events, i.e. flash floods, hail storms, tempest storms, tornados, and lightning. There is also a positive trend in insured damage from US flooding events, which includes both flash floods and general floods (Figure 6c). The same is true for events caused by temperature highs (Figure 6d). There is however, no significant trend for events caused by temperature lows (Figure 6e). If we look at winter storms (Figure 6f), which also include snow storms and blizzards, we find a significant upward trend. The same is true for all storms, which besides winter storms include convective storms (hail storm, tempest storms, tornado, lightning), sand storms and storm surges (figure 6g). Focusing on hurricanes, an upward trend in insured losses is found, which is statistically significant at the 10 percent level (Figure 6h). This is consistent with results on total economic loss from US hurricanes reported in Schmidt, Kemfert and Höppe (2009).

Turning to Germany, the trend in insured loss from non-geophysical disasters is significant at the 10 percent level (figure 7a), despite the volatility introduced by the four strong loss spikes in 1984 (predominantly caused by Munich hail storm), 1990 (predominantly winter storm series), 2002 (predominantly river flooding along the Elbe, Danube and contributory rivers and a winter storm in late October) and 2007 (predominantly winter storm Kyrill). If these events are excluded, the trend becomes significant at the one percent level. For convective events (figure 7b), however, no such significant trend can be established unless the large outlier from 1984 (Munich hail storm) is dropped from the analysis. Figure 7c, which shows normalized loss from flooding similarly demonstrates by just how much single outliers, like the massive damage caused by the floods in 2002, can dominate the entire picture. However, with or without this outlier, there is no significant trend. Contrarily, there is a trend, which is significant at the 10 percent level, in normalized insured loss from winter storms (figure 7d). The trend becomes significant at the 5 percent level (p-value 0.025) if the large outlier from 1990 is dropped from the analysis. There is similarly a significant upward trend for the category of all storms (figure 7e). Note that for Germany hurricanes are irrelevant and there are very few events related to temperature highs and temperature lows. These disaster types are therefore not included in our analysis for Germany.

5. Conclusion

In this article, we have analyzed whether one can detect a trend in data on *insured* damage from natural disasters. Insurance companies are naturally worried about climate change as the predicted increase in the frequency and/or intensity of natural hazards is likely to lead to higher economic and, ceteris paribus, higher insured damage in the future, unless defensive mitigating measures make exposed wealth less vulnerable to the impact of disasters. Whilst we have not found any evidence that normalized insured damage has trended upward at the global level, for developed countries and independently of the type of disaster looked at, our finding of an upward trend in insured losses from non-geophysical disasters and certain specific disaster types in the US, the biggest insurance market in the world, and in Germany represents a finding to be taken seriously in the risk analysis undertaken by insurance and re-insurance companies.

As in the interpretation of trends in all economic losses, much caution is required in correctly interpreting our findings. In particular, we cannot normalize for changes in mitigating measures, which, if increasingly undertaken over time, would reduce countries' vulnerability to the impact of natural disasters and thus bias the analysis against finding significant upward trends. What the results tell us is that, based on the very limited time-series data we have for most countries, there is no statistically significant evidence so far for a significant upward trend in normalized insured loss from natural disasters outside the US and Germany. One cannot infer from our analysis that there have not been more frequent and/or more intensive weather-related natural disasters in other places. In addition to our inability to take into account defensive mitigating measures undertaken by rational individuals and governments, which could translate into lower insured damage compared to the damage in the absence of defensive mitigation, the time period 1990 to 2008 may simply be too short to find significant trends in our global analysis. It is noteworthy that for the US and Germany, for which we can analyze normalized loss from, respectively, 1973 and 1980 onwards, we do find a significant increase in normalized insured losses for some relevant disaster types over time.

By the same token, we warn against taking the findings for the US and Germany as *conclusive* evidence that climate change has already caused more frequent and/or more intensive natural disasters affecting this country. To start with, one needs to be careful in attributing such a trend to anthropogenic climate change, i.e. climate change caused by man-made greenhouse gas emissions. Our findings reported in this article could be down to natural climate variability that has nothing to do with anthropogenic climate change. Such natural climate variability may well explain our finding of a significant upward trend in insured loss from hurricanes in the US, for example. It is less plausible as a potential explanation for the significant upward trends in convective events and flooding events, however.

Alternatively, our findings of upward trends could be driven by insurance penetration representing a poor proxy for the share of insured wealth potentially destroyable. However, in further analysis of overall economic loss, rather than merely insured loss, for which one does not need to include a correction factor for insurance penetration, we found for the same time period and using otherwise the same methodology that trends in total economic loss for Germany and the US resemble those for trends in insured loss (detailed results available upon request).[11] Insurance penetration as such is thus unlikely to be the main driver behind the upward trend in insured losses.

As another potential contributing factor, there are some drivers of change on the insurance side that might have contributed to more expensive disasters and are hard to quantify. For instance, insured losses can also be influenced by changes in insurance claims handling procedures and the costs of these. Such changes could have had an effect on insured losses over the past decades, but are very difficult to quantify.

Lastly, our findings could be driven by reporting bias if insured loss from early periods is systematically under-reported and thus under-represented in our analysis. However, for the US and Germany a significant reporting bias regarding the more substantial losses is much less likely than for other countries, given these are two of the biggest insurance markets in the world.

Our findings are interesting, but before any firm conclusions can be drawn from them, more research is needed to analyze which of these potential explanatory factors, of which anthropogenic climate change is but one possibility, or which combination of factors drive the observed upward trends. With these caveats in mind, our findings only provide *tentative* evidence that anthropogenic climate change may possibly already have triggered more frequent and/or more intensive relevant natural disasters affecting Germany as well as the US and thus, ironically, the biggest emitter of greenhouse gas emissions in the world.

---

[11] The estimated p-values of the coefficients for the *year* variable are typically higher, possibly corroborating the argument that insured loss is measured with greater precision, but we find significant upward trends in total economic loss for six of the ten cases in which we find significant trends for insured loss and, with the exception of events from temperature highs in the US, in the other cases the estimated coefficients are not far from being statistically significantly different from zero.

References

Barredo, J.I., 2009, Normalised flood losses in Europe: 1970–2006, *Natural Hazards and Earth Systems Sciences*, 9, pp. 97-104.

BEA, 2010, Regional Economic Accounts, available at: http://www.bea.gov/regional/index.htm.

Bouwer, Laurens M., 2010, Have past disaster losses increased due to anthropogenic climate change?, *Bulletin of the American Meteorological Society* (forthcoming). doi: 10.1175/2010BAMS3092.1.

Brooks, Harold E. and Charles A. Doswell, 2001, Normalized Damage from Major Tornados in the United States: 1890-1999, *Weather and Forecasting*, 16, pp. 168-176.

Cambridge Econometrics, 2010, *European Regional Data*, Cambridge, UK.

Changnon, Stanley A., 2001, Damaging Thunderstorm Activity in the United States, *Bulletin of the American Meteorological Society*, 82(4), pp. 597-608.

Changnon, Stanley A., 2009a, Temporal and spatial distributions of wind storm damages in the United States, *Climatic Change*, 94, pp. 473-482.

Changnon, Stanley A., 2009b, Increasing major hail losses in the U.S., *Climatic Change*, 96, pp. 161-166.

Changnon, Stanley A. and Joyce M. Changnon, 1992, Storm Catastrophes in the United States, *Natural Hazards*, 6, pp. 93-107.

Crompton, Ryan P. and K. John McAneney, 2008, Normalised Australian insured losses from meteorological hazards: 1967-2006, *Environmental Science & Policy*, pp. 371-378.

D'Adda, Carlo and Antonello E. Scorcu, 2003, On the Time Stability of the Output-capital Ratio, *Economic Modelling*, 20, pp. 1175-1189.

De Ronde, J.G., J.P.M. Mulder, and R. Spanhoff, 2003, Morphological Developments and Coastal Zone Management in the Netherlands, International Conference on Estuaries and Coasts November 9-11, 2003, Hangzhou, China.

IPCC, 2001, Climate Change 2001: *Impacts, Adaptation, and Vulnerability*, New York: Cambridge University Press.

IPCC, 2007a, *Climate Change 2007: The Physical Science Basis*, New York: Cambridge University Press.

IPCC, 2007b, *Climate Change 2007: Impacts, Adaptation, and Vulnerability*, New York: Cambridge University Press.

Institute for Business and Home Safety, 2008, The Benefits of Modern Wind Resistant Building Codes on Hurricane Claim Frequency and Severity – A Summary Report; available at: http://www.ibhs.org/newsroom/downloads /20070810_102941_10167.pdf.

Katz, R. W., 2002, Stochastic modeling of hurricane damage, *Journal* of *Applied Meteorology*, 41(7), pp. 754-762.

Krugman, Paul, 1992, Comment. *NBER Macroeconomics Annual*, 7, pp. 54-56.

Kuntz, M., J. Sander and Ch. Kottmeier, 2009, Recent trends of thunderstorm and hailstorm frequency and their relation to atmospheric characteristics in southwest Germany, *International Journal of Climatology*, 29, pp. 2283-2297.

Lavery, Sarah and Bill Donovan, 2005, Flood risk management in the Thames Estuary looking ahead 100 years, *Philosophical Transactions of the Royal Society A*, 363, pp. 1455-1474.

Miller, Stuart, Robert Muir-Wood and Auguste Boissonade, 2008, An exploration of trends in normalized weather-related catastrophe losses, in: Diaz, Henry F. and

Richard J. Murnane (eds), *Climate Extremes and Society*, pp. 225-247. New York: Cambridge University Press.

NHGIS, 2010, Census of Population and Housing 1970-2010, available at: http://data.nhgis.org/nhgis/.

