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Fabian Barthel and Eric Neumayer

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A Trend Analysis of Normalized Insured Damage from Natural Disasters

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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

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[*] Corresponding author (email: f.barthel@lse.ac.uk). The authors acknowledge 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, Lenny Smith and Bob Ward as well as three referees 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 hazard event 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 West 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 West 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 hazards. 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; Vranes and Pielke 2009; Schmidt, Kemfert and Höppe 2009; Barredo 2009; Nordhaus 2010). 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 (Bouwer 2011). Second, insured losses are estimated with greater precision than total economic losses, estimates of which are often simply taken as multiples of insured loss. All other things equal, the greater precision 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 a greater value of assets at risk in the present compared to the past.

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[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).

Normalization thus adjusts nominal economic loss from past disasters upwards by multiplying past damage with a factor for inflation, for population growth and for growth in wealth per capita, thus in effect estimating the damage a past hazard event 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 hazards have necessarily become more frequent and/or more intensive, but simply because the value of assets at risk has increased over time. For normalizaton of insured disaster losses, one additionally needs to adjust for changes in insurance penetration over time, i.e. the value of insurance premia generated as a percentage of GDP which approximates the share of wealth covered by insurance. 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, in more detail, for West Germany and the US. 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 was developed by Roger Pielke Jr. and co-authors (see Pielke and Landsea 1998, Pielke et al. 1999, 2003, 2008; Vraines and Pielke 2009). Following their approach, normalized disaster damage can be calculated 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 to which one wishes to normalize and t is the disaster year. Inflation (i.e. the change in producer prices) is accounted for by using the Gross Domestic Product (GDP) deflator, while the remaining two correction factors adjust for *changes in* population and wealth per capita. Ideally, the population and wealth changes should reflect changes in the exact areas affected by the natural disaster in question. Yet, in practice it is often impossible to determine the exact affected areas and time series information on GDP and population in these areas is not available, 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). Existing work differs with respect to how wealth per capita is measured: while 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 due to the lack of data, simply use GDP per capita (e.g., Raghavan and Rajseh 2003; Pielke et al. 2003; Miller et al. 2008; Barredo 2009; Nordhaus 2010). If there is more than one disaster in a given country per year, the measure of disaster loss is the annual sum of normalized damages from each disaster as per equation (1).

Neumayer and Barthel (2011) have criticized conventional normalization methodology on the grounds that it adjusts for differences in wealth over time, but not for differences in the level of 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 (2011) 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* assets potentially at risk 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 (2011), 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 West 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 NatCatSERVICE database. Munich Re also supplied us with data on insurance premia in a country. The NatCatSERVICE database provides a very high quality source for insured loss data worldwide since the re-insurance company is in a privileged position to collect these data, has done so for many years and has invested much time, money and effort in the data collection. But it is of course not perfect. For example, smaller disasters may be somewhat under-reported in the early periods relative to later periods. In order to maintain the database, several members of staff browse daily international and regional sources to gather information about natural disaster events. Data are collected from a variety of sources such as 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 NatCatSERVICE 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). Table 1 shows the number and average insured losses for the period 1980 to 2008 for those disasters with a positive recorded insured loss for each disaster sub-type and for the global sample as well as for Germany and the US separately. By far the most costly hazard sub-type consists of tropical cyclones.[2]

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[2] One has to keep in mind that the NatCatSERVICE data base was set up as an insurance industry-related loss data base that is organized according to the most significant hazardous

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:

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

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 at risk from destruction by

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impact involved with a disastrous event. Hence the disaster subtype is nothing else than a significant type of hazard that has caused a significant proportion of the loss. But any subtype given does not exclude another subtype to be additionally involved while the event occurred. For instance, among the convective events associated with a positive loss there have been 185 events reported where tornados have caused significant insured loss. Definitely, this does not exclude tornados occurring also with some of the 213 hailstorm events that have been reported to have caused losses from hail. Nor does it exclude tornados occurring with the 765 reported tempest storm events. Hence, the subtype tornado does not comprise all the tornado events occurred, but those where tornado was the most significant type of hazard produced by the thunderstorm cell. In order to include comprehensively all the tornado losses, one would have to integrate over all the convective hazards (i.e. flash flood, hailstorm, lightning, tempest storm, tornado), but will at the same time integrate all losses from convective events. Another example of disaster subtypes that often are linked to each other is the ensemble of drought, heat wave and subsidence disasters.[3] While GDP is a flow of economic activity, economic wealth is a stock. 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 since the physical wealth stock is used to produce GDP in conjunction with other forms of capital, such as human and natural capital. 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). Yet this ratio will vary across countries and, more importantly, is a national macro-economic average, which can differ more drastically across sub-country units.[4] 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.

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

[4] It has also changed over time (see D'Adda and Scorcu 2003). Nevertheless 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 changes in insurance coverage as such. As an approximation we use insurance penetration, which is defined as premia divided by GDP (UNCTAD 2005: 7). For our global analysis, we use data on property and, where available, also engineering insurance premia. For West 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. 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 our analysis is shown in table 2.

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.[5] 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 premia relative to GDP should in the long run by and large represent an acceptable proxy for changes in insurance penetration. For the German insurance market, Munich Re undertook an analysis on the relationship between premia and total sum of insured values and found the two to be very highly linearly correlated over time (figure 1).[6] In general, insurance penetration in West Germany and the US exhibit little volatility over time (see figure 2).

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:

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

Normalization equation (4) is the one we use in our global analysis. The loss data in the NatCatSERVICE 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

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[5] Furthermore, comparability of insured losses over time and space could be limited by differences and changes in insurance conditions which affect the insured risk and the size of losses, such as maximum coverage and deductibles (Changnon 2009a, Botzen et al. 2010).

[6] For the US, due to lack of data no similar analysis could be undertaken on a market-wide basis. 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).

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.[7]

For West 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 administrative units, i.e. on a more fine-grained spatial resolution. The NatCatSERVICE database provides a geo-reference of the disaster center which allows us to match each disaster with the sub-national administrative unit in which its centre occurred. For Germany, our spatial resolution is on the NUTS3 level (which 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 West Germany is thus in local currency units, we also used the GDP deflator for Germany and normalized damage is expressed in Euros.[8] Since loss data is less reliable for East Germany before reunification, we restrict our analysis to West Germany. For this, the share of insured loss of each event that occurred in the Western parts of Germany was determined by Munich Re and only this loss is included in the analysis. Data on insurance premia, however, is not separately available for West Germany. Since there

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[7] 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.

[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 West 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.

was no private insurance market in the former German Democratic Republic, before 1990 only Western premia (and Western GDP) are used. Since 1990, both the GDP as well as the insurance premia relate to the whole of the re-unified Germany.[9]

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

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[9] This will inevitably create some (small) bias of unknown direction. To test the robustness of our results, we assumed as a shortcut that the share of Western premia was equal to the share of total disaster damage in the entire post-1990 period. Thus estimating, admittedly rather crudely, Western premia and employing these in the normalization leads to qualitatively similar results. In fact, the marginally insignificant upward trend in normalized damage from all storms becomes significant at the 5 per cent level with this alternative premia measure.

[10] 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

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

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:

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

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 West Germany. Figure 3 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 the value of insured assets at risk, i.e. if we normalize insured disaster loss

(Figure 4). Losses before 1990 are not shown since we have data on insurance premia only for few countries before 1990. The analysis still covers 13,055 disasters, with 1,785 of them resulting in a known damage claim to insurance companies.[11]

Some natural hazards will be practically unaffected by climate change and are therefore irrelevant if one wants to detect whether climate change already has potentially lead to increased insured damages. In Figure 5, we therefore excluded geophysical disasters (earthquakes, rock falls, subsidence, volcanic eruptions, and tsunamis) and only include the following disaster sub-types: landslides, 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.[12] 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

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[11] To cover as many country-years as possible, we extrapolated data on insurance penetration for some missing years such that the analysis is based on a balanced panel of countries. The results are, however, fully robust if only countries with full time series in the original insurance penetration data are included.

[12] While landslides are generally geo-physical events, they are regularly triggered by sustained wet conditions in a mountainous region. We dropped the landslides, which were classified as a geo-physical event in the database, but kept those that were recorded as hydrological events. However, none of the former and only five events of the latter resulted in a known insured loss. Similarly, a subsidence might be driven by droughts as a consequence of which moist and welled clay soils lose water and compact. The inclusion of 19 subsidence events with a positive known insured loss in our global sample does not alter the results. For the US and Germany, there are no such events with a positive insured loss.

Organisation of Economic Co-operation and Development (OECD) and other high-income countries, according to World Bank classification (Figure 6).[13]

Convective events, i.e. flash floods, hail storms, tempest storms, tornados, and lightning, deserve closer attention since these are likely to be particularly affected by future global warming (Trapp et al. 2007, 2009; Botzen et al. 2009) and there is some evidence that past climatic changes already affected severe thunderstorm activity in some regions (Dessens 1995; Kunz et al. 2009). Figure 7a shows that there is no significant trend in global insured losses for these peril types. Similarly, there is no significant trend in insured losses for storm events (Figure 7b), tropical cyclones (Figure 7c) or precipitation-related events (Figure 7d).[14]

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 8a 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

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[13] 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.

[14] Precipitation-related events encompass both floods and wet mass movements.

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 8b 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 8c). The same is true for events caused by temperature highs (Figure 8d). There is however, no significant trend for events caused by temperature lows (Figure 8e). If we look at winter storms (Figure 8f), which also include snow storms and blizzards, we find a significant upward trend. The same is true for the category all storms except tropical cyclones, which besides winter storms include convective storms (hail storm, tempest storms, tornado, and lightning), sand storms and storm surges (figure 8g). Focusing on hurricanes, an upward trend in insured losses is found, which is statistically significant at the 10 percent level (Figure 8h).

Turning to West Germany, the trend in insured loss from non-geophysical disasters is marginally significant at the 10 percent level (figure 9a), 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, even though the flood disaster mainly affected East Germany) and 2007 (predominantly winter storm Kyrill). If these events are excluded, the trend becomes significant at the five percent level. For convective events (figure 9b), however, no such significant trend can be established unless the large outlier from 1984 (Munich hail storm) is dropped from the analysis. Figure 9c, 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 9d). The upward trend for the category of all storms (figure 9e) only marginally fails to reach conventional significance thresholds. 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.

Table 3 compares and contrasts our findings with those of previous studies. For most of our analyses, however, there is no truly comparable previous work, either because no previous study exists or because existing studies analyze different time periods as well as, for the most part, economic rather than insured loss. With these caveats in mind our finding of a positive trend for non-geophysical disasters is not in line with Changnon et al. (2000). However, the study periods of these two analyses differ considerably (1949 to 1996 as opposed to 1973 to 2008). On the one hand, longer study periods are in principle preferable, but by missing out more recent data, this older study may fail to capture the very period in which increases in trends could be most likely. While our results for storms in the United States corroborate earlier findings by Changnon (2001, 2009a), contrary to Changnon (2007) we do not detect a positive trend for winter storms in the US. While we find a positive trend for floods in the United States, no such trend has been found by Downton et al (2005) in their study covering a much longer time period (1926 to 2000). The same is true for our hurricanes results in the US, where our positive trend since 1973 does not match the findings by Pielke and Landsea (1998) and Pielke et al (2008) in their study from 1925 and 1900, respectively, onwards. Our results are, however, in line with studies by Schmidt et al. (2009) who find a positive trend for a similar study period as ours. Where this paper's analysis of insured loss overlaps with our previous study of total economic loss (Neumayer and Barthel 2011), the findings are largely consistent.

How do our findings of positive trends in non-geophysical disasters and specific sub-types in the US and Germany compare to the evidence on trends in extreme weather events? There are many difficulties, which hamper such a comparison. To start with, our study periods of 1973-2008 and 1980-2008 do not necessarily overlap with the periods analyzed in the studies examining trends in extreme weather events. Second, such studies often are not undertaken at the country level or, if they are, not necessarily for Germany and the US. Third, lack of data and particularly of reliable time-series often prevent scientists from analyzing trends in extreme weather events. For example, the IPCC (2007: 308) concludes that 'observational evidence for changes in small-scale severe weather phenomena (such as tornadoes, hail and thunderstorms) is mostly local and too scattered to draw general conclusions'.[15] With these caveats in mind, there is evidence for increases in heavy and very heavy precipitation events (IPCC 2007: 315; Peterson et al. 2008) and in tropical storm and hurricane intensities and durations (IPCC 2007: 315; Elsner, Kossin and Jagger 2008) as well as, possibly, in hurricane frequency (US Climate

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[15] See, however, Schiesser (2003) who reports evidence on increased frequency of strong hailstorm events in Switzerland after 1980 and, similarly, Kunz, Sander and Kottmeier (2009) for the South-West of Germany. Also, Botzen, Bouwer and van den Bergh (2010) find a strong correlation between minimum temperatures (see, similarly, Dessens 1995) as well as precipitation and total agricultural hailstorm damage in the Netherlands. Since there has been higher precipitation and higher minimum temperatures in Northern latitudes, an increase in the frequency and/or intensity of extreme hailstorm events is likely.

Change Science Program 2008: 35) in North America, consistent with our finding of positive trends in normalized flooding and hurricane losses in the US.

Another question is to what extent it is likely that anthropogenic emissions have contributed to this observed increase in some extreme weather events. Using an ‘optimal fingerprinting technique’ and comparing observed to multi-model simulated changes in extreme precipitation over the second half of the 20th century, Min et al. (2011: 378) come to the conclusion ‘that human-induced increases in greenhouse gases have contributed to the observed intensification of heavy precipitation events found over approximately two-thirds of data-covered parts of Northern Hemisphere land areas.’ Based on a ‘probabilistic event attribution’ framework, Pall et al. (2011) conclude ‘that it is very likely that global anthropogenic greenhouse gas emissions substantially increased the risk of flood occurrence in England and Wales in autumn 2000’. For tropical storms and hurricanes, however, there is considerable natural variability, which may well explain the increase in normalized hurricane damage since 1973. After acknowledging the many problems posed by ‘substantial limitations in the availability and quality of global historical records of tropical cyclones’ for attributing any trends to anthropogenic greenhouse gas emissions, Knutson et al. (2010: 157) come to the conclusion that ‘it remains uncertain whether past changes in any tropical cyclone activity (frequency, intensity, rainfall, and so on) exceed the variability expected through natural causes, after accounting for changes over time in observing capabilities’.

5. Conclusion

Climate change neither is nor should be the main concern for the insurance industry. The accumulation of wealth in disaster-prone areas is and will always remain by far the most important driver of future economic disaster damage. Nevertheless, insurance companies are concerned 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 hazards.

In this article, we have analyzed whether one can detect a trend in data on *insured* damage from natural 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 detection of an upward trend in insured losses from non-geophysical disasters and certain specific disaster sub-types in the US, the biggest insurance market in the world, and in West 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 (Neumayer and Barthel 2011), 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 evidence so far for a statistically significant upward trend in normalized insured loss from extreme events outside the US and West Germany. There could have been more frequent and/or more intensive weather-related natural disasters even in these other places, but our study could have simply been incapable of detecting them. 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 West 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 all non-geophysical disasters and some disaster sub-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.

Alternatively, our findings of upward trends could be driven by insurance penetration representing a poor proxy for the share of insured assets at risk. 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 coverage and 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. Claiming on insurance policies for damage caused by weather-related disasters could have gone up over time. There is also the moral hazard problem. It is well known that with the knowledge of being insured, individuals take less care to avoid and mitigate damage than in the absence of insurance. If such moral hazard problems became more prevalent over time (for which we have no evidence, but cannot exclude as a possibility either), then this would lead to an increasing trend in normalized insured damages over time, all other things equal.

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 West 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. In sum, therefore, before any firm conclusions can be drawn from our results, 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 in normalized insured disaster damage in the US and West Germany.

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.

Botzen, W.J.W., Laurens M. Bouwer, and Jeroen J.C.J.M. van den Bergh, 2010, Climate change and hailstorm damage: empirical evidence and implications for agriculture and insurance, *Resource and Energy Economics* 32, pp. 341-362.

Bouwer, Laurens M., 2011, 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. and Joyce M. Changnon, 1992, Storm Catastrophes in the United States, *Natural Hazards*, 6, pp. 93-107.

Changnon, Stanley A., Roger A. Pielke, David Changnon, Richard T. Sylves and Roger Pulwarty, 2000, Human Factors Explain the Increased Losses from Weather and Climate Extremes, *Bulletin of the American Meteorological Society*, 81(3), pp. 437-442.

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., 2003, Shifting Economic Impacts from Weather Extremes in the United States: A Result of Societal Changes, Not Global Warming, *Natural Hazards*, 29, pp. 273-290.

Changnon, Stanley A., 2007, Catastrophic winter storms: An escalating problem, *Climatic Change*, 84, pp. 131-139.

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.

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.

Dessens, J., 1995, Severe convective weather in the context of a nighttime global warming. *Geophysical Research Letters*, 22 (10), pp. 1241–1244.

Downton, M., J. Z. B. Miller, and R. A. Pielke Jr., 2005, Reanalysis of U.S. National Weather Service flood loss database, *Natural Hazards Review*, 6, pp. 13-22.

Elsner, J. P., J.P. Kossin, and T. H. Jagger, 2008, The increasing intensity of the strongest tropical cyclones, *Nature* 455, pp. 92-95.

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.

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.

Karl, Thomas R., Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.), 2008, *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*, Report by the US Climate Change Science Program and the Subcommittee on Global Change Research, Synthesis and Assessment Product 3.3. http://downloads.climatescience.gov/sap/sap3-3/sap3-3-final-all.pdf.

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

Knutson, Thomas R., John L. McBride, Johnny Chan, Kerry Emanuel, Greg Holland, Chris Landsea, Isaac Held, James P. Kossin, A. K. Srivastava and Masato Sugi, 2010, Tropical cyclones and climate change. *Nature Geoscience*, 3, 157-163.

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

Kunz, 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.

Min, Seung-Ki, Xuebin Zhang, Francis W. Zwiers, and Gabriele C. Hegerl, 2011, Human contribution to more-intense precipitation extremes, *Nature* 470, pp. 378-381.

Neumayer, Eric and Fabian Barthel, 20102011, Normalizing Economic Loss from Natural Disasters: A Global Analysis. *Global Environmental* Change, 21(1), pp. 13-24. doi:10.1016/j.gloenvcha.2010.10.004.

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

Nordhaus, William D., 2010, The economics of hurricanes and implications of global warming, *Climate Change Economics,* 1, pp. 1-20.

Pall, Pardeep, Tolu Aina, Dáithi A. Stone, Peter A. Stott, Toru Nozawa, Arno G.J. Hilberts, Dag Lohmann, and Myles R. Allen, 2011, Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000, *Nature* 470, pp. 382-385.

Peterson, Thomas C., Xuebin Zhang, Manola Brunet-India, and Jorge Luis Vázquez-Aguirre, 2008, Changes in North American extremes derived from daily weather data, *Journal of Geophysical Research*, 113, D07113.

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.

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.

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

Schiesser, Hans-Heinrich, 2003, Hagel. In: *Extremereignisse und Klimaänderung*. Bern: Organe consultatif sur les changements climatiques (OcCC). pp. 65–68. Bern. http://www.proclim.ch/4dcgi/occc/fr/Report?859.

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, and Alexander Gluhovsky, 2009, Transient response of severe thunderstorm forcing to elevated greenhouse gas concentrations, *Geophysical Research Letters*, 36, L01703.

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.

UNCTAD (2005), Trade and Development Aspects of Insurance Services and Regulatory Frameworks, Geneva: UNCTAD; available at http://www.unctad.org/en/docs/ditctncd200515_en.pdf.

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.

Weather Service flood loss database, *Natural Hazards Review,* 6, pp. 13-22.

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

Table 1: Average insured losses and disaster counts per sub-type.

	Average positive loss per event		
Disaster subtype	Global	Germany	United States
All disasters	245.5	103.7	385.2
	2,553	*274*	*1,047*
Avalanches	250.1	-	-
	1		
Blizzard/ snow storm	245.3	195.6	315.6
	32	*1*	*18*
Cold wave	242.9	210.6	-
	10	*3*	
Drought	299.4	-	409.9
	14		*9*
Flash flood	64.3	20.7	61.5
	63	*4*	*9*
General flood	176.7	166.5	194.2
	268	*18*	*46*
Earthquake	344.5	8.9	1537.5
	107	*1*	*15*
Hailstorm	92.4	116.5	143.4
	213	*25*	*67*
Heat wave	16.2	11.5	-
	3	*1*	
Lightning	-	-	-
Landslide	60.9	-	-
	5		
Local windstorm	21.1	67.4	33.6
	76	*12*	*6*
Rock fall	-	-	-
Sandstorm	16.3	-	-
	1		
Storm surge	2.1	2.1	-
	1	*1*	
Subsidence	591.6	-	-
	23		
Tropical cyclone	921.8	-	2,855.0
	292		*74*
Tempest storm	112.5	48.6	155.0
	765	*100*	*479*
Tornado	145.6	6.9	185.2
	185	*17*	*139*
Tsunami	8.3	-	-
	2		
Volcanic eruption	86.5	-	61.2
	9		*1*
Winter damage	271.7	100.5	279.2
	55	*5*	*31*
Wildfire	165.5	-	211.1
	79		*54*
Winter storm	222.3	177.7	204.3
	349	*86*	*99*

Note: All values in non-normalized million USD of 2008; Number of events in italics.

Table 2: List of insurance types for which premia are included.

Insurance class	**Insurances included**	**Disaster subtypes affected**
Global sample		
Property insurance	e.g. residential - buildings, residential - contents, commercial - buildings, commercial - contents, commercial - business interruption, industrial - buildings, industrial - contents, industrial - business interruption	all disaster subtypes
Engineering insurance	e.g. machinery breakdown, machinery - business interruption, boiler, erection all risk, construction all risk, electronic equipment insurance	
United States		
Property insurance	Householders/Homeowners: Homeowners Multiple Peril	all disaster subtypes
	Agriculture: Farmowners multiple peril, crop (multiple peril)	
	Industrial/ Commercial: Non-liability multiple peril, commercial multiple peril, other	
	Allied lines	
	Earthquake	
	Flood from National Flood Insurance Program NFIP	
	Other flood	
Engineering insurance	Machinery breakdown	all disaster subtypes
	Boiler and machinery	
	Inland marine (Construction all risk, Cargo)	
	Ocean Marine (Offshore Energy, among others)	
Other	Aircraft	
Motor physical damage	Motor hull (no third party liability)	all disasters subtypes, excl. temperature highs and lows
West Germany		
Property insurance	Glass (Private Sachversicherung: Glasversicherung)	all disaster subtypes
	Residential - contents (Private Sachversicherung: Verbundene Hausratversicherung)	
	Residential - buildings (Private Sachversicherung: Verbundene Wohngebäudeversicherung)	
	Commercial - fire (partially windstorm included) (Feuerversicherung: Gewerbe/Sonstige (enthielt Sturmdeckungen in früheren Jahren)	
	Extended coverage to industrial fire (Industrieversicherung: Extended Coverage)	
	Industrial all risk (Industrieversicherung: Alle Risiken)	
	Commercial - windstorm (Gewerbliche Sachversicherung: Sturmversicherung)	

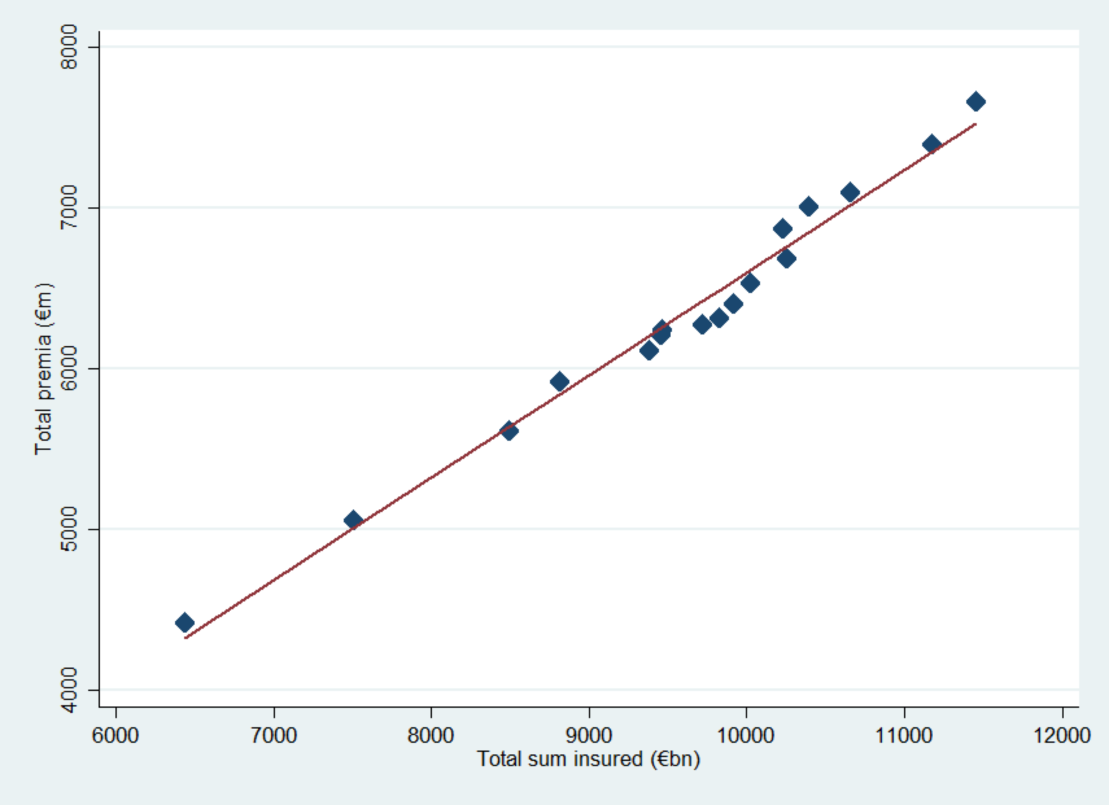
	Agriculture - animal (Landwirtschaftliche Sachversicherung: Tier)	
	Agriculture - hail (Landwirtschaftliche Sachversicherung: Hagel)	
Engineering insurance	Machinery breakdown (Technische Versicherung: Maschinenversicherung)	all disaster subtypes
	Errection/construction (Technische Versicherung: Montageversicherung)	
	Electronics/electric devices (Technische Versicherung: Elektronik/Schwachstrom)	
	Construction work (Technische Versicherung: Bauleistung)	
	Machinery - business interruption (Technische Versicherung: Maschinen-Betriebsunterbrechungsversicherung)	
Motor physical damage	Motor hull (no third party liability) (Kraftfahrzeugkaskoversicherung)	all disasters subtypes, excl. temperature highs and lows

Notes: For the global sample, only examples given as insurance markets differ and not all products are available on all insurance markets; Engineering insurance data not available for all countries; for those, only property insurance premia used.

Table 3: Comparison of our results with previous studies

This paper's analysis				Comparable analyses			
Disaster type	Region	Study period	Results	Study	Study period	Results	Remarks
All disasters	Global	1990-2008	no trend	Neumayer and Barthel 2011	1980-2009	no trend	economic loss
Non-geophysical	Global	1990-2008	no trend	Miller et al. 2008	1950-2005	no trend since 1950/ positive trend since 1970	economic loss
				Neumayer and Barthel 2011	1980-2009	no trend	economic loss
Non-geophysical	Developed countries	1990-2008	no trend	Neumayer and Barthel 2011	1980-2009	no trend	economic loss
Convective events	Global	1990-2008	no trend	Neumayer and Barthel 2011	1980-2009	no trend	economic loss
Storm events (excl. tropical cylcones)	Global	1990-2008	no trend	Neumayer and Barthel 2011	1980-2009	no trend	economic loss
Tropical cyclones	Global	1990-2008	no trend	Neumayer and Barthel 2011	1980-2009	no trend	economic loss
Precipitation-related events	Global	1990-2008	no trend	Neumayer and Barthel 2011	1980-2009	no trend	economic loss
Non-geophysical	United States	1973-2008	positive trend	Changnon et al. 2000	1950-1996	no trend	
Convective events	United States	1973-2008	positive trend	Neumayer and Barthel 2011	1970-2009	positive trend	economic loss
Flooding	United States	1973-2008	positive trend	Downton et al. 2005	1926-2000	no trend	economic loss
Temperature highs	United States	1973-2008	no trend	*no previous study*			
Temperature lows	United States	1973-2008	no trend	*no previous study*			
Winter storms	United States	1973-2008	no trend	Changnon 2007	1949-2003	positive trend	
All storms	United States	1973-2008	positive trend	Changnon 2001	1949-1998	increase since 1974	only thunderstorms
				Changnon 2003	1950-1997	no trend	storms and floods
				Changnon 2009a	1952-2006	increase since 1992	only windstorms
Hurricanes	United States	1973-2008	positive trend	Pielke and Landsea 1998	1925-1995	no trend	economic loss
				Pielke et al. 2008	1900-2005	no trend	economic loss
				Neumayer and Barthel 2011	1970-2009	no trend	economic loss
				Schmidt et al. 2009	1950-2005	no trend since 1950/ positive trend since 1970	economic loss
				Nordhaus 2010	1900-2008	positive trend since 1900	economic loss
Non-geophysical	West Germany	1980-2008	positive trend	*no previous study*			
Convective events	West Germany	1980-2008	no trend	*no previous study*			
Flooding	West Germany	1980-2008	no trend	*no previous study*			
Winter storms	West Germany	1980-2008	positive trend	*no previous study*			
All storms	West Germany	1980-2008	no trend (marginal)	*no previous study*			

Figure 1: Correlation of total sum insured and total premia in Germany.



Notes: R-squared of regression 0.983. Analysis covers period from 1993 to 2009; Due to data availability, only values for insurance types residential – buildings (Verbundene Wohngebäudeversicherung), residential – contents (Verbundene Hausratsversicherung), commercial wind storm – buildings & contents (Gewerbliche Sturmversicherung), and crop hail insurance (Landwirtschaftliche Hagelversicherung) are included. In 2009, premia for these insurance types constituted 67 percent of all premia for property and engineering insurance affected by natural disasters.

Figure 2: Insurance penetration in the United States and West Germany.

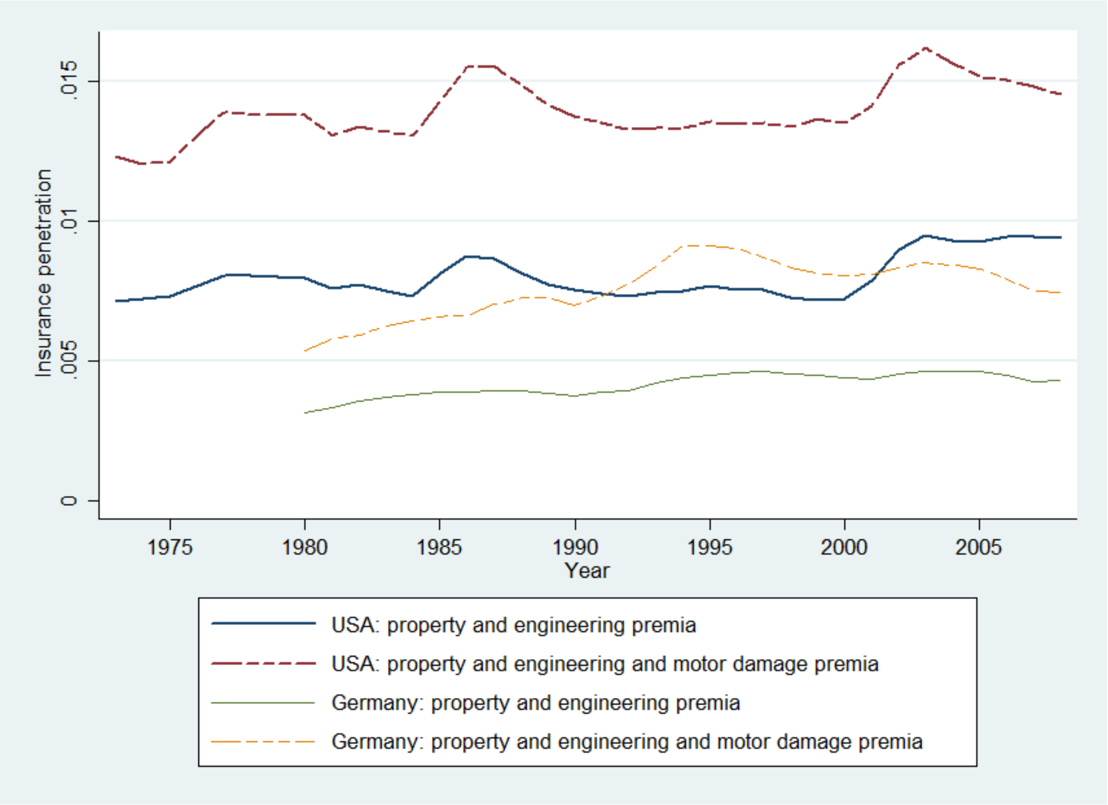
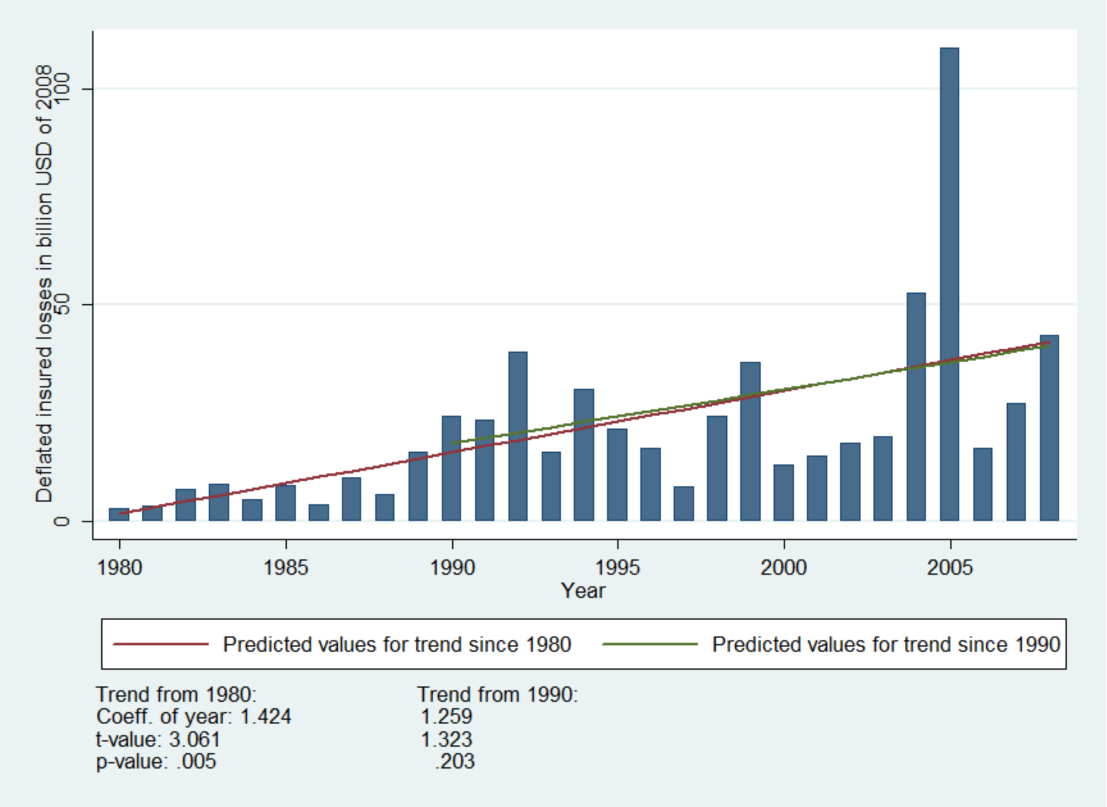
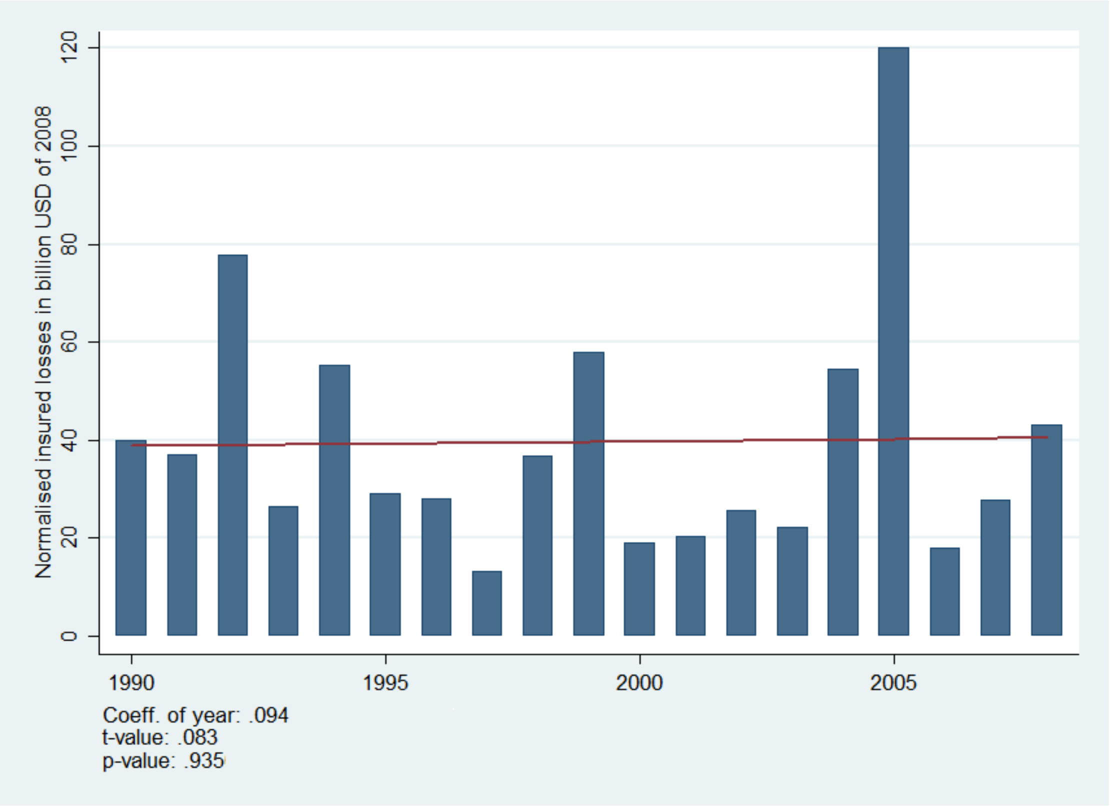


Figure 3: Global deflated insured losses from natural disasters.



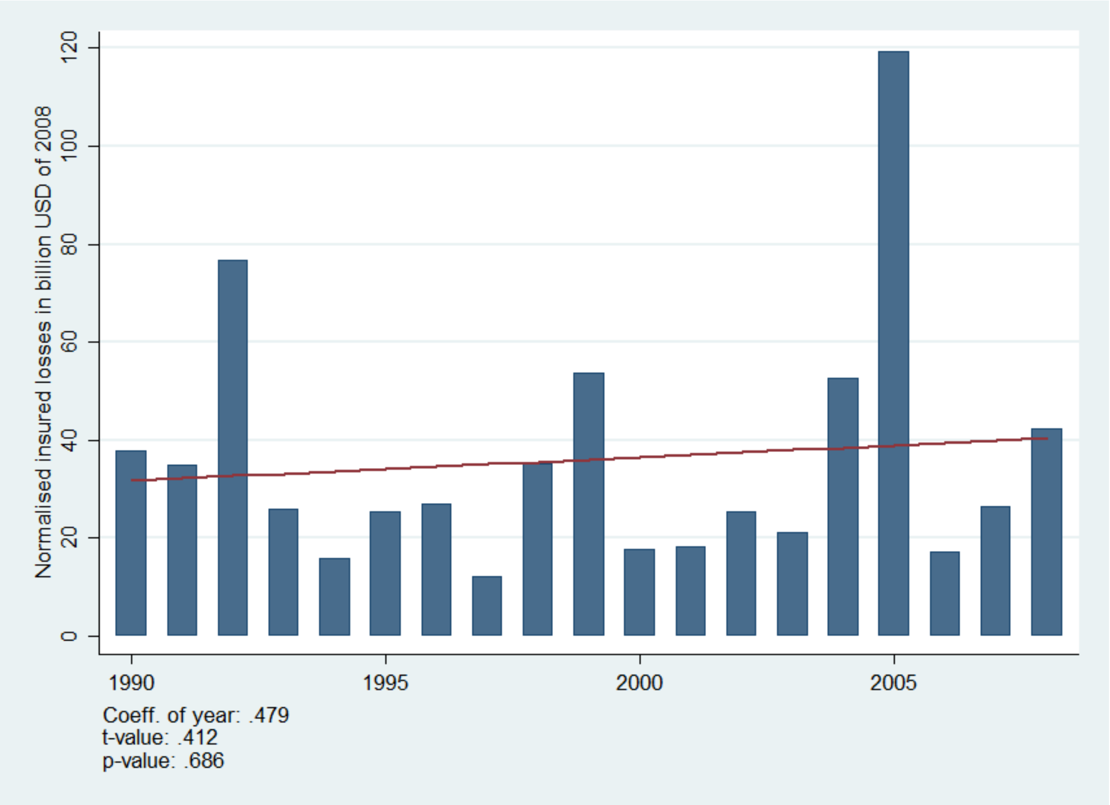
Note: 19,367 disasters, thereof 2,553 with a positive insured loss for whole period, 14,876 (1,855) for the period from 1990.

Figure 4: Global normalised insured losses from all disasters.



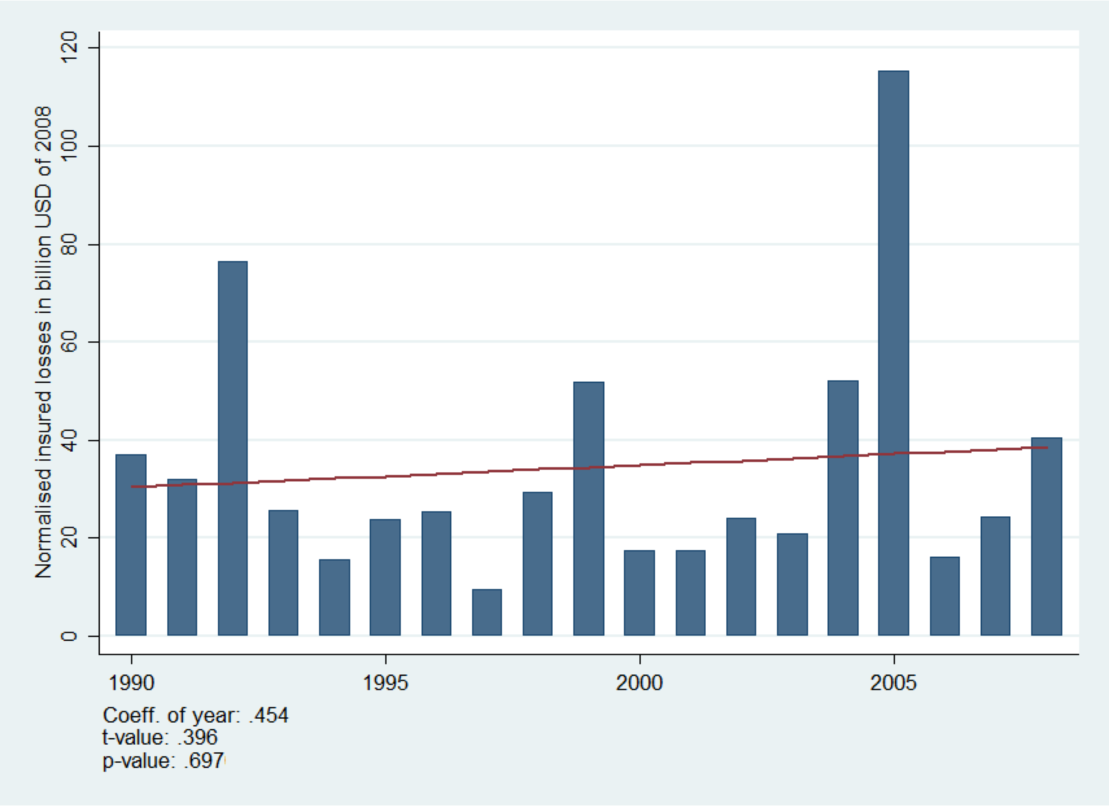
Note: 13,055 disasters, thereof 1,785 with a positive insured loss.

Figure 5: Global normalised insured losses from non-geophysical disasters.



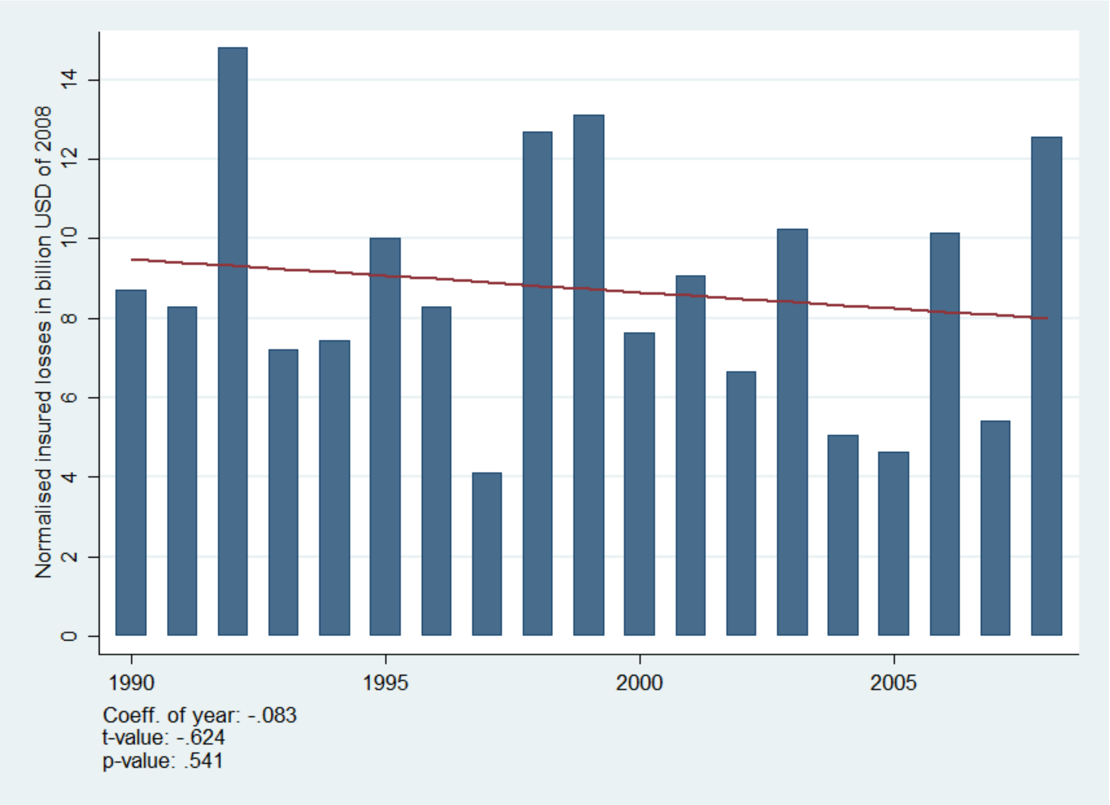
Note: 11,423 disasters, thereof 1,678 with a positive insured loss.

Figure 6: Normalised insured losses from non-geophysical disasters in developed countries.



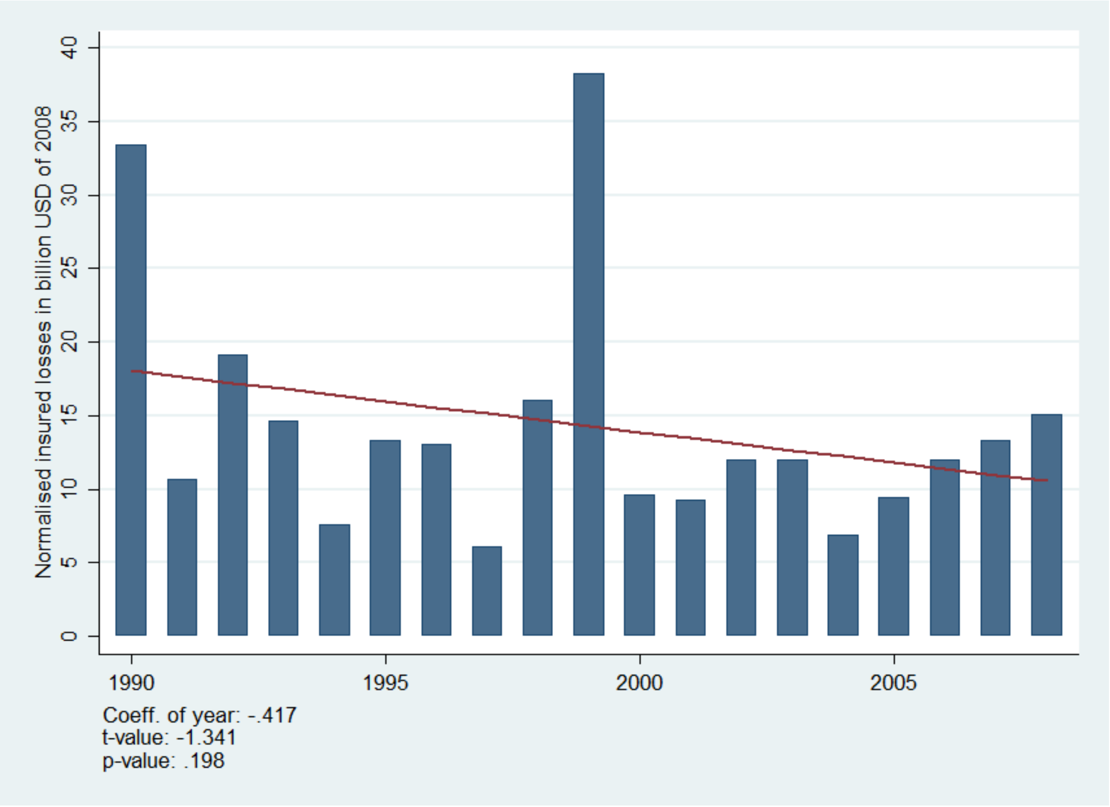
Note: 6,060 disasters, thereof 1,550 with a positive insured loss; developed countries cover OECD countries and other high-income countries according to World Bank classification.

Figure 7a: Global normalized insured losses from convective events.



Note: 4,156 disasters, thereof 841 with a positive insured loss; Includes damages from flash floods, hail storms, tempest storms, tornados, and lightning.

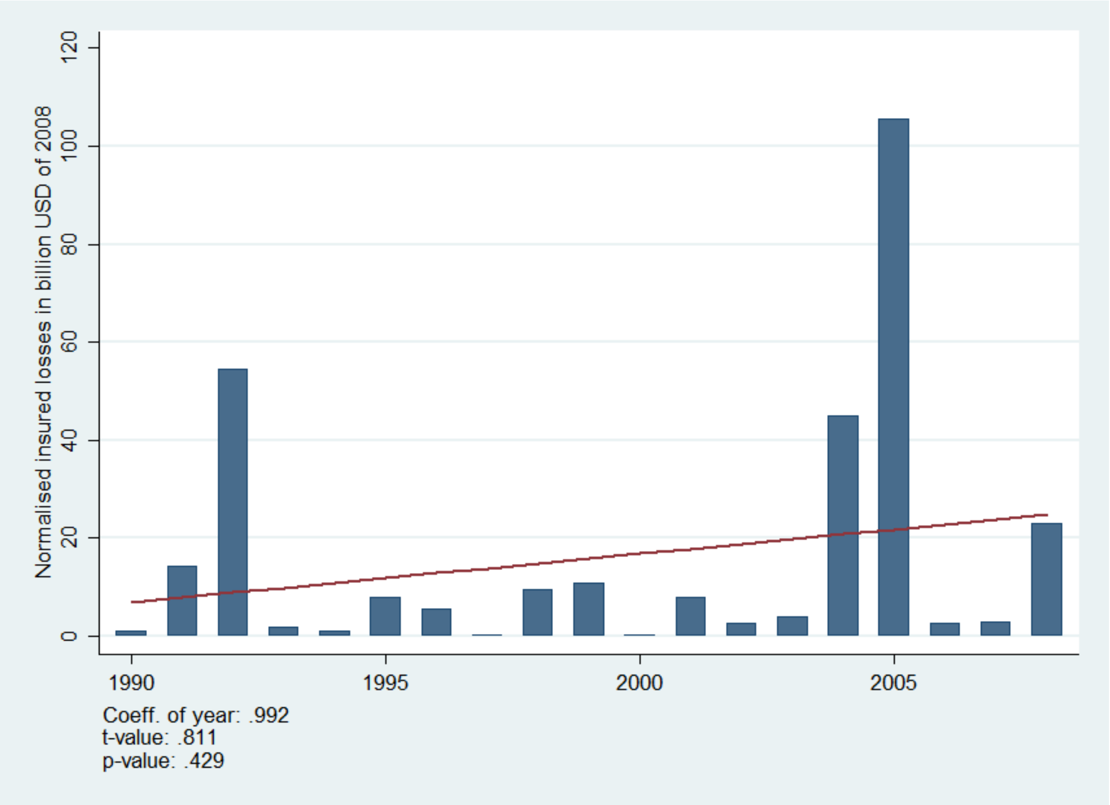
Figure 7b: Global normalized insured losses from all storm events except tropical cyclones.



Coeff. of year: -.417
t-value: -1.341
p-value: .198

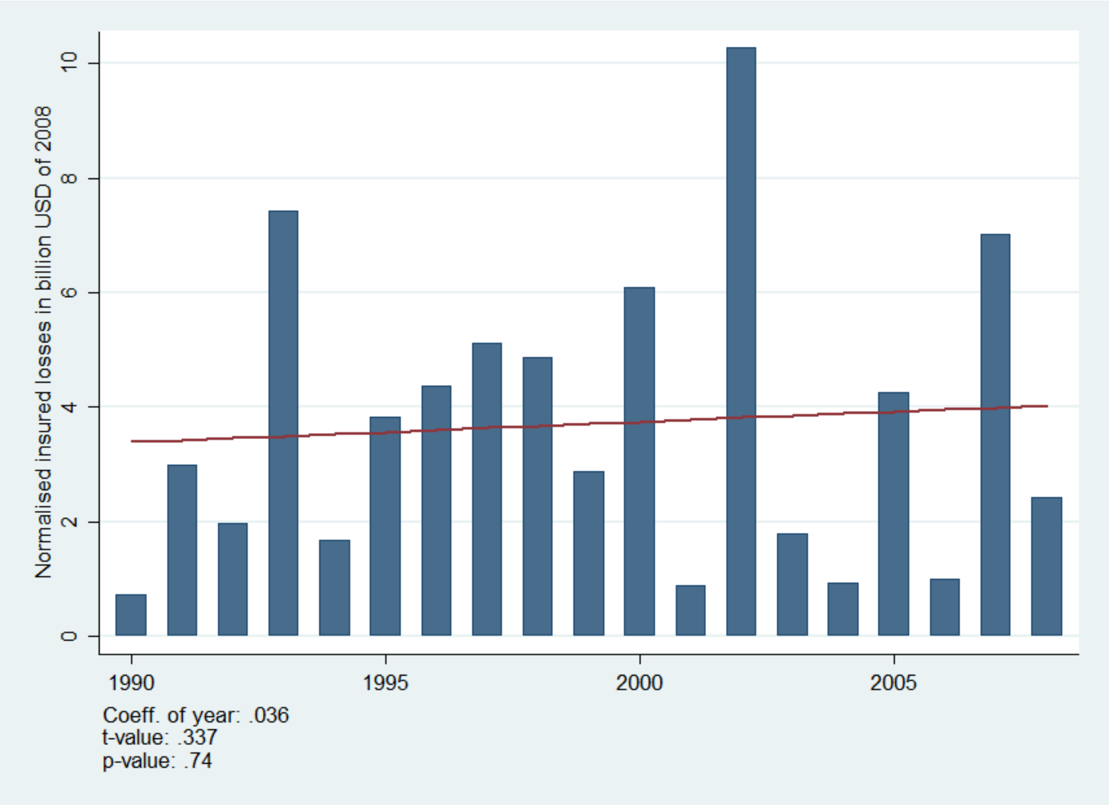
Note: 4,369 disasters, thereof 1,128 with a positive insured loss; Includes damages from winter storms (winter storm and blizzard/ snow storm), convective storms (hail storm, tempest storm, tornado, and lightning), sand storms, local windstorms, and storm surges.

Figure 7c: Global normalized insured losses from tropical cyclones.



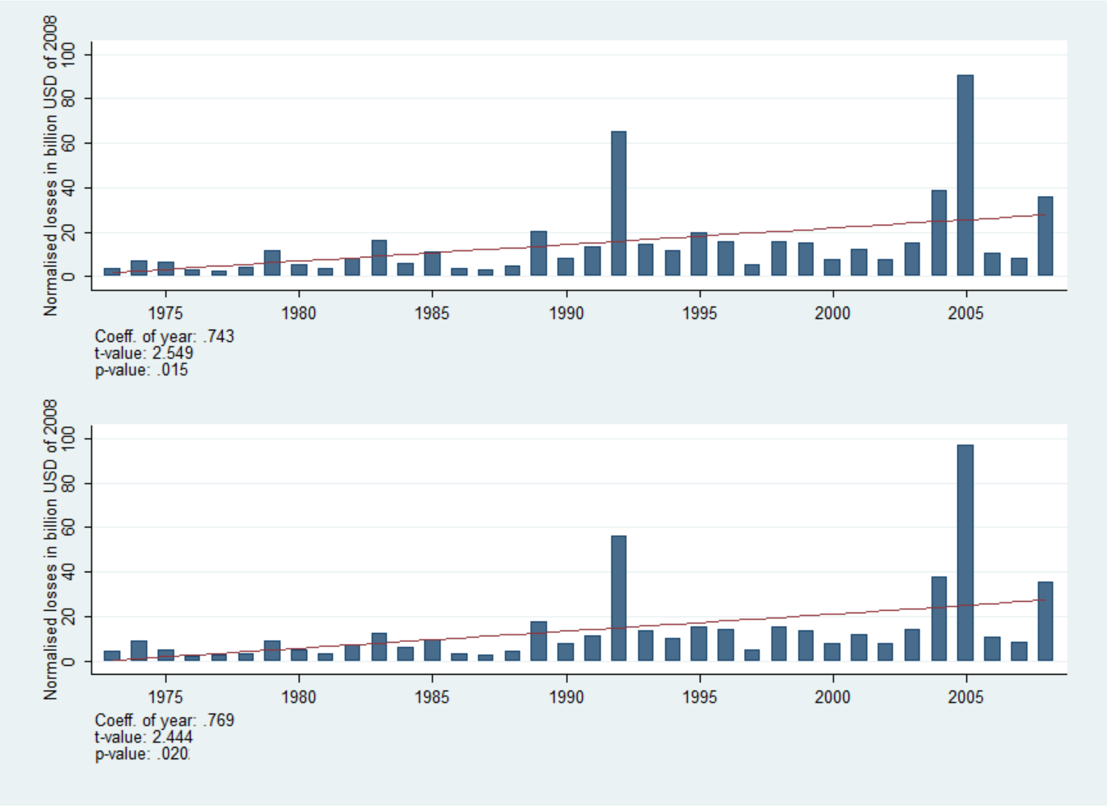
Note: 874 disasters, thereof 176 with a positive insured loss.

Figure 7d: Global normalized insured losses from precipitation-related events.



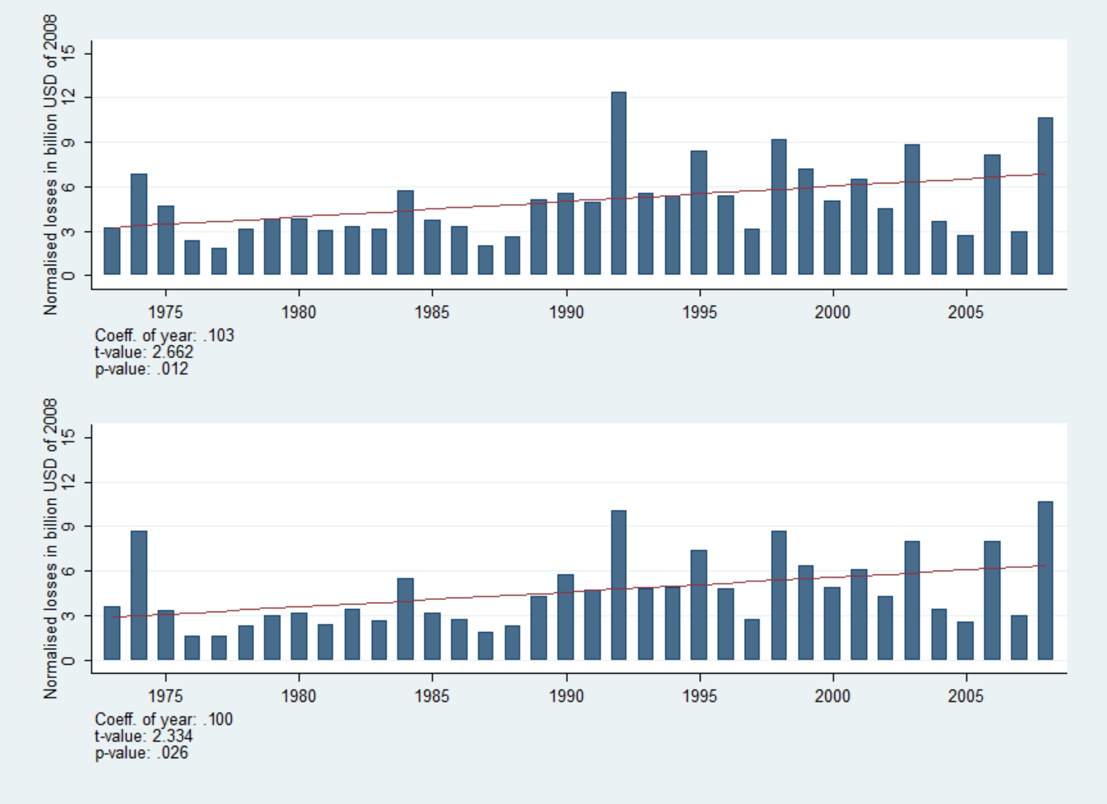
Note: 4,374 disasters, thereof 258 with a positive insured loss; Includes damages from flooding (flash flood and general flood) and mass movement (rock falls, landslides, and avalanches).

Figure 8a: 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).



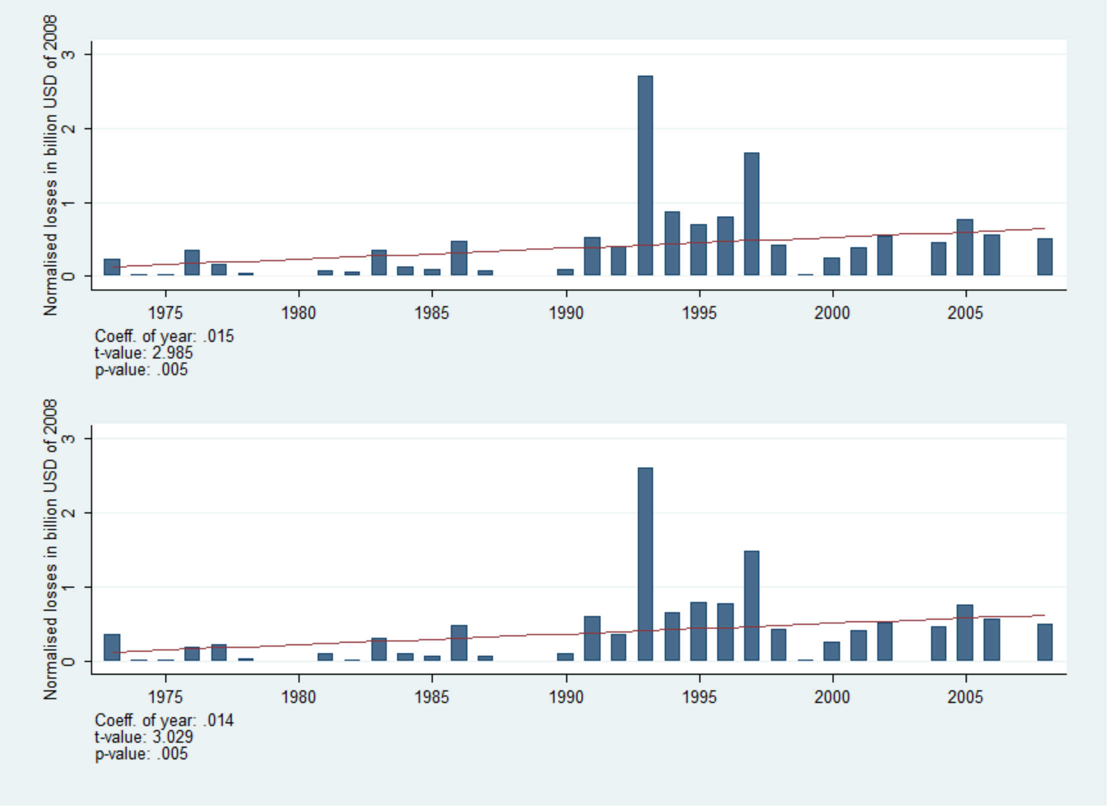
Note: 2,674 disasters, thereof 1,277 with a positive insured loss.

Figure 8b: Normalized insured losses from convective events in the United States using changes in personal income (top) and changes in value of housing units (bottom).



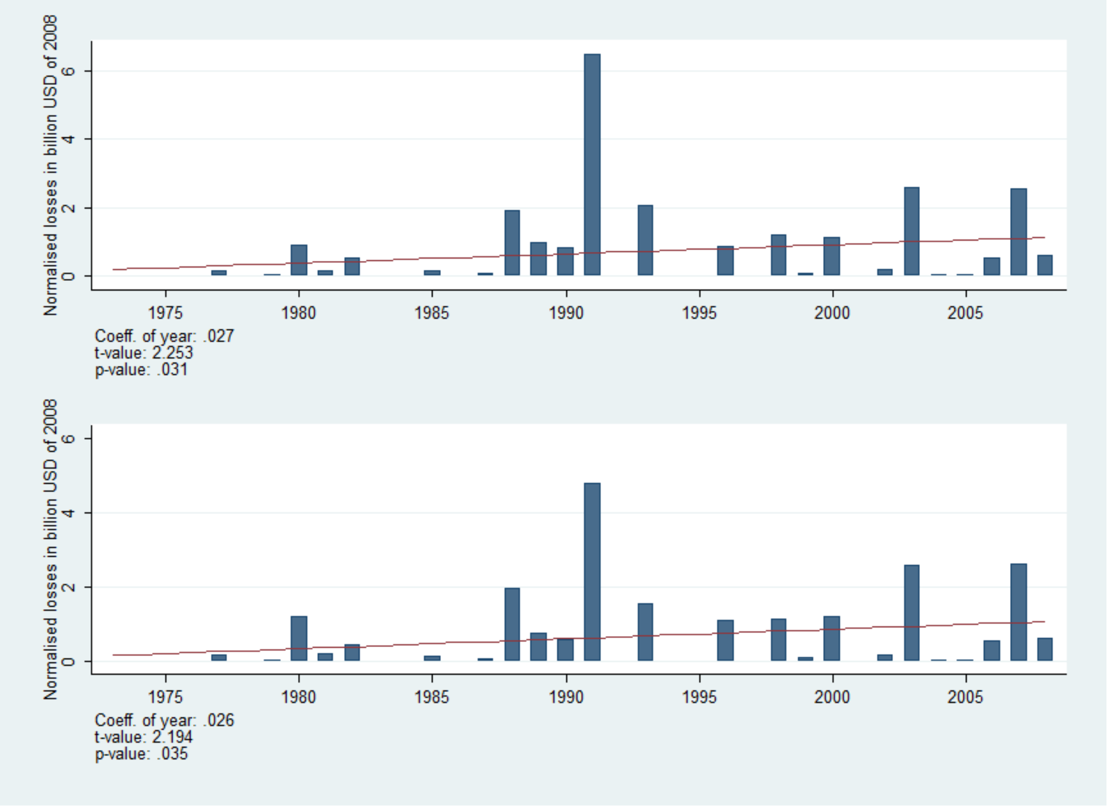
Note: 1,646 disasters, thereof 916 with a positive insured loss; Includes damages from flash floods, hail storms, tempest storms, tornados, and lightning.

Figure 8c: Normalized insured losses from flooding in the United States using changes in personal income (top) and changes in value of housing units (bottom).



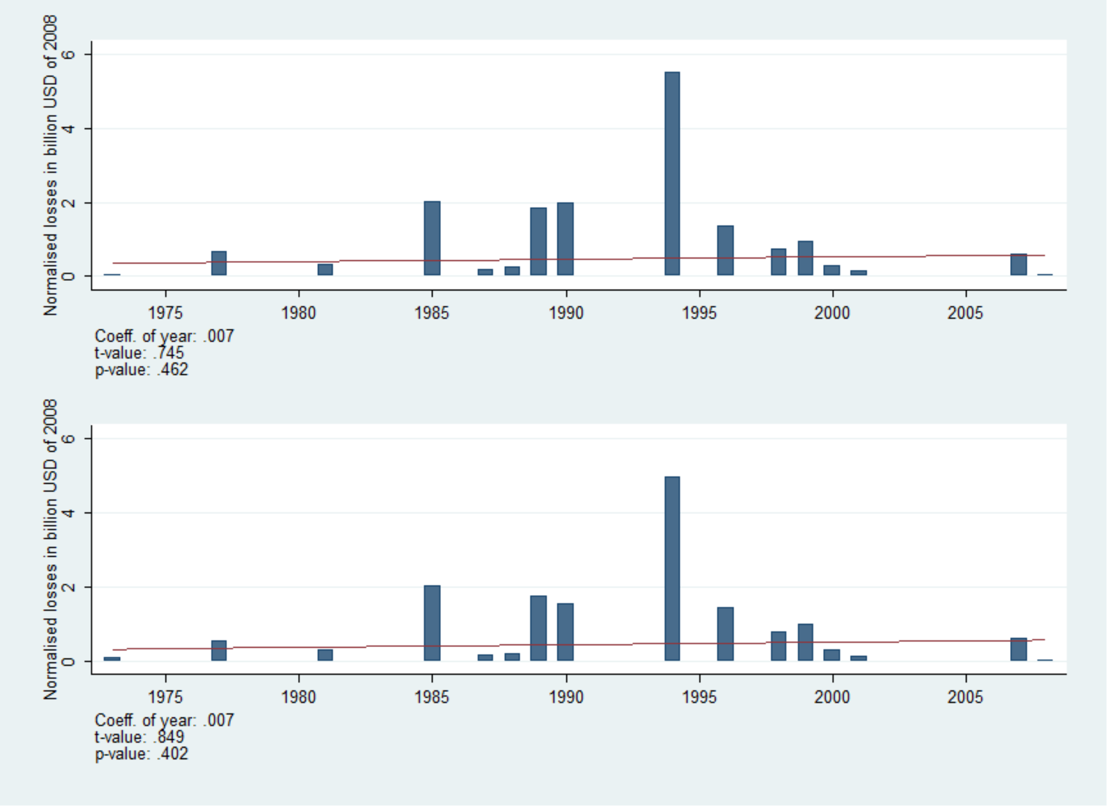
Note: 337 disasters, thereof 63 with a positive insured loss; Includes damages from flash floods and general floods.

Figure 8d: Normalized insured losses from temperature highs in the United States using changes in personal income (top) and changes in value of housing units (bottom).



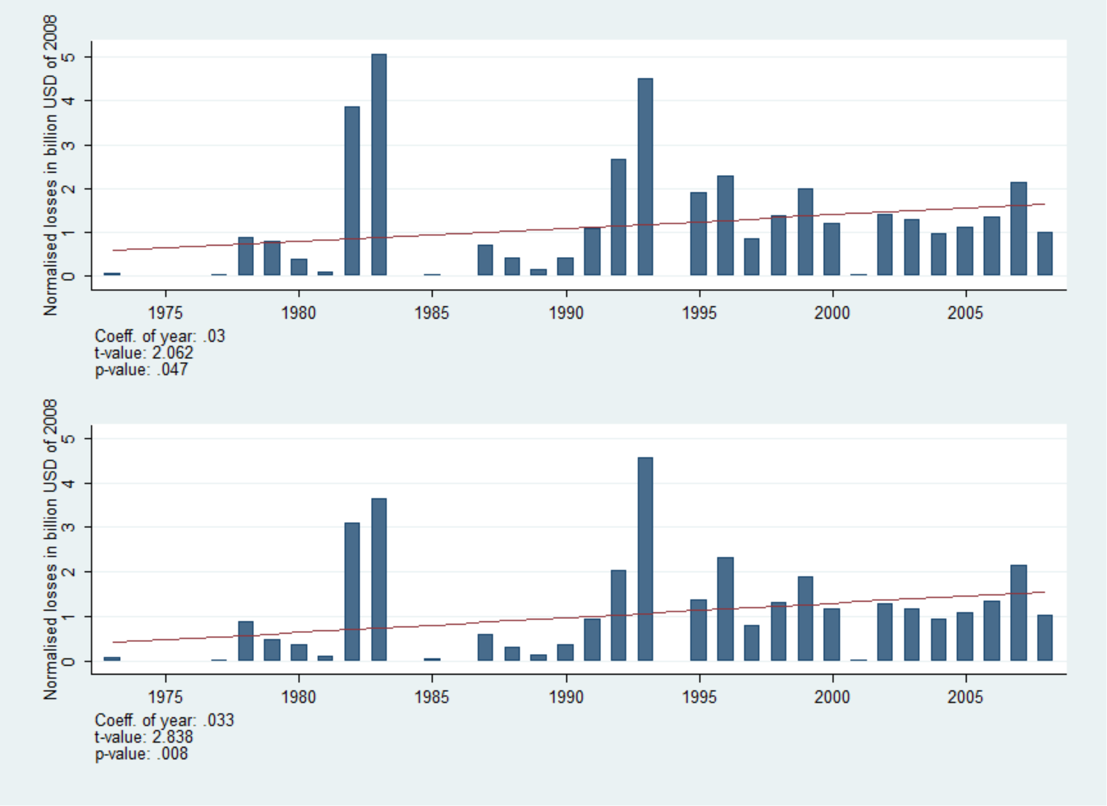
Note: 340 disasters, thereof 65 with a positive insured loss; Includes damages from heat waves, droughts and wild fires.

Figure 8e: Normalized insured losses from temperature lows in the United States using changes in personal income (top) and changes in value of housing units (bottom).



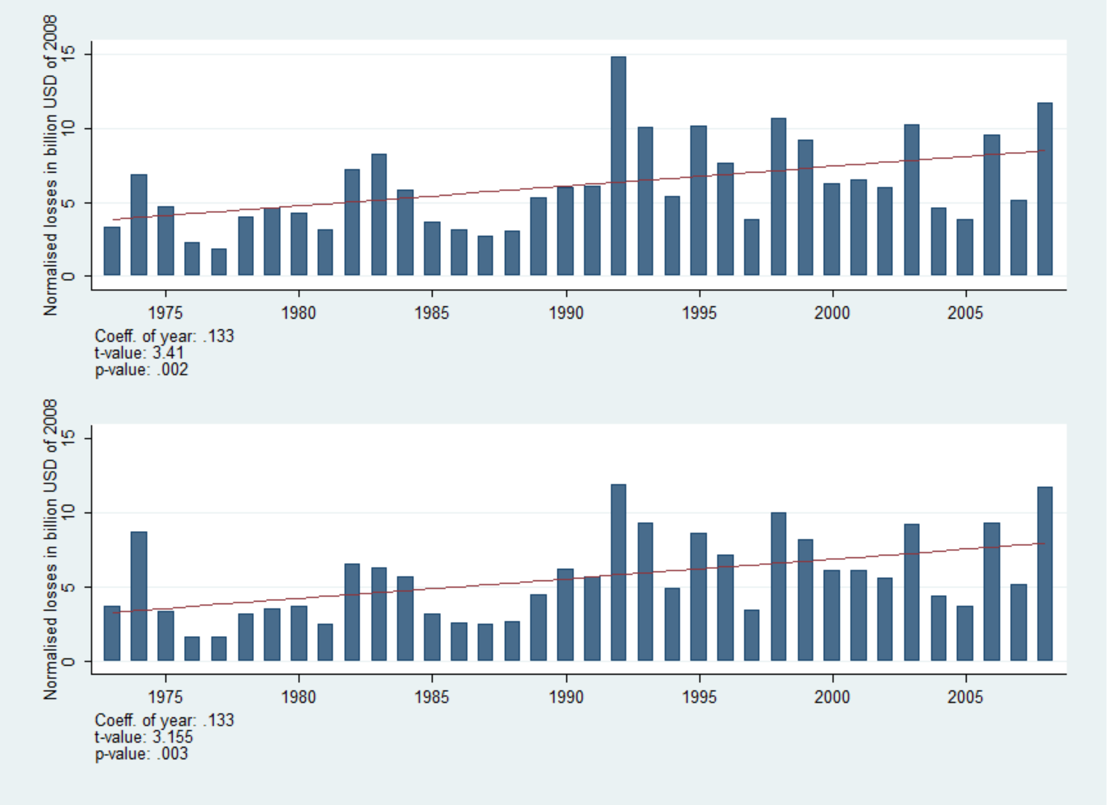
Note: 60 disasters, thereof 33 with a positive insured loss; Includes damages from winter damages and cold waves.

Figure 8f: Normalized insured losses from winter storms in the United States using changes in personal income (top) and changes in value of housing units (bottom).



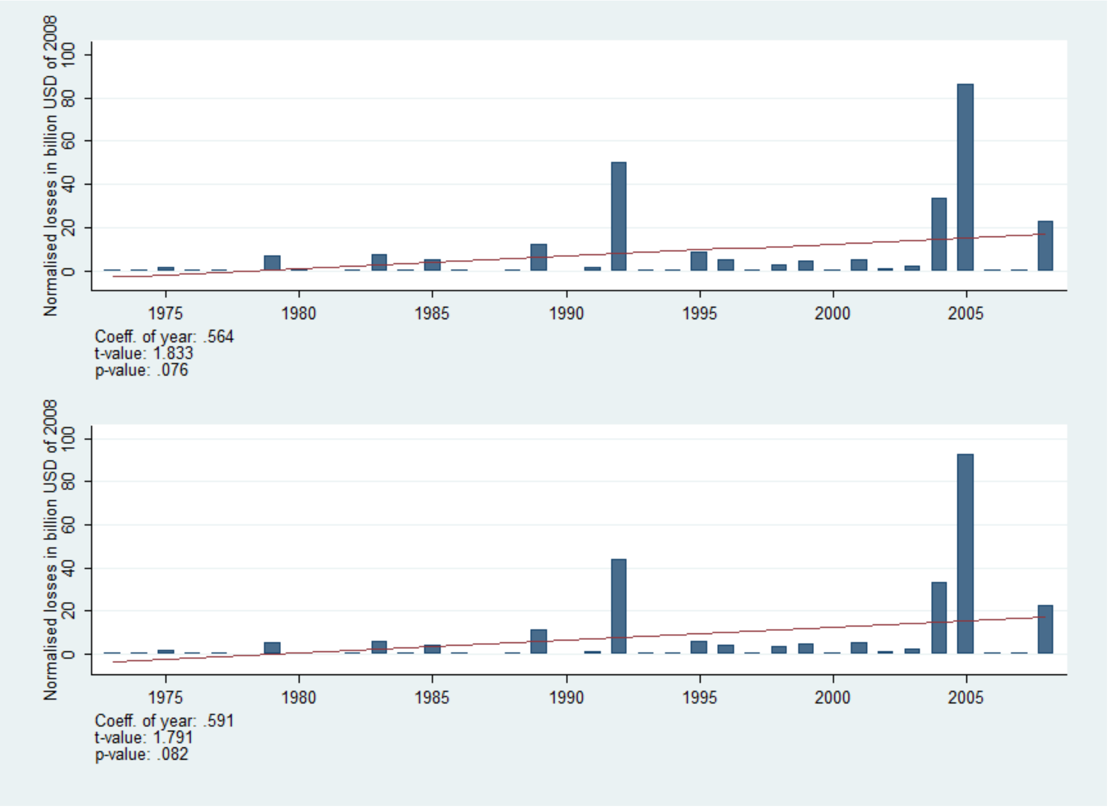
Note: 214 disasters, thereof 122 with a positive insured loss; Includes damages from winter storms, blizzards and snow storms.

Figure 8g: Normalized insured losses from all storms in the United States using changes in personal income (top) and changes in value of housing units (bottom).



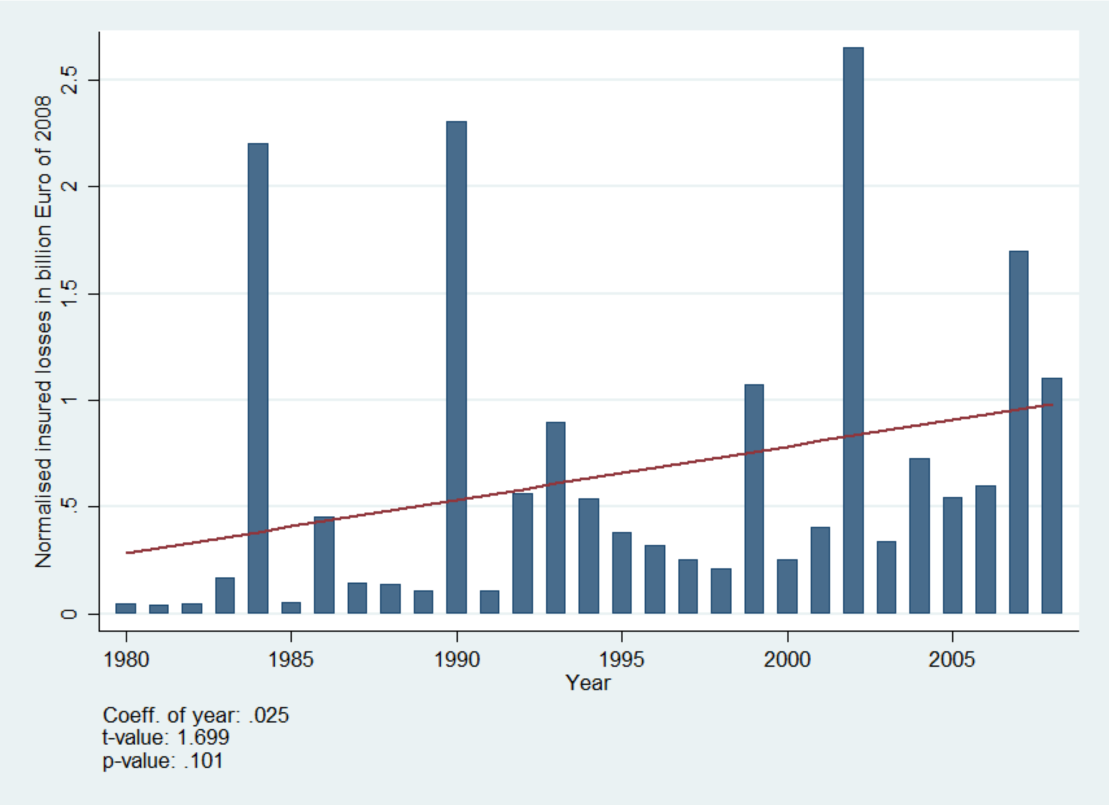
Note: 1,756 disasters, thereof 1,034 with a positive insured loss; Includes damages from winter storms, blizzards, snow storms, hail storms, tempest storms, tornado, lightning, sand storms and storm surges.

Figure 8h: Normalized insured losses from hurricanes in the United States using changes in personal income (top) and changes in value of housing units (bottom).



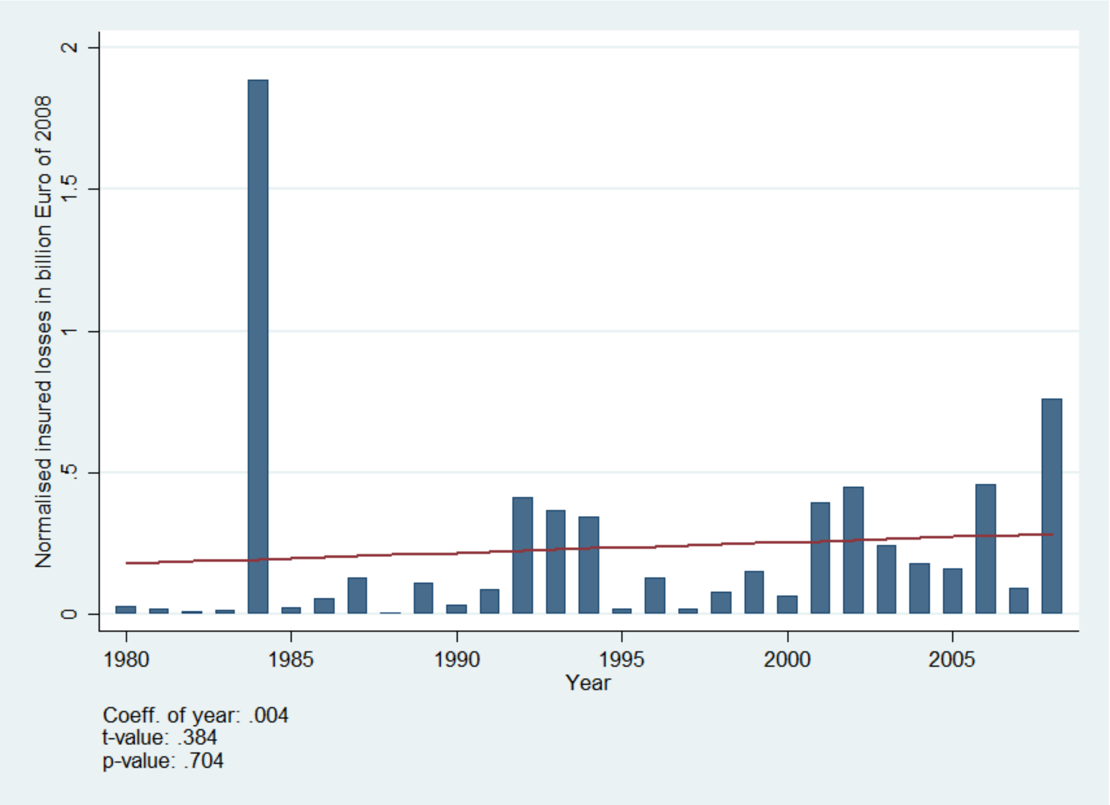
Note: 113 disasters, thereof 82 with a positive insured loss.

Figure 9a: Normalized insured losses of non-geophysical disasters in West Germany.



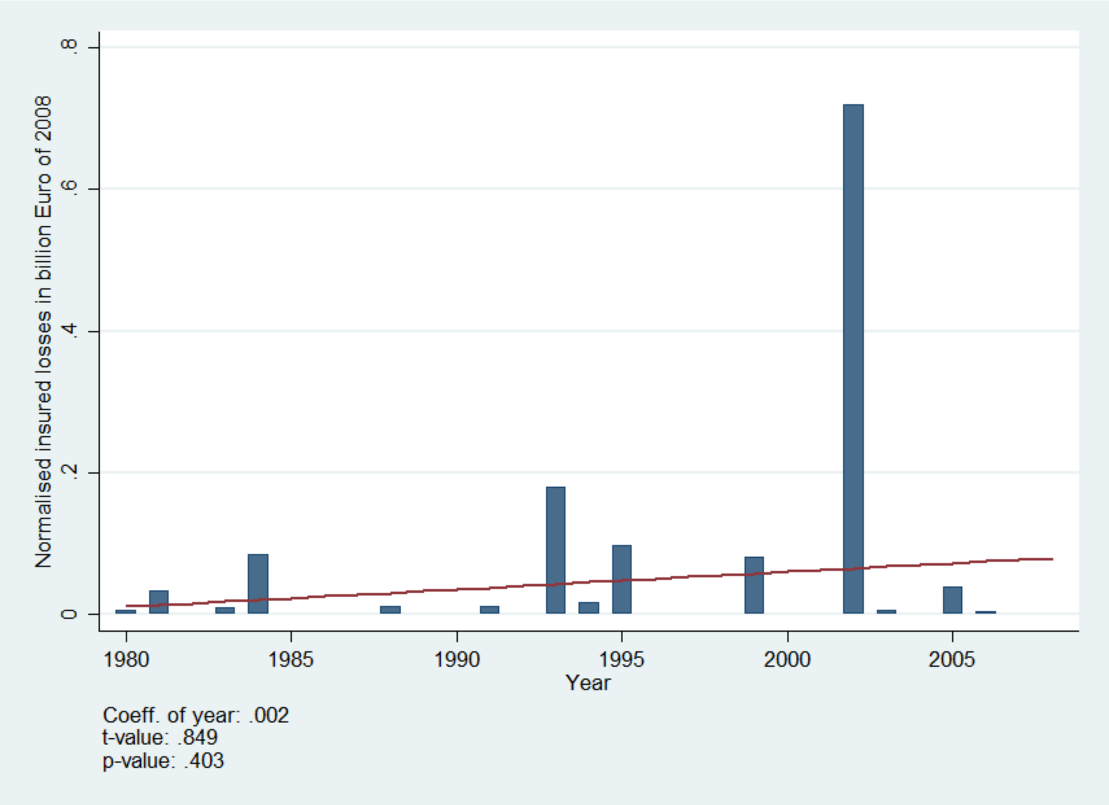
Note: 577 disasters, thereof 265 with a positive insured loss.

Figure 9b: Normalized insured losses from convective events in West Germany.



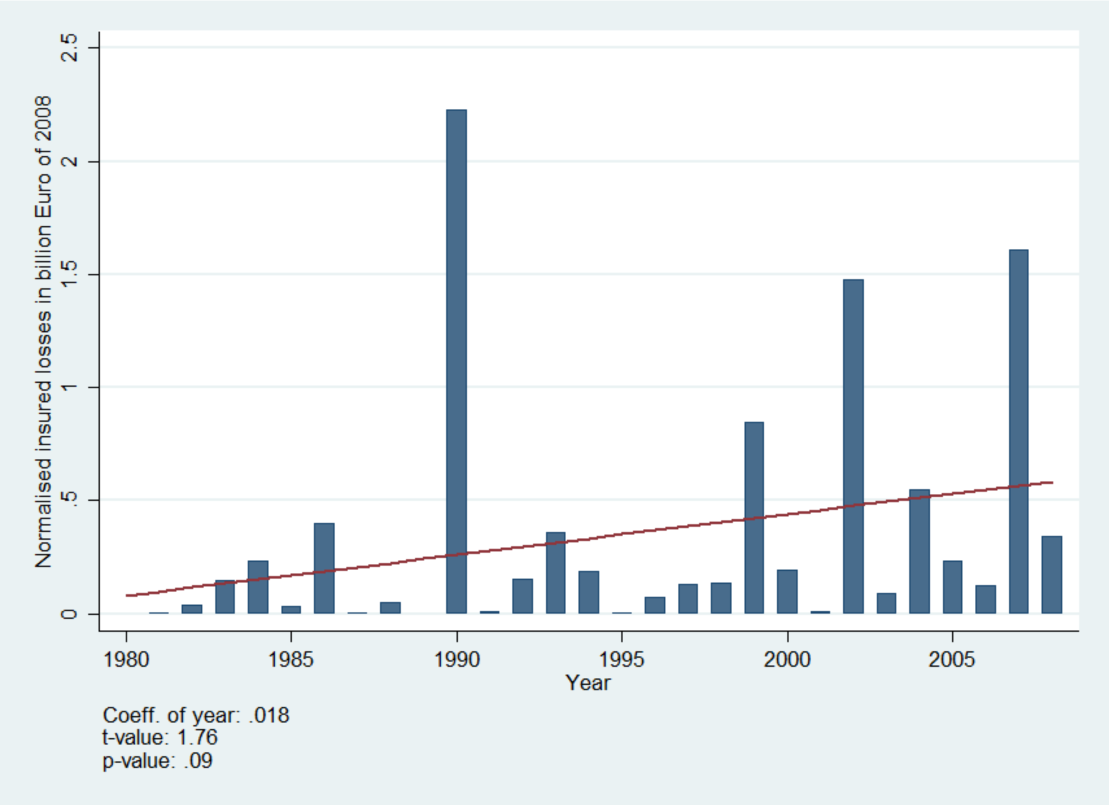
Note: 323 disasters, thereof 147 with a positive insured loss; Includes damages from flash floods, hail storms, tempest storms, tornados, and lightning.

Figure 9c: Normalized insured losses from flooding in West Germany.



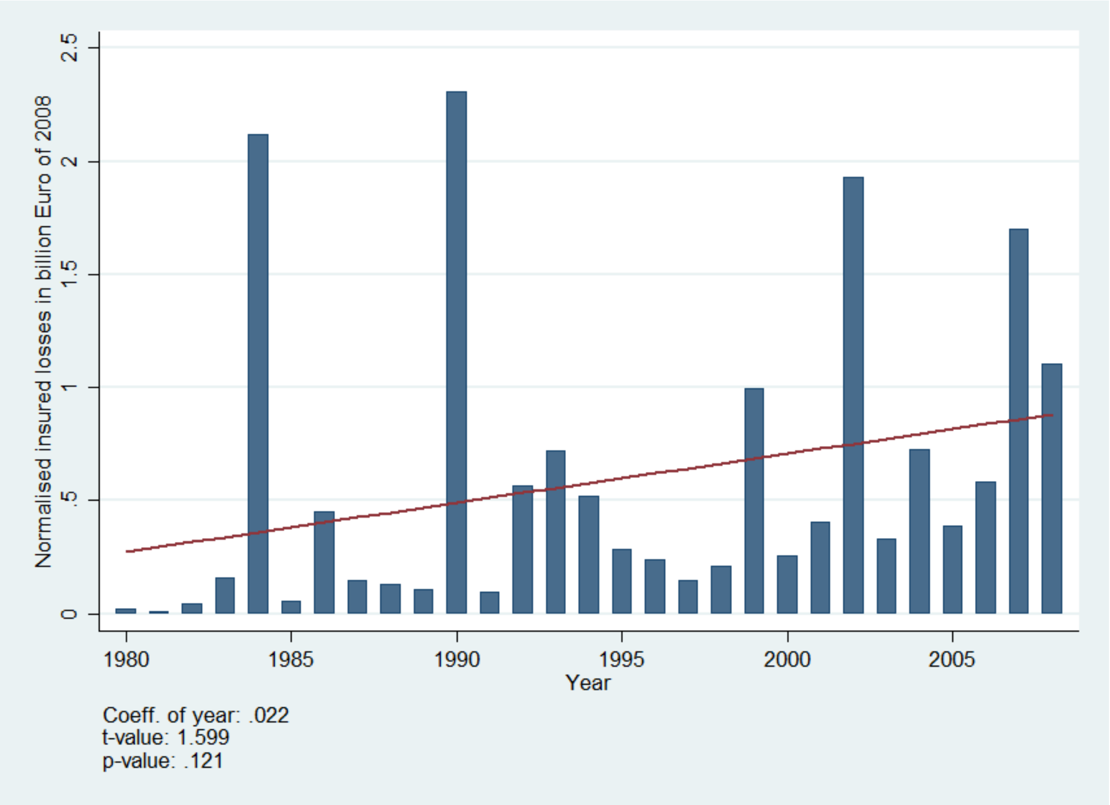
Note: 94 disasters, thereof 20 with a positive insured loss; Includes damages from flash floods and general floods.

Figure 9d: Normalized insured losses from winter storms in West Germany.



Note: 112 disasters, thereof 84 with a positive insured loss; Includes damages from winter storms, blizzards and snow storms.

Figure 9e: Normalized insured losses from all storms in West Germany.



Note: 416 disasters, thereof 238 with a positive insured loss; Includes damages from winter storms, blizzards, snow storms, hail storms, tempest storms, tornado, lightning, sand storms and storm surges.