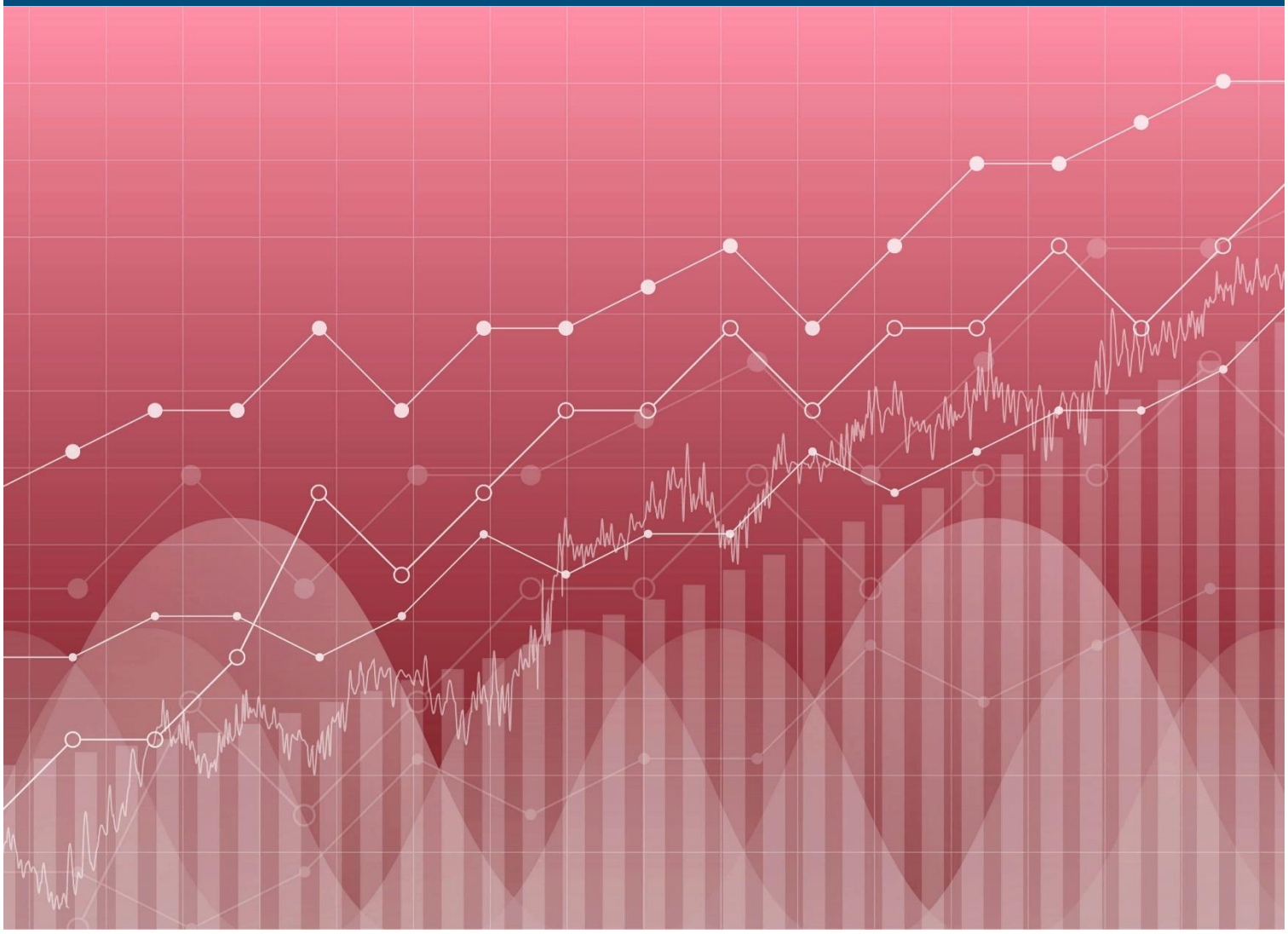
SOCIETY OF ACTUARIES

# Catastrophe & Climate Strategic Research Program Newsletter – August 2020



August 2020

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## August 2020

## About the Program

The board of the Society of Actuaries (SOA) authorized in 2017 a research strategy placing increased focus on five strategic research programs. One of those programs is the Catastrophe and Climate Strategic Research Program. Some of those programs have launched, and the last one to launch will be the Catastrophe & Climate, in 2021. A steering committee for the program was established in October 2019 as a standing committee and consists of an energetic and diverse group of volunteers – actuaries from multiple practice areas and continents, meteorologists, academics, and climate policy experts. The purpose of the programs is to encourage the development of research and branding for the SOA on a cohesive theme and related topics, and this program is dedicated to furthering actuaries' and the SOA's stakeholders' body of knowledge on climate trends and its impacts, and on catastrophic events.

Our focus has been in identifying areas of climate research which may benefit from traditional actuarial methods or which addresses a question for insurers. We look forward to engaging in further research in 2021, and we look forward to helping meet the need for actuarial thought leadership around topics from extreme weather such as heat waves and impact on health and mortality to wildfire and flood risk and insurability, and the disparate impact all these have by socioeconomic class. Please read the sections below for a taste of recent completed research and current work in progress. Also important to us is to the education component – developing a series of environmental papers and also webinars to educate our members on climate risk. This newsletter also lends a casual format to this education component.

Though it is fair to say our initial efforts as a steering committee have been vetting and prioritizing project themes – with a focus on natural catastrophes and insurance costs or future strains caused by climate-related events – we have also more recently explored the catastrophe we are in the midst of now, with COVID-19 at each of our front doors. The SOA has been actively shifting resources to address actuarial questions on this pandemic, and we are also actively engaged in developing ideas for further in-house research. We have also just released a call for volunteers to submit data visualizations on how COVID-19 is correlated with a risk of choice – anything from long-term care facility mortality to health insurance availability and mix by US state. Please consider sending in a submission. To participate, please follow this link for further information: https://www.soa.org/research/opportunities/2020-covid-19-visualizations/

We also have a set of volunteers in a data group, the Climate Data Analysis Group led by staff member Patrick Wiese, which is busy studying various weather databases with the aim of assessing resolution, reporting gaps and other weaknesses, and ultimately correlations to actuarial risk. This is a great example of actuaries coming together to study a topic of interest, and we hope to foster that spirit of knowledge-sharing with this preliminary newsletter – this is meant for any actuary concerned and interested in climate and catastrophe risk (shouldn't that be us all?) Perhaps this and future iterations will spur further interest, so please read on! We hope you enjoy,

Sara Goldberg

Chair, Catastrophe and Climate Strategic Research Program

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## SOA Catastrophe & Climate Published Research Overview – Rob Montgomery

The SOA publishes sponsored research as well as reports completed internally. Published climate research can be found here: https://www.soa.org/research/topics/research-emerging-topics/#climate

This category of research reports explores how climate risk may affect the finance and insurance industries. Topics include extreme weather, impact of weather perils on mortgage credit risk, trend reports, ideas for risk pooling, modeling, measuring and pricing flood risks, climate risk fundamentals, and sources for actuaries and links to related works.

Works currently underway include the impact of heatwaves on human health and the attribution to climate change, appropriate discounting of future climate risks to the present, a series of papers to be published every 1-2 months featuring environmental risks, an ongoing series on weather extremes in an historical context and participation in the multi-organization Actuaries Climate Index.

Looking ahead, the Catastrophe & Climate Strategic Research Program looks to sponsor research which focuses on the impact of shifting climate patterns and the frequency and severity of events on the public and the insurance industry.

## Featured Research Projects – Rob Montgomery

### RESIDENTIAL FLOOD RISK IN THE UNITED STATES

Residential Flood Risk in the United States: Quantifying Flood Losses, Mortgage Risk and Sea Level Rise was published in May 2020 and can be found here: https://www.soa.org/resources/research-reports/2020/soa-flood-report/

This report examines current countrywide residential exposure to flooding, considers how it could be impacted by sea level rise, evaluates how this could affect the financial health of residential householders, explores a new technique to determine whether it could impair their ability to meet their mortgage obligations, and analyzes the effects of defaults to other parties or institutions.

### MODELING, MEASURING AND PRICING FLOOD RISK

https://www.soa.org/resources/research-reports/2019/flood-risk/

As found in this report, floods are, by far, the most frequent and destructive natural disaster in North America. In the U.S., they accounted for nearly two-thirds of all presidential disaster declarations over the period from 1953 to 2010. Floods are particularly devastating because of their pervasive impact, widespread loss of lives and assets, and the level of the associated disruption to communities and businesses. Eight out of 10 catastrophes in the U.S. have been flood-related, and in the five years leading up to the report all 50 states had experienced flooding with varying degrees of severity. The situation is very similar in Canada, where floods are recognized to be the most frequently occurring natural hazard. More specifically, the Canadian disaster database had recorded 241 flood disasters between the years 1900 and 2006, which is five times the number of wildfires, the next most common disaster in the country.

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Although there is a large body of literature focusing on the investigation of flood risk, the contribution of the actuarial community (theoreticians and practitioners) has been rather restricted. The report mentions the following three reasons: (1) flood risk possesses characteristics that make it significantly different from the risks that actuaries have experience dealing with; (2) flood risk models are highly specialized and therefore not easy to understand for someone who is not specifically trained; and (3) flood risk insurance treaties are often not price-to risk contracts, which leaves less room to trigger actuarial expertise and involvement. The report discusses these points in more detail along with others. The major goals are (1) to sketch the landscape of flood risk management, in general, and flood risk insurance, in particular and (2) to draw the attention of the actuarial community to these subjects and the opportunities they present.

## In the News – Michael Fung

Here are some recent articles focusing on catastrophe, climate and insurance, as well as a climate analysis tool that we find interesting. As you click through to the articles below, we invite you to consider how these phenomena and trends can impact actuarial applications, and to note any associations to economic and insured losses.

### Tools

Climate reanalyzer: https://climatereanalyzer.org/wx/DailySummary/#t2anom
This is a climate monitoring website. This tool provides a lot of useful information, including temperature anomalies, which show current temperature vs the historical average.

### News clippings

I) Siberian heat
https://www.washingtonpost.com/weather/2020/07/15/siberian-heat-streak-arctic-temperature-record-virtually-impossible-without-global-warming-study-says/

> Siberian heat wave not possible without human-caused global warming, study finds - The Washington Post
>
> In a stark new finding, a study shows that six straight months of anomalously mild conditions in large parts of northern Siberia so far this year, along with an Arctic temperature record of 100.4 ...
>
> www.washingtonpost.com

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**Awareness of climate change is still important even though we are battling the pandemic.**

II) https://news.bloomberglaw.com/environment-and-energy/plastic-pollution-spawned-by-pandemic-already-hitting-the-oceans

> Plastic Pollution Spawned by Pandemic Already Hitting the Oceans
>
> A new kind of plastic has been showing up in the oceans in recent months—personal protective equipment—joining the discarded plastic straws, bags and other detritus polluting the waters.
>
> news.bloomberglaw.com

III) Reinsurance Price and Negative Outlook

https://www.fitchratings.com/research/insurance/reinsurance-price-hikes-attract-capital-amid-coronavirus-fallout-26-06-2020

> Reinsurance Price Hikes Attract Capital Amid Coronavirus Fallout - Fitch Ratings
>
> Fitch Ratings-Chicago/New York-26 June 2020: (Re)insurance market dynamics including increased pricing, years of accumulating catastrophic losses, investment market losses and the significant losses expected from the fallout of the coronavirus pandemic have led to reinsurers' push for further price increases, Fitch Ratings says.
>
> www.fitchratings.com

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Because of the shutdown, the sources of weather data become unstable...

IV) Covid19 and Weather Forecast Accuracy

https://edition.cnn.com/2020/07/18/weather/fewer-flights-covid-weather-forecast-hurricane-impact/index.html

> Weather forecasts are less accurate because of Covid-19, a new study reveals - CNN
>
> (CNN)As the US heads into peak hurricane season, a reduction in commercial airline flights due to Covid-19 has significantly impacted our ability to accurately forecast the weather. A study out ...
>
> edition.cnn.com

Thanks to climate change, insurers discover new methods to process claims

V) New Styles of Catastrophe Claims
https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/p-c-insurers-moving-into-new-virtual-era-for-catastrophe-claims-handling-59265048

Climate change impacts everywhere in the world, including both the northern and southern hemispheres.

VI) Australian Bushfire Losses
https://www.insurancejournal.com/news/international/2020/07/07/574617.htm

> Insured Losses for 2019/2020 Australia Bushfires Estimated at A$1.9B (US$1.3B): PERILS
>
> The insurance industry's loss footprint for the Australian bushfires of 2019/2020 is estimated at A$1.9 billion (US$1.3 billion), according to PERILS, the independent Zurich-based organization ...
>
> www.insurancejournal.com

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# Good Read – Max Rudolph

## BOOK REVIEW – THE ENDS OF THE WORLD BY PETER BRANNEN

Peter Brannen is not a scientist, but his ability to describe the distant past in a compelling way makes this 2017 book both informative and readable.[1] Historically, each of the five extinction events the earth has endured was driven either mostly or in part by changes in the level of carbon dioxide in the atmosphere. The carbon cycle loses its equilibrium when greenhouse gases are released into the atmosphere through volcanic activity over many years. In each of these events at least 75% of the species at the time became extinct.

We are now in a race to determine if humans are causing a sixth extinction, also driven by greenhouse gas emissions. Since the beginning of the industrial revolution carbon dioxide in the air, measured today using the Keeling Curve, has grown from less than 300 parts per million to over 400. Average temperatures over this period have increased by over 1 degree Celsius. This doesn't seem like a lot, but seemingly small changes have caused both hot and cold periods across history.

The reader is introduced to five events, occurring during the Ordovician period, Devonian period, Permian period (a cold event preceded warming), Triassic period (the book debates the role of volcanos played, along with the asteroid that hit with an estimated magnitude 12 on the Richter scale) and the Cretaceous period, but is not overwhelmed by details. Some of these volcanic events covered entire continents miles deep with lava and released gases that temporarily destroyed the ozone layer.

Volcanic activity puts carbon dioxide in the atmosphere as a greenhouse gas and makes the oceans of the world acidic as the water absorbs the gases, but also releases sulfuric dioxide that blocks solar radiation. You can temper greenhouse gases with limited volcanic activity because of the sulfur and this can create ice ages, but eventually long-lasting volcanic activity increases levels of carbon dioxide and warms the planet. None of these outcomes is conducive to supporting life. Plants may flourish within a small band of higher temperatures by absorbing more carbon, but the environment moves at a pace beyond their ability to adapt. Today we see aquatic life moving toward the poles, crops more successful as they move away from the equator and wild plants moving higher up mountains to a cooler climate. We are testing the ecosystem's ability to keep up with these changes, starting with a band surrounding the equator. Extinctions are occurring at much higher rates than would normally be expected, but it is not too late yet to avoid a mass extinction.

The book provides thought provoking comments about oxygen's role in life processes. An example that is recent enough to understand is the mini ice age that may have been caused as reforestation drove natural carbon capture after the peak American Indian population (their agriculture was built around slash-and-burn techniques), when Europeans arrived with various diseases (e.g., smallpox, measles) the indigenous peoples had no immunity against. Over time, humans have converted half of earth's land surface to farmland. As a result of using nitrogen and phosphorous fertilizers, runoff has depleted oxygen in rivers, lakes and coasts of oceans, creating dead zones.

Perhaps the common-sense answer to today's biodiversity threat goes back to the carbon cycle. Photosynthesis, weathering and erosion, and dying plants and animals capture carbon that ends up underground. Continents collide, creating mountains. Respiration, volcanic activity and burning (of plant matter or fossil fuels) add carbon to the atmosphere. This cycle has been in balance for millions of years. During the past 250 years humans have released

[1] Brannen, Peter. The Ends of the World: Volcanic Apocalypses, lethal oceans, and our quest to understand earth's past mass extinctions. 2017. HarperCollins Publishers.

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carbon back into the air and sea through fossil fuel extraction and burning. The earth has moved away from equilibrium, with continued pressure to warm, so it will take a dedicated effort to move back in balance.

What's important to remember is that the earth always survives these events. It doesn't care if dinosaurs or man roam the earth. It always has another day. The pace of change of atmospheric carbon dioxide matters, and we are allowing it to accumulate in the atmosphere much faster even than these extinction events.

Humans have created a scenario that is unique in the history of the earth. We impact the ecosystem in ways that we control. As population levels are estimated by the United Nations to grow toward 11 billion people,[2] our actions have reduced diversity and set up feedback loops as temperatures, pollution and resource exploitation have all increased. Higher order interactions matter. We could be approaching a tipping point that leads to rapid ecosystem collapse. A leading indicator will be regional conflicts, or water wars, where combatants fight over fresh water using even more fossil fuels. Brannen's book walks the reader through five times in the past when the ecosystem crashed and expresses hope that we can change direction before it is too late to avoid a sixth. Let's hope he is right.

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## Studies / Research Published Outside the SOA

### CLIMATE CHANGE AND MARKET-BASED INSURANCE FEEDBACKS

The University of Nebraska

# Climate Change and Market-Based Insurance Feedbacks

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[2] https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html

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Climatic events have accounted for 91% of $1.05 trillion in insured costs for global catastrophic events from 1980 to 2016. Costs are driven by socio-economic development and increased frequency and severity of climatic disasters driven by climate change. Government policies to reduce systemic risk (e.g., cap-and-trade, carbon tax) have been a predominant approach for mitigation and adaptation. Alternatively, market-based incentives for climate change adaptation and mitigation already operate via the insurance industry to lessen impacts on society. Insurance feedbacks include changes in 1) premiums and insurance policies, 2) non-coverage, and 3) policy making and litigation. Alongside government policies, insurance feedbacks could be used to facilitate climate change adaptation and mitigation to a significant degree. Ultimately, a negotiated distribution of climate-related costs between the public and private insurance is needed.

Keywords: Insurance, Risk, Catastrophic Disasters, Adaptation, Resilience

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## 1. Introduction

Adaptation and mitigation are the reactive and proactive (respectively) responses to an event. Adaptation measures reduce direct impacts from an event (e.g., sandbags against a flood) whereas mitigation measures reduce risk of an event (e.g., frequency and/or severity of natural catastrophes). Government policies have been a predominant approach to adapt to and mitigate climate change impacts (Drouet, et al. 2015; Stern 2015). Yet past political agreements have been largely unsuccessful in reducing carbon emissions necessary to avert probable widespread catastrophic effects (Stern 2015). Changes in insurance coverage has been identified as an important external factor in driving adaptation and mitigation measures, among many other factors (USGCRP, 2018). Where future binding agreements are slow to develop (Stern 2007; Lomborg 2010), insurance feedbacks are under-recognized mechanisms and incentives to induce climate change adaptation and mitigation (Mills 2005; Mills 2012; Kunreuther et al. 2013; Botzen 2013; Attali 2006; III 2014). Market-based insurance feedbacks that are systemic, forceful, and knowledge-driven may become more active and apparent as the percentage of insured claims increases from natural catastrophes (Figure 1). Alongside other factors, market-based insurance feedbacks provide a framework to recognize the challenges posed by climate change and incorporate the problem and potential solutions into existing structures (USGCRP, 2018). Each factor has its limitations, and must be part of a larger, coordinated effort to address climate change adaptation and mitigation.

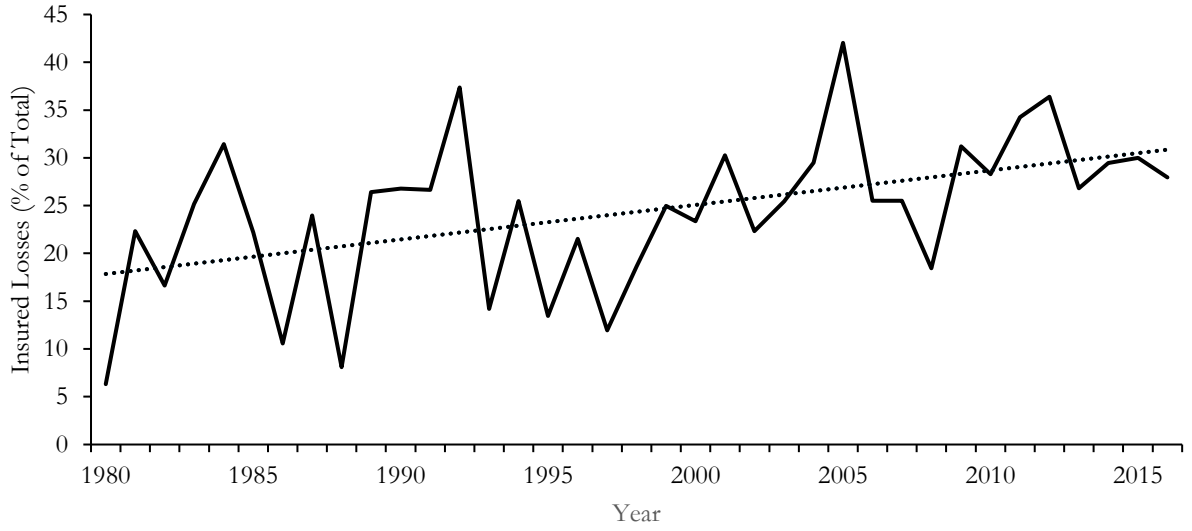


Figure 1. Insured losses as fraction of overall losses from natural catastrophes, 1980 to 2016. Source: Munich Re 2016.

In 2019, the World Economic Forum ranked extreme weather events, failure of climate change mitigation and adaptation, and natural catastrophes as the first, second and third most probable (respectively) and the third, second, and fifth most impactful economic risks to occur in the next 10 years (WEF 2019). Downside risks associated with weather-related events are increasingly managed by the insurance industry, the largest global economic sector, with revenue of $4.6 trillion or 7% of the global economy in 2011 (Mills 2012). Climatic events have accounted for 91% of the $1.05 trillion in insured losses concerning property and casualty insurance claims from 1980 to 2016 for global catastrophic events, and average costs per event have been steadily increasing (Figure 2); Hurricanes Harvey, Irma, and Maria in 2017 further add to this trend. Mounting external costs are also not included on corporate balance sheets or asset prices (Dietz et al. 2016). But businesses, governments, and financially concerned organizations are increasingly incorporating externalities in their plans and are making climate risk management a higher priority (Chestney 2016).

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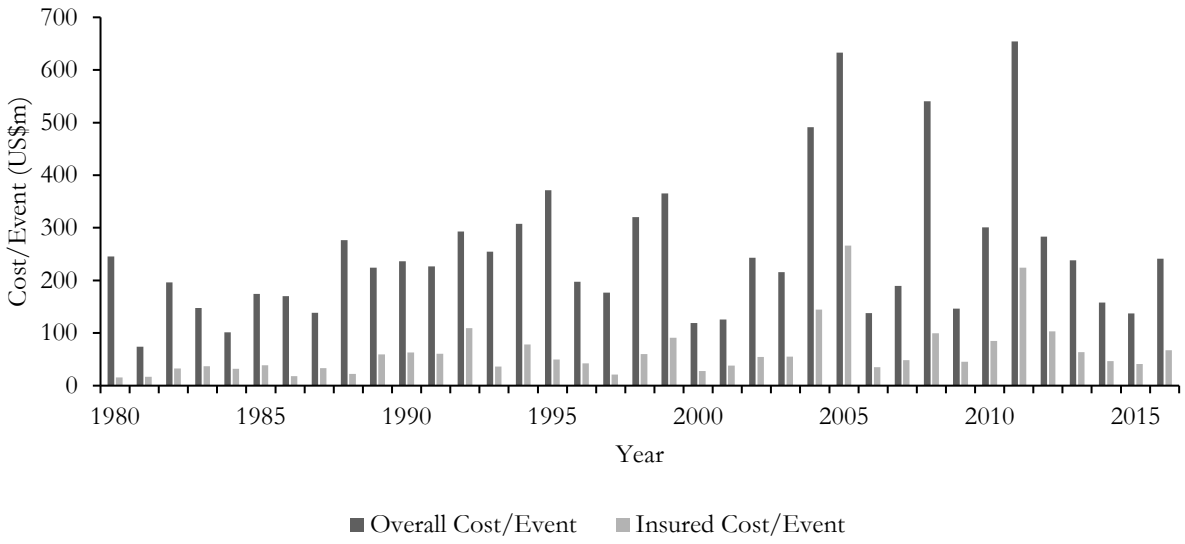


Figure 2. Overall and insured costs per event globally from 1980 to 2016 for relevant events only (At least 1 death and/or produced normalized losses ≥ US$ 100k, 300k, 1m, or 3m (depending on the assigned World Bank income group of the affected country). Source: Munich Re 2016.

The following sections describe the forceful and extensive mechanisms by which the insurance industry manages its role in adaptation and mitigation in market-based insurance markets. While some of our specific examples may cite the United States, these mechanisms and feedback processes are fundamental features of market-based insurance markets. Although the United States has the largest single share, the ten largest non-life insurance markets include Germany, the United Kingdom, France, Japan, Korea, Canada, Spain, Italy and Switzerland (OECD, 2016). Moreover, the most rapid percentage growth in private non-life insurance markets is occurring in Ecuador, Nicaragua, Columbia, Finland, Singapore, Poland, Israel, Portugal, Mexico and South Africa (OECD, 2017). Thus, the mechanisms described in our paper already operate in many developed countries (excluding public-private markets) and are rapidly expanding in a number of developing countries with market-based insurance. The descriptions following serve as a basis to understand the crucial interactions between the public and the insurance industry and to provide a framework for future research.

## 2. Premiums and Insurance Policy Feedbacks

Insurance premiums act as a signal of the average probability of a loss, and high initial premiums generally deter customers (Höppe and Gurenko 2006, Kunreuther et al. 2013). Insurers will only offer catastrophe insurance if premiums can be priced sufficiently and where risks are not excessively uncertain (Jaffee and Russell 1997; Kunreuther and Michel-Kerjan 2007; Ferguson 2008). Premiums often reflect one-year contracts between the insurer and insured. This time frame allows premiums to be adjusted in response to new information about the expected value of future losses in the short or long term. An increase in premiums to cover the newly-realized costs and unknown risks from climate change may leave previously insured assets without insurance and exposed to financial losses (Mills 2005; Kunreuther and Michel-Kerjan 2007; Young and Schwartz 2014). Financial viability of policies also relies on applying differential pricing to coverage limits and deductibles (Höppe and Gurenko 2006). Individual actions can lead to policy benefits, such as premium discounts or higher levels of coverage due to increased risk reduction behaviors (Botzen et al. 2009), which may also reduce post-disaster risk associated with structural failures or environmental contaminants.

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High premiums signal there is a large amount of uncertainty, or that more risk management techniques by at-risk parties are needed (Höppe and Gurenko 2006). Individual adaptation or societal mitigation can lead to decreased risk and cost savings for society (Ferguson 2008; Young and Schwartz 2014; Michel-Kerjan and Kunreuther 2011; Aerts and Botzen 2011). For example, in a hard-market scenario, where events lead to higher premiums and full adaptation, annual premium costs were projected to decrease to $5-6 billion after adaptation compared to $10-14 billion with existing building status in Florida (Young and Schwartz 2014). More proactive engagement of risk management is a valuable investment that builds resilience and ultimately reduces insured losses (Jaffee et al. 2008). However, the cost of risk reduction may offset the effectiveness of risk-based pricing (Surminski 2016) as those most vulnerable to risks may not be able to afford risk-based premiums or have the means to reduce their risk. This equity-efficiency tradeoff (Picard 2008) might be bridged through subsidies for risk-reduction measures, subsidized insurance, cost-effective technology, or a guaranteed reduction in premiums to offset the initial or recurring costs of adaptation and mitigation efforts (Botzen et al 2009; Surminski 2016).

But empirical studies show that people do not voluntarily invest in adaptation measures even when they are cost effective (Kunreuther et al. 2011, Bouwer et al. 2007). The theory of moral hazard suggests that those with a risk sharing mechanism such as insurance may be more likely to engage in risky behavior due to the protection provided by that risk sharing mechanism (Hölmstrom 1979). However, Hudson et al. (2017) found that in some catastrophe insurance markets moral hazard is not present, due likely to the internal characteristics of individual policy-holders and the low-probability/high-impact nature of catastrophe events. Strong market pressure and marketable solutions, such as catastrophe bonds that transfer peak risks to capital markets, are proven incentives to adopt adaptation measures (Michel-Kerjan and Kunreuther 2011). Multi-year contracts could also make the benefits of adaptation clearer, as the probability of a disaster during the time frame would be higher (Dlugolecki and Hoekstra 2006; Kunreuther et al. 2011; Michel-Kerjan and Kunreuther 2011). Incentives that both limit damage and reduce the probability of natural catastrophes have been the most effective way to reduce extreme costs (Aerts et al. 2008).

Premiums reflect the direct demand and supply of insurance policies between customers and the insurance industry (Surminski et al., 2016). High premiums signal limited coverage availability, or low supply, due to high uncertainty or risk. These high premiums decrease the demand for coverage as many cannot afford it. Subsidizing premiums allows for more affordable premiums but ultimately fails to reduce risk and reduces the effectiveness of feedback between insurer and insured. While climate insurance can enhance resilience by providing post-disaster liquidity (World Bank, 2012), this requires affordable coverage. Lowering premiums to reward mitigation and adaptation behavior can help bridge the gap between higher premiums and affordable coverage for policy-holders (reflecting reduced risk of loss and greater certainty, resulting in lower premiums).

## 3. Non-Coverage Feedbacks

Inaction is a major factor contributing to negative economic impacts from climate change (Tucker 1997). The undesired result of inaction is non-coverage, consisting of two subtypes: (1) insurance premiums do not reflect true risk, leading insurers to not offer a policy and (2) premiums are allowed to reflect true risk, but the premiums and deductibles (out-of-pocket costs for a claim) are too costly for the consumer to purchase the policy (Kunreuther et al. 2013; Botzen et al. 2009; Tucker 1997). Non-coverage occurs when the insurance supply is low and premiums are high (Surminski, 2016). Non-coverage is a deterrent to compounding harmful behaviors related to climate change such as rebuilding in catastrophe zones and failing to improve preparation or response to catastrophes (Mills 2005; Aerts and Botzen 2011; Tucker 1997). Non-coverage also pressures public organizations to assume more climate risks, which may lead to more federal debt. When the National Flood Insurance Program (NFIP) insured damages from Hurricanes Katrina, Rita, and Sandy, the NFIP incurred $24 billion in debt from these hurricanes alone (Kunreuther et al. 2013; Kunreuther and Michel-Kerjan 2007). Other examples include hurricane protection in Florida, earthquake protection in California, and the crop insurance system in the United States (Kousky and Kunreuther 2017).

Risk financing comes from a variety of sources (Figure 3). The primary source is the party itself through a deductible (where losses are paid through savings or working capital) for events that are below a threshold of cost and are usually frequent and not severe. Insurance protects against events that are somewhat frequent and severe

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enough that equity alone cannot cover the losses. Reinsurance, state-aid, and tort law cover rare events that have high financial impacts which an insurance company's equity alone cannot cover. These methods transfer risks from an insurer to a third-party, protecting them in the case of a catastrophic event. Tort law is rare but may increase in the future if significant disagreements