Neumayer, Eric and Fabian Barthel, 2010, Normalizing Economic Loss from Natural Disasters: A Global Analysis. *Global Environmental Change* (forthcoming). doi:10.1016/j.gloenvcha.2010.10.004.

Nordhaus, William D., 2006, The Economics of Hurricanes in the United States, Working Paper. New Haven: Yale University.

Pielke, Roger A. Jr. and Christopher W. Landsea, 1998, Normalized Hurricane Damages in the United States: 1925-1995, *Weather and Forecasting*, Sept. 1998, pp. 621-631.

Pielke, Roger A. Jr., Christopher W. Landsea, Rade T. Musulin and Mary Downton, 1999, Evaluation of Catastrophe Models using a Normalized Historical Record, *Journal of Insurance Regulation*, 18(2), pp. 177-194.

Pielke, Roger A. Jr., Jose Rubiera, Christopher Landsea, Mario L. Fernández, and Roberta Klein, 2003, Hurricane Vulnerability in Latin America and The Caribbean: Normalized Damages and Loss Potentials, *Natural Hazards Review*, 4(3), pp. 101-114.

Pielke, R. A., Jr., Gratz, J., Landsea, C. W., Collins, D., Saunders, M. A., and Musulin, R., 2008, Normalized hurricane damages in the United States: 1900–2005, *Natural Hazards Review*, 9(1), pp. 29-42.

Raghavan, S. and S. Rajseh, 2003, Trends in Tropical Cyclone Impact: A Study in Andhra Pradesh, India, *American Meteorological Society*, 84, pp. 635-644.

Schmidt, Silvio, Claudia Kemfert and Peter Höppe, 2009, Tropical cyclone losses in the USA and the impact of climate change — A trend analysis based on data from a new approach to adjusting storm losses, *Environmental Impact Assessment Review*, 29, pp. 359-369.

Schwab, Anna K., Katherine Eschelbach and David J. Brower, 2007, *Hazard Mitigation and Preparedness*. Hoboken: Wiley & Sons.

Trapp, Robert J., Noah S. Diffenbaugh, Harold E. Brooks, Michael E. Baldwin, Eric D. Robinson, and Jeremy S. Pal, 2007, Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing, *Proceedings of the National Academy of Sciences of the United States of America*, 104, pp. 19719-19723.

Trapp, Robert J., Noah S. Diffenbaugh, and Alexander Gluhovsky, 2009, Transient response of severe thunderstorm forcing to elevated greenhouse gas concentrations, *Geophysical Research Letters*, 36, L01703.

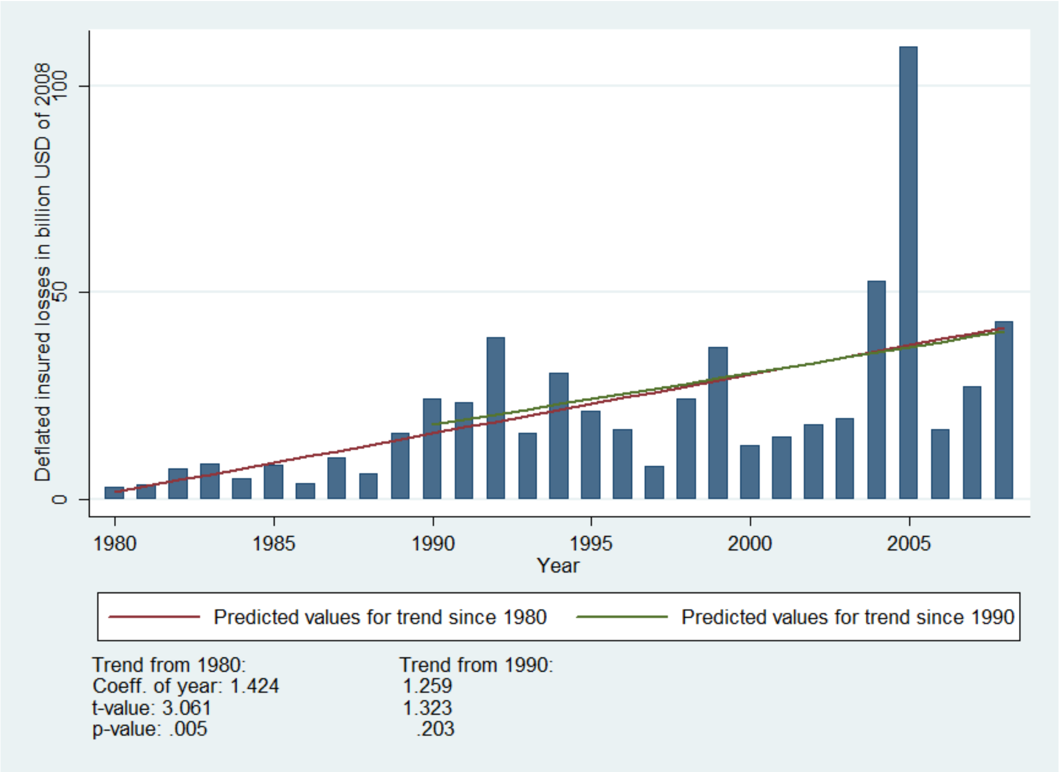
US Census Bureau, 2010a, Population Estimates: Housing Units, available at: http://www.census.gov/popest/housing/.

US Census Bureau, 2010b, Historical Census of Housing Tables: Home Values, available at: http://www.census.gov/hhes/www/housing/census/historic /values. html.

Vranes, Kevin and Roger Pielke Jr., 2009, Normalized Earthquake Damage and Fatalities in the United States: 1900-2005, *Natural Hazards Review*, 10(3), pp. 84-101.

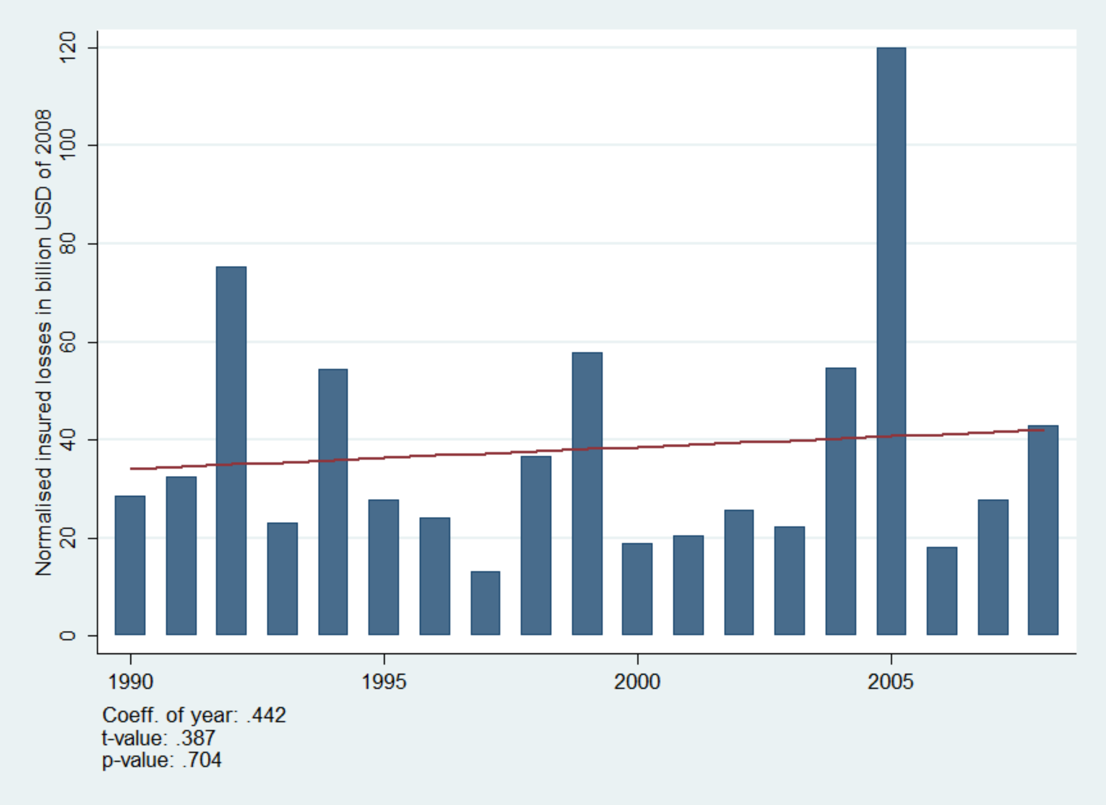
World Bank, 2010, *World Development Indicators Online Database*. Washington, C: World Bank.

Figure 1: Global deflated insured losses from natural disasters



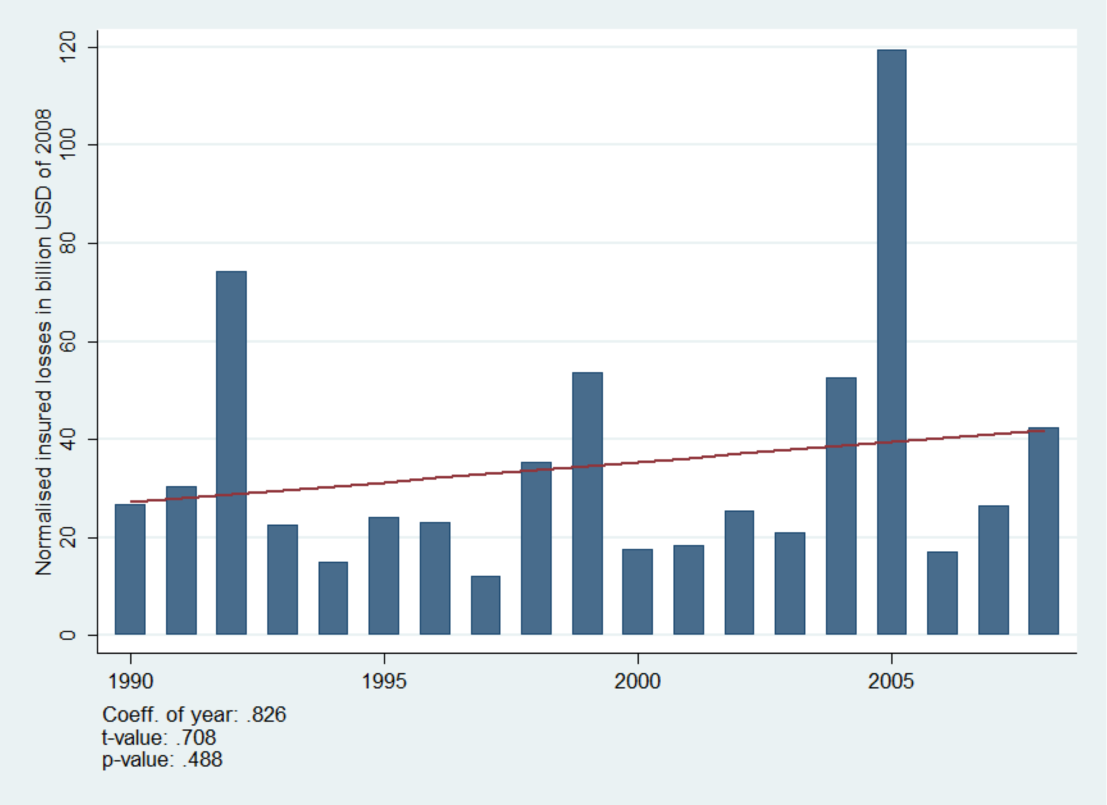
Note: 19,367 disasters, thereof 2,553 with a known insured loss for whole period, 14,876 (1,855) for the period from 1990.

Figure 2: Global normalised insured losses from all disasters



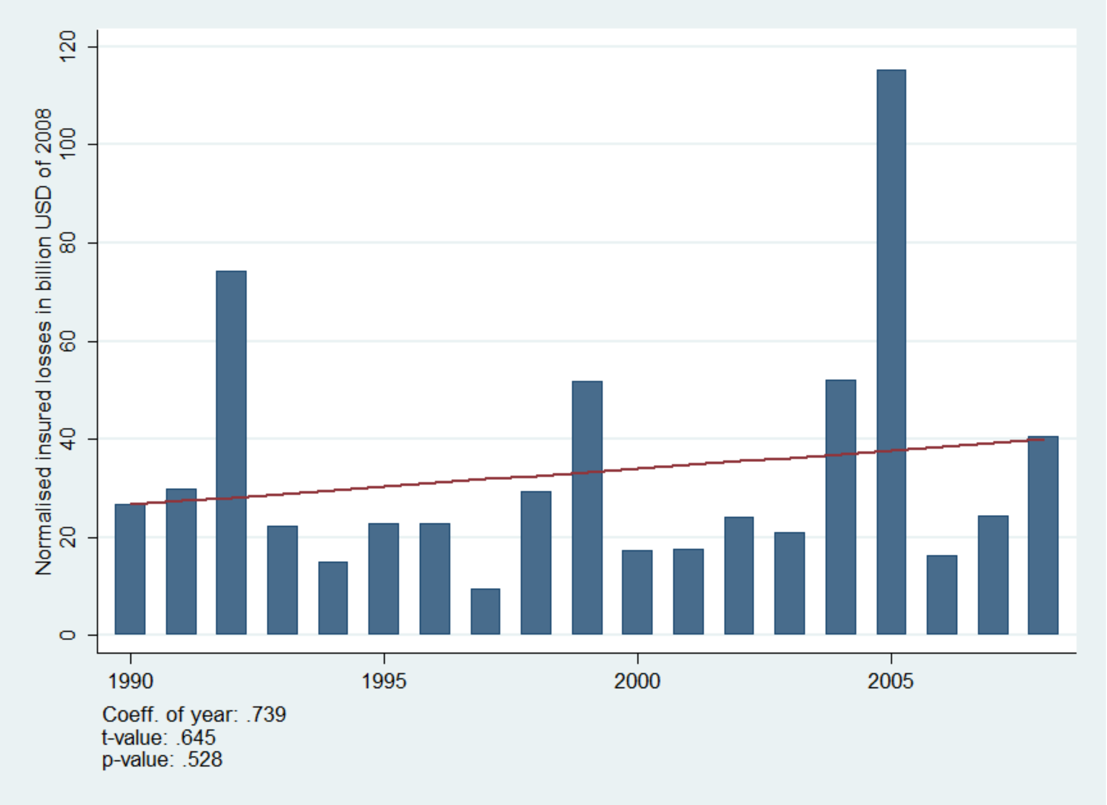
Note: 11,988 disasters, thereof 1,636 with a known insured loss.

Figure 3: Global normalised insured losses from non-geophysical disasters



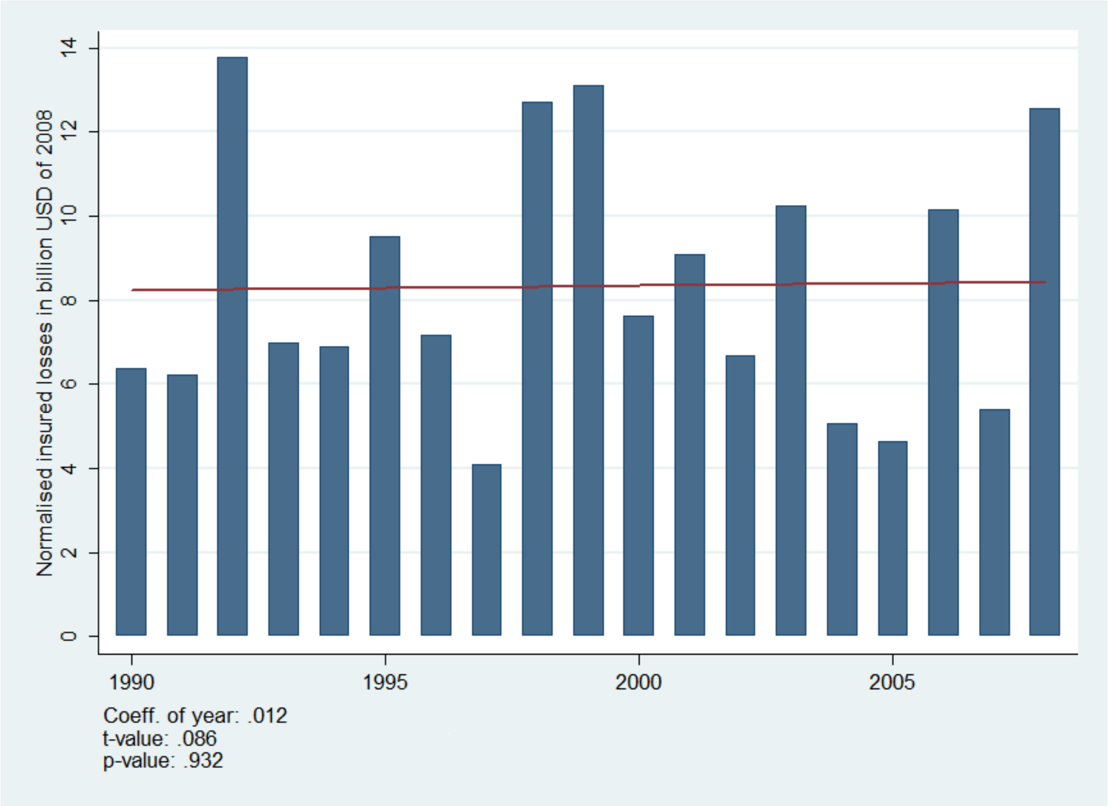
Note: 10,434 disasters, thereof 1,531 with a known insured loss.

Figure 4: Normalised insured losses from non-geophysical disasters in developed countries



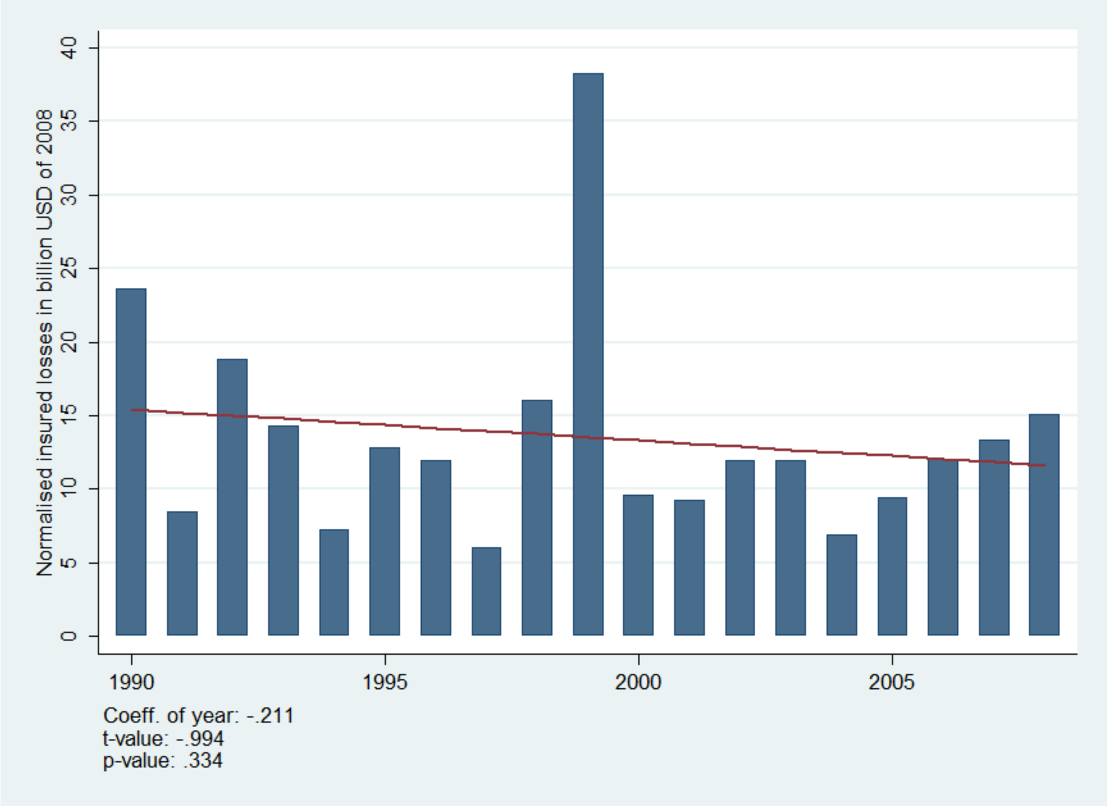
Note: 5,538 disasters, thereof 1,416 with a known insured loss; developed countries cover OECD countries and other high-income countries according to World Bank classification.

Figure 5a: Global normalized insured losses from convective events



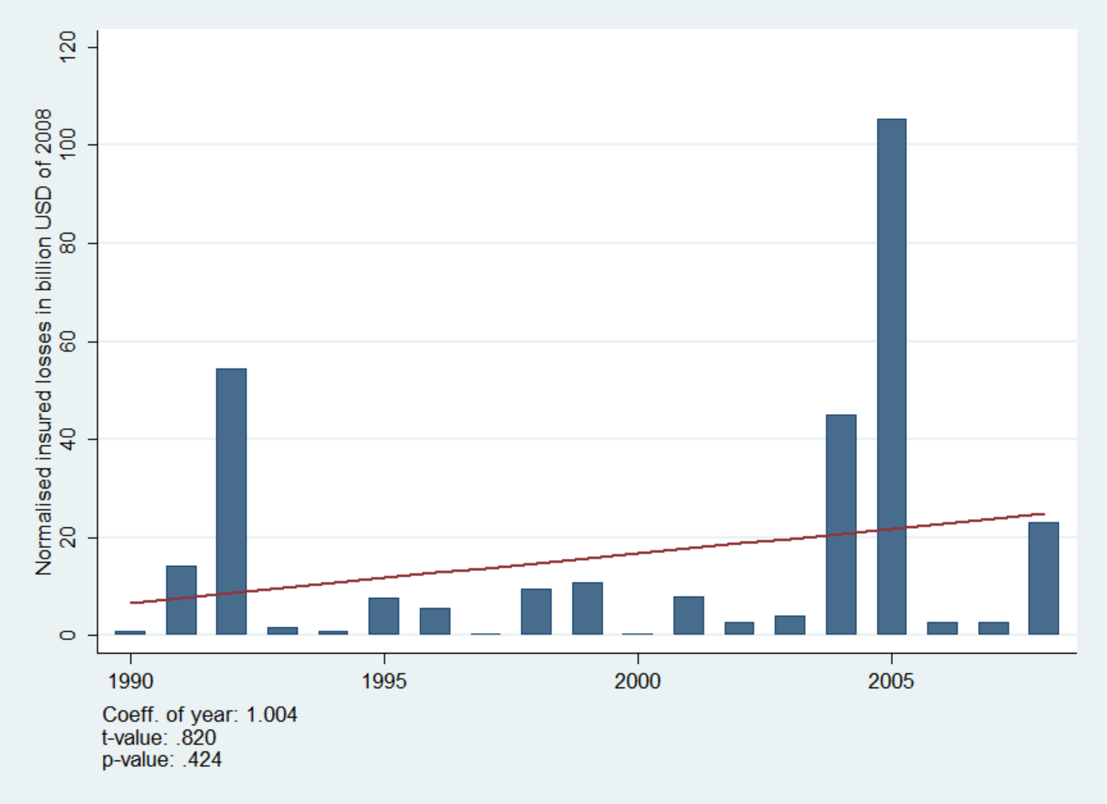
Note: 3,783 disasters, thereof 770 with a known insured loss; Includes damages from flash floods, hail storms, tempest storms, tornados, and lightning.

Figure 5b: Global normalized insured losses from storm events (not including tropical cyclones)



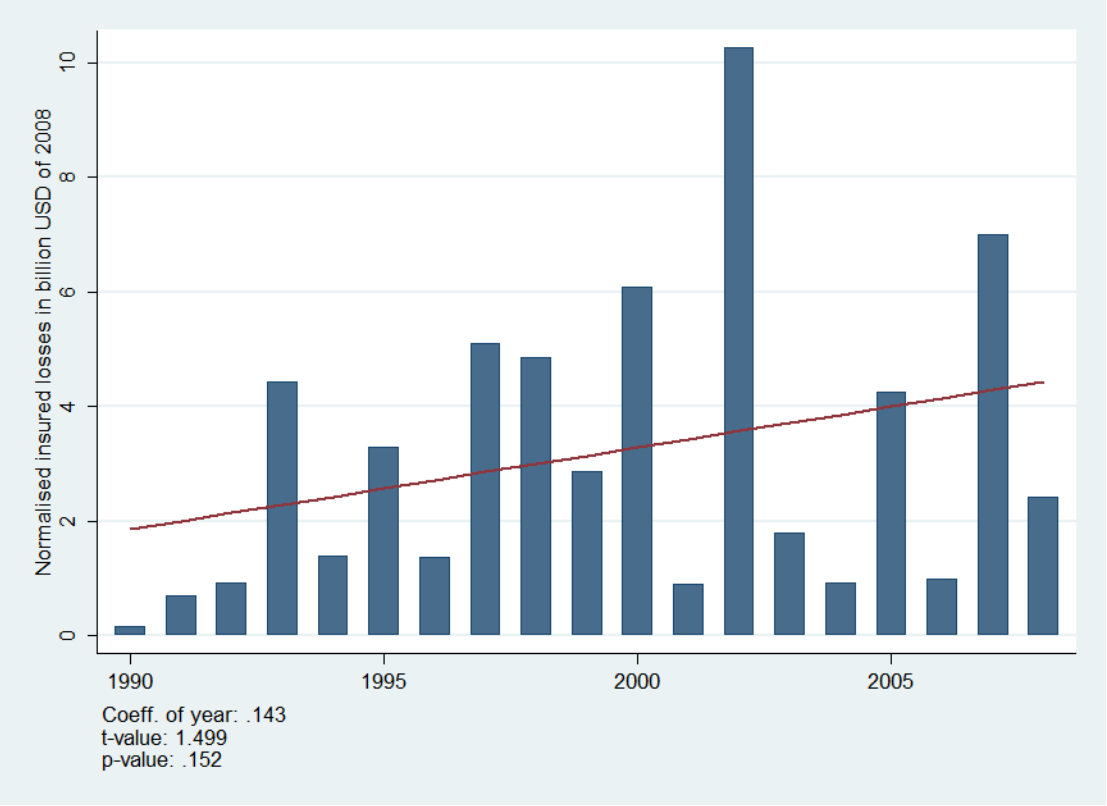
Note: 3,971 disasters, thereof 1,032 with a known insured loss; Includes damages from winter storms (winter storm and blizzard/ snow storm), convective storms (hail storm, tempest storm, tornado, and lightning), sand storms, local windstorms, and storm surges.

Figure 5c: Global normalized insured losses from tropical cyclones



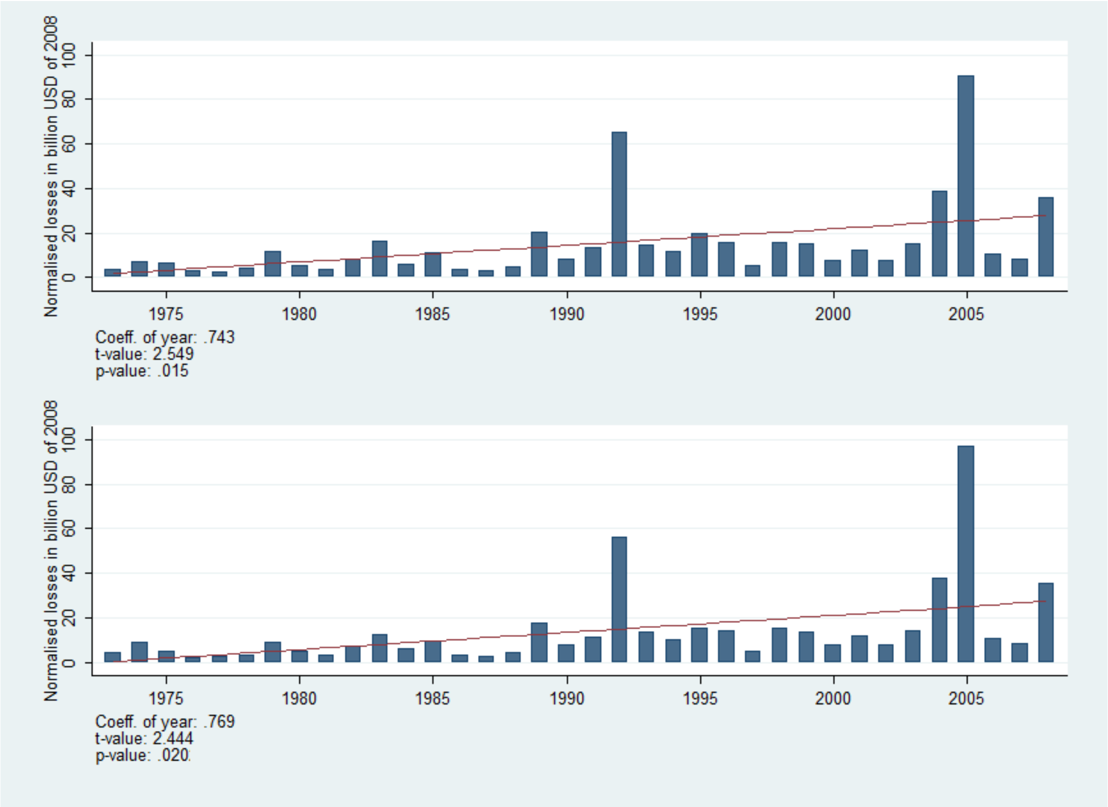
Note: 798 disasters, thereof 167 with a known insured loss.

Figure 5d: Global normalized insured losses from precipitation-related events



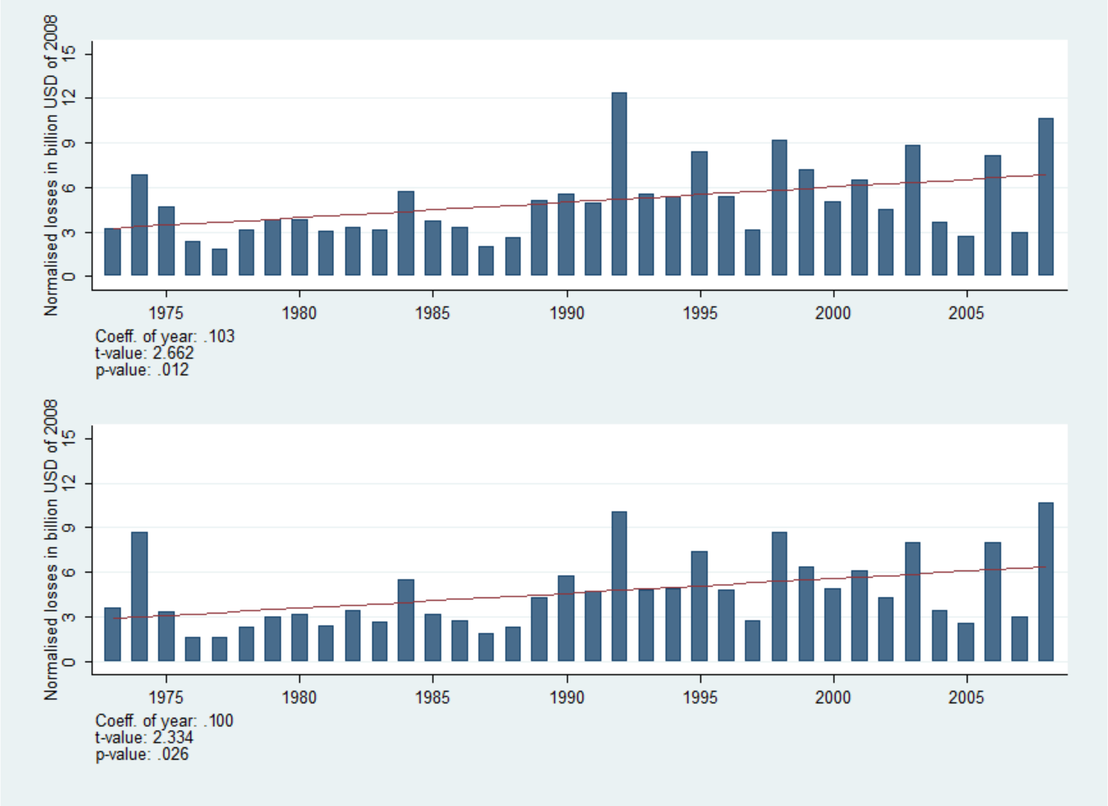
Note: 4,014 disasters, thereof 223 with a known insured loss; Includes damages from flooding (flash flood and general flood) and mass movement (rock falls, landslides, and avalanches).

Figure 6a: Normalized insured losses of non-geophysical disasters in the United States using changes in personal income (top) and changes in value of housing units (bottom)



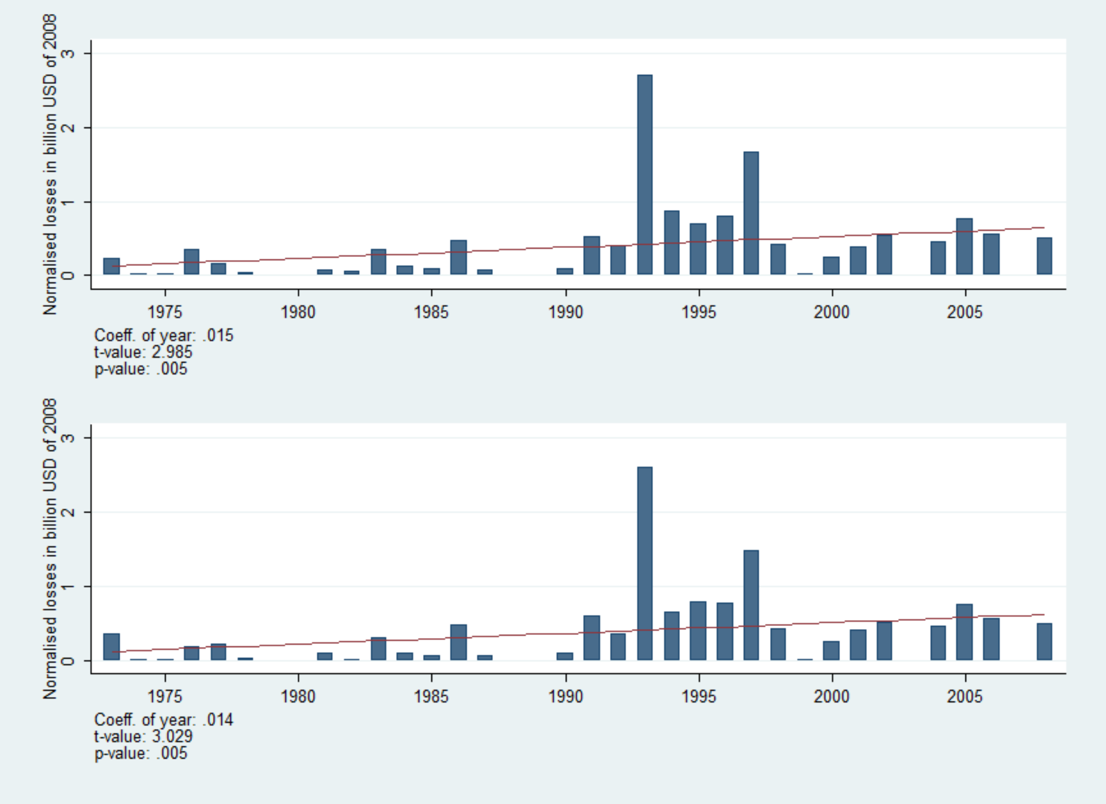
Note: 2,674 disasters, thereof 1,277 with a known insured loss.

Figure 6b: Normalized insured losses from convective events in the United States using changes in personal income (top) and changes in value of housing units (bottom)



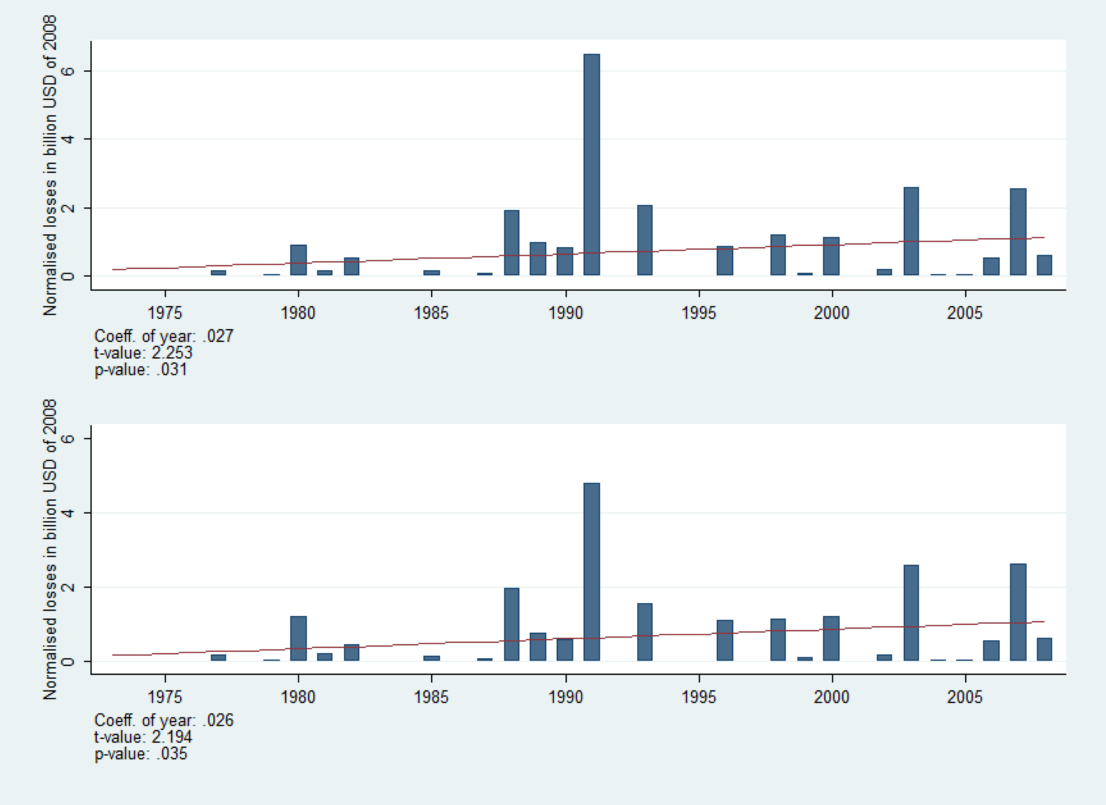
Note: 1,646 disasters, thereof 916 with a known insured loss; Includes damages from flash floods, hail storms, tempest storms, tornados, and lightning.

Figure 6c: Normalized insured losses from flooding in the United States using changes in personal income (top) and changes in value of housing units (bottom)



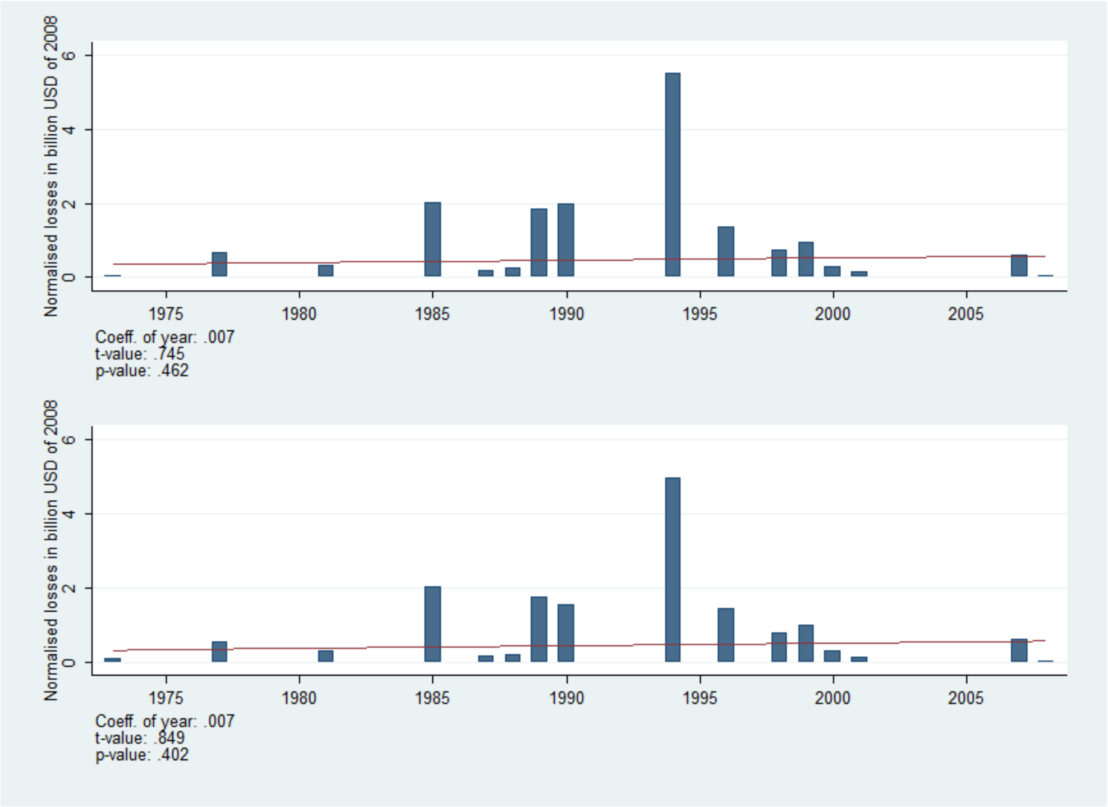
Note: 337 disasters, thereof 63 with a known insured loss; Includes damages from flash floods and general floods.

Figure 6d: Normalized insured losses from temperature highs in the United States using changes in personal income (top) and changes in value of housing units (bottom)



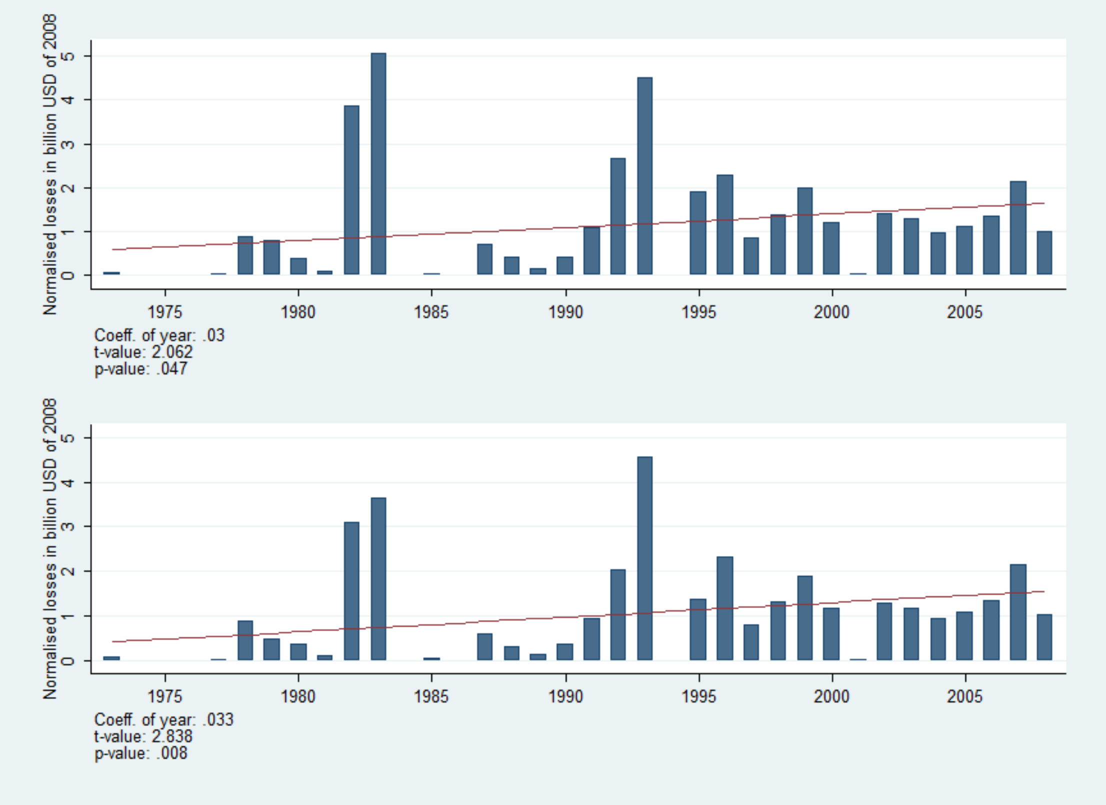
Note: 340 disasters, thereof 65 with a known insured loss; Includes damages from heat waves, droughts and wild fires.

Figure 6e: Normalized insured losses from temperature lows in the United States using changes in personal income (top) and changes in value of housing units (bottom)



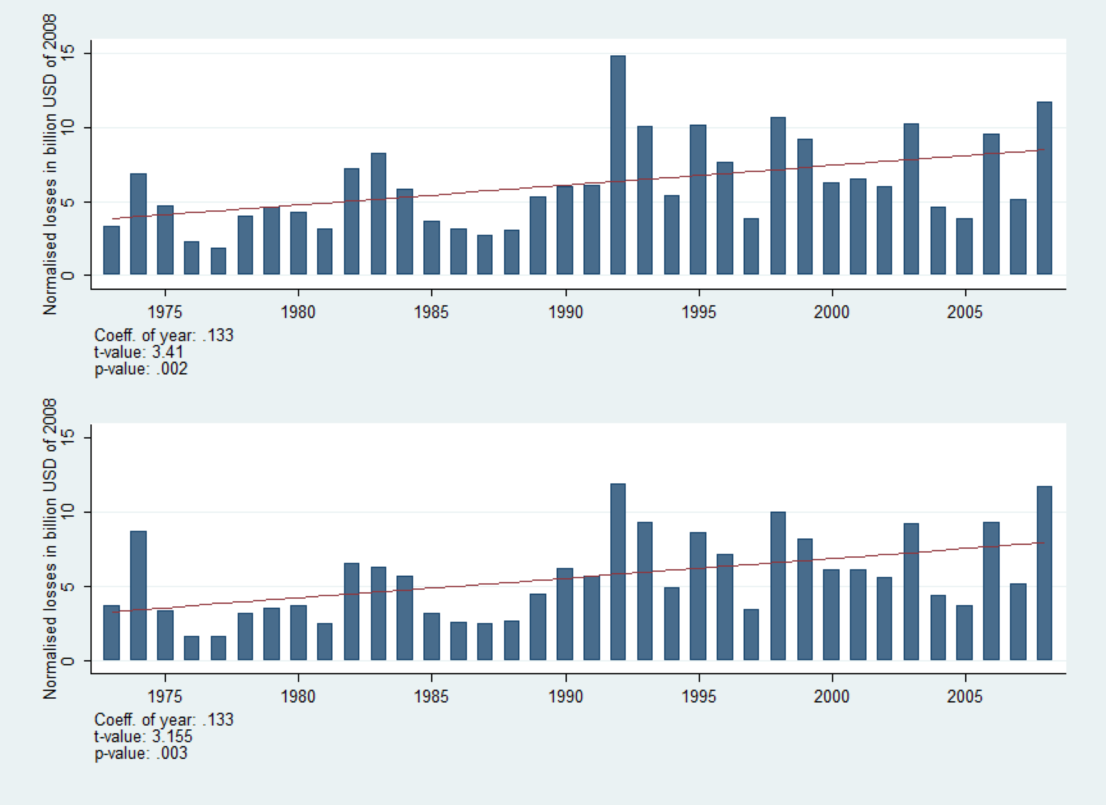
Note: 60 disasters, thereof 33 with a known insured loss; Includes damages from winter damages and cold waves.

Figure 6f: Normalized insured losses from winter storms in the United States using changes in personal income (top) and changes in value of housing units (bottom)



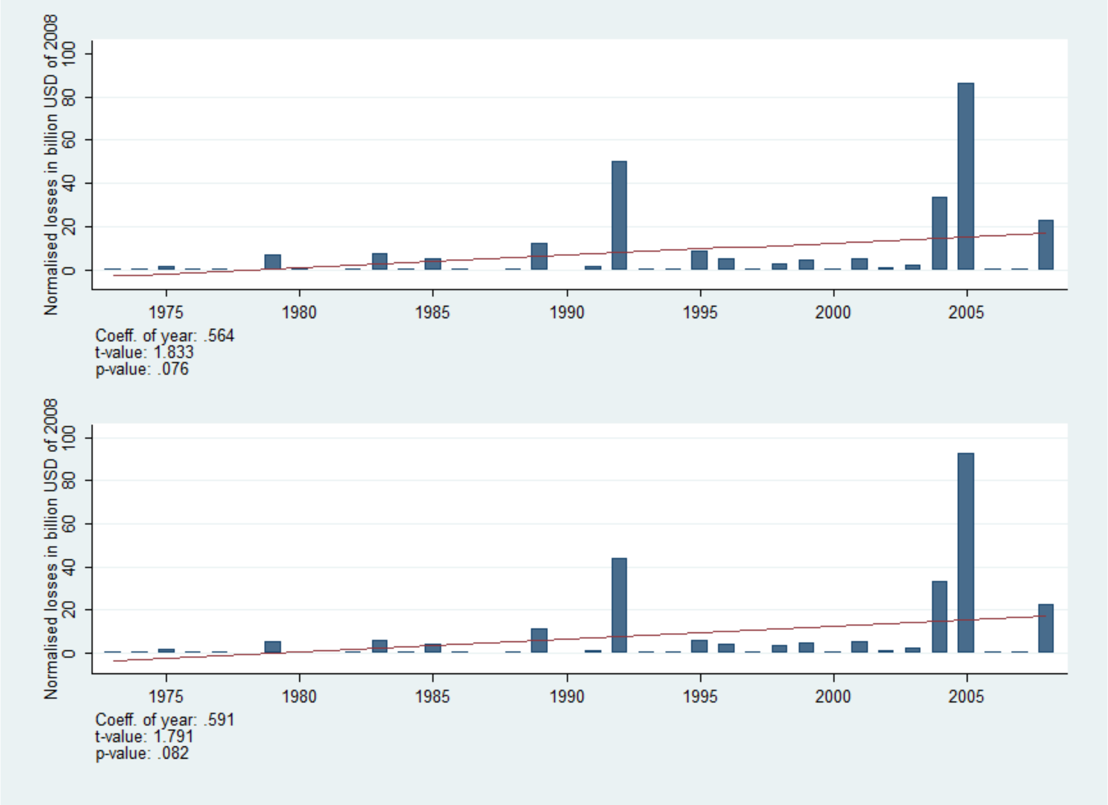
Note: 214 disasters, thereof 122 with a known insured loss; Includes damages from winter storms, blizzards and snow storms.

Figure 6g: Normalized insured losses from all storms in the United States using changes in personal income (top) and changes in value of housing units (bottom)



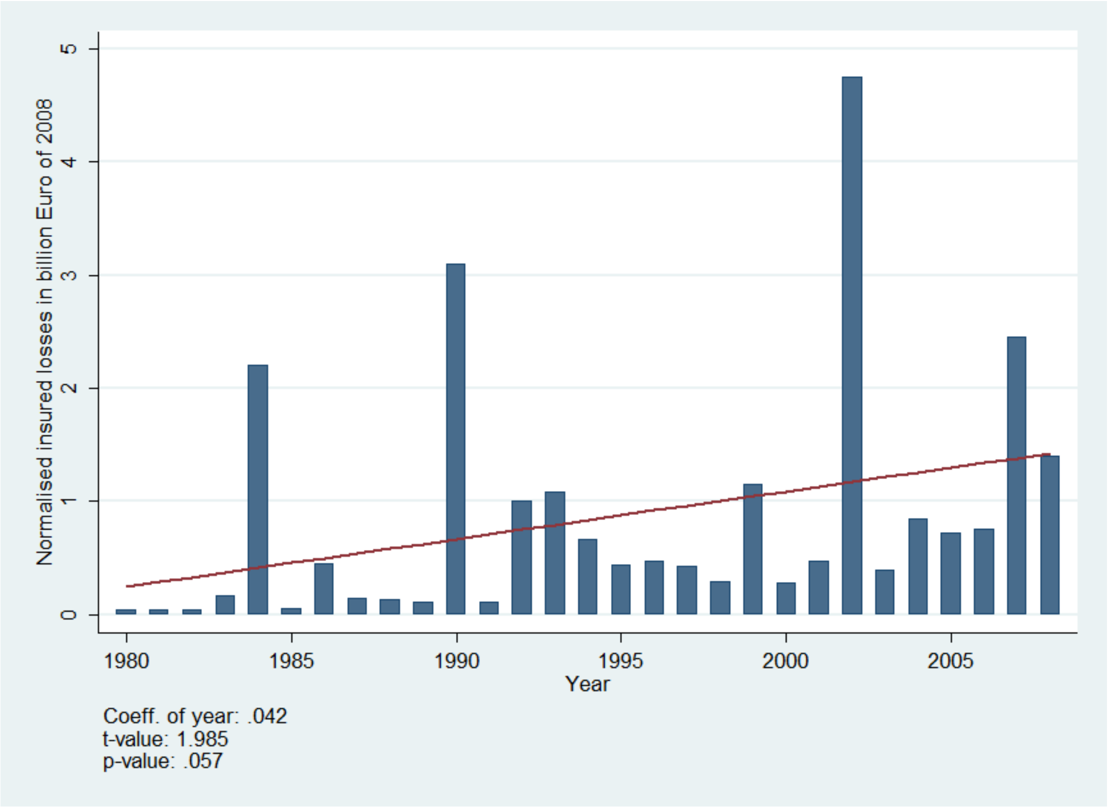
Note: 1,756 disasters, thereof 1,034 with a known insured loss; Includes damages from winter storms, blizzards, snow storms, hail storms, tempest storms, tornado, lightning, sand storms and storm surges.

Figure 6h: Normalized insured losses from hurricanes in the United States using changes in personal income (top) and changes in value of housing units (bottom)



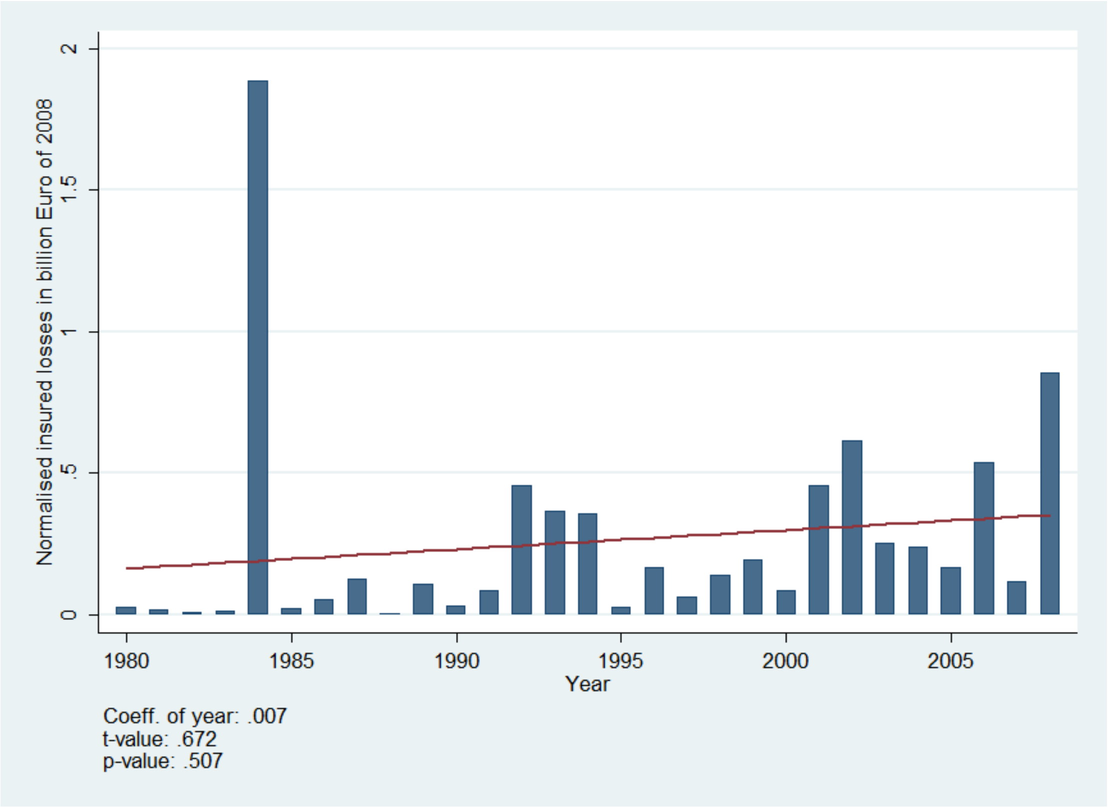
Note: 113 disasters, thereof 82 with a known insured loss.

Figure 7a: Normalized insured losses of non-geophysical disasters in Germany



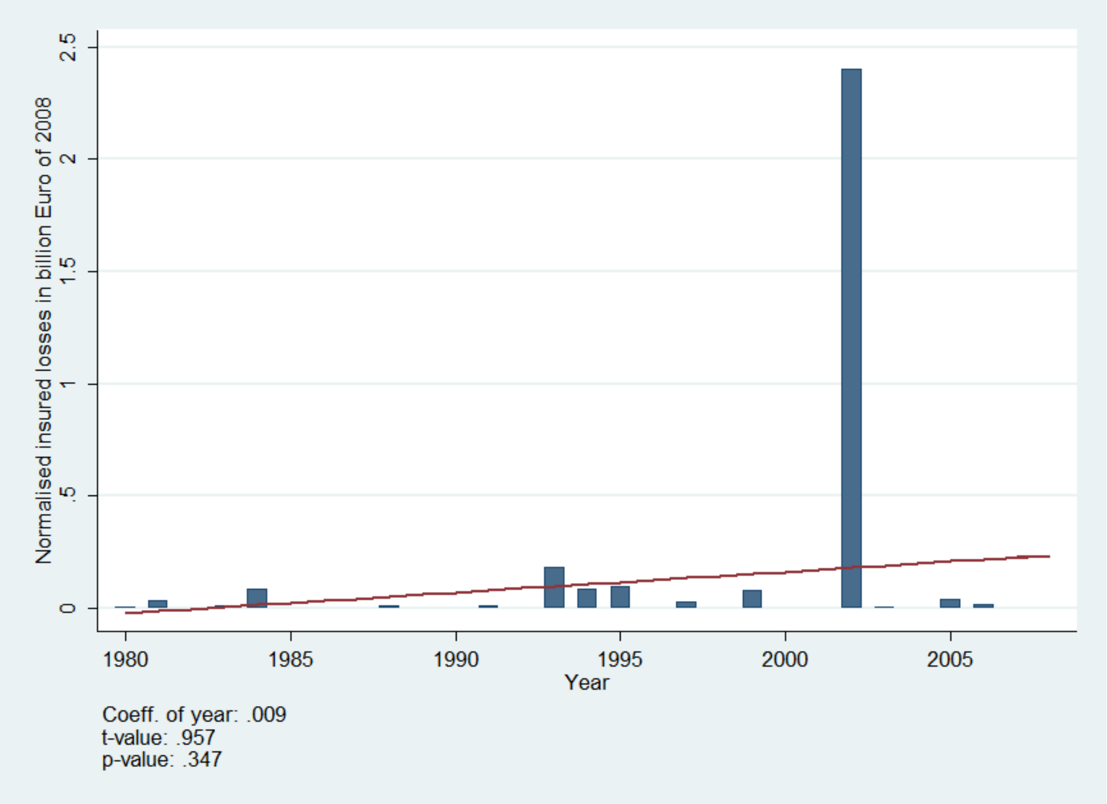
Note: 577 disasters, thereof 268 with a known insured loss.

Figure 7b: Normalized insured losses from convective events in Germany



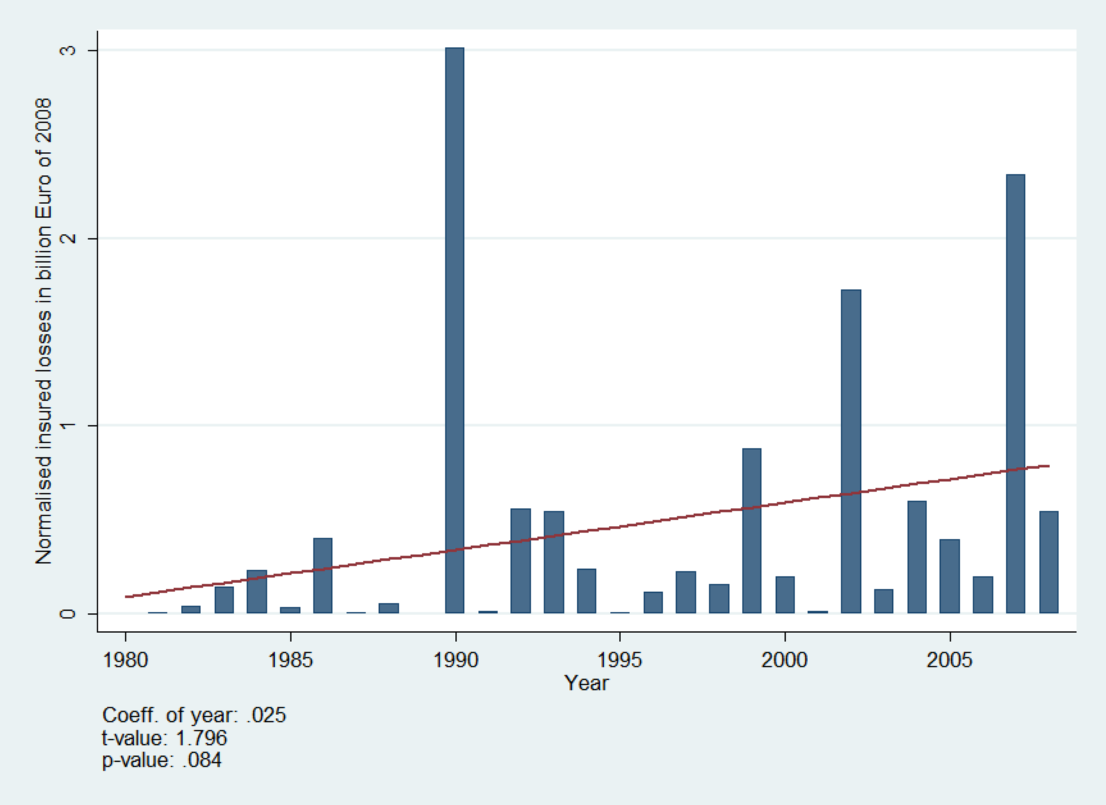
Note: 323 disasters, thereof 146 with a known insured loss; Includes damages from flash floods, hail storms, tempest storms, tornados, and lightning.

Figure 7c: Normalized insured losses from flooding in Germany



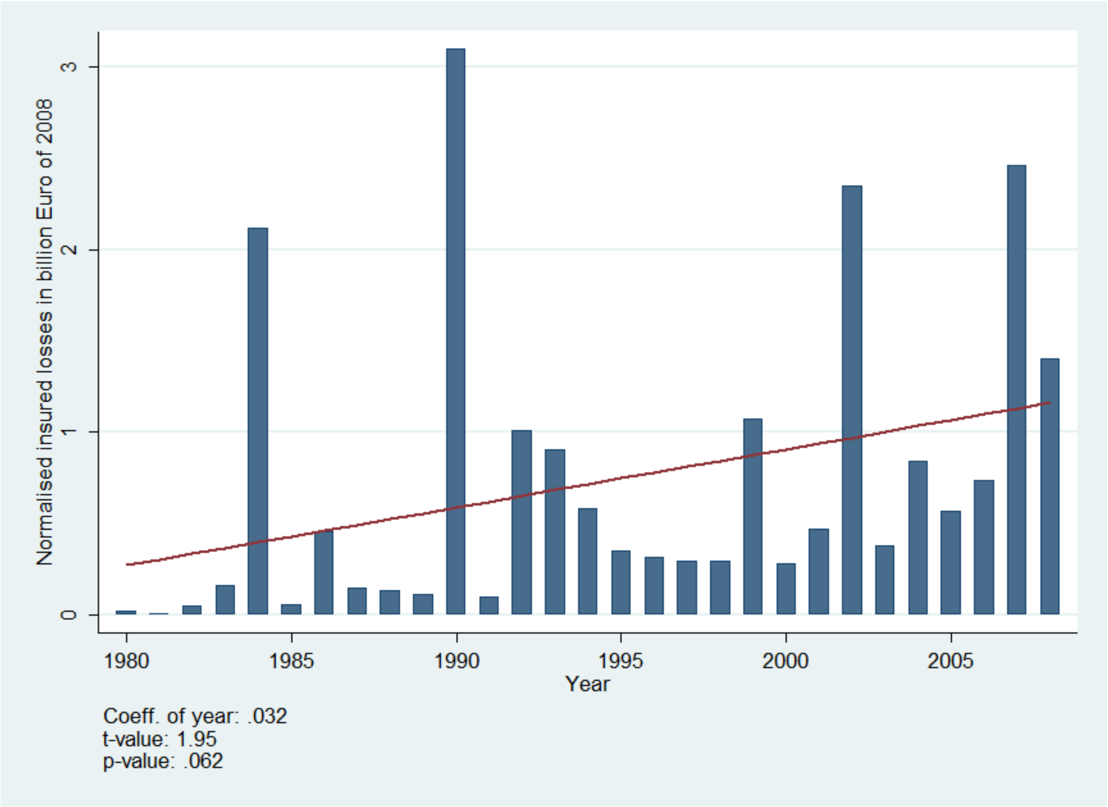
Note: 94 disasters, thereof 22 with a known insured loss; Includes damages from flash floods and general floods.

Figure 7d: Normalized insured losses from winter storms in Germany



Note: 112 disasters, thereof 86 with a known insured loss; Includes damages from winter storms, blizzards and snow storms.

Figure 7e: Normalized insured losses from all storms in Germany



Coeff. of year: .032
t-value: 1.95
p-value: .062

Note: 416 disasters, thereof 239 with a known insured loss; Includes damages from winter storms, blizzards, snow storms, hail storms, tempest storms, tornado, lightning, sand storms and storm surges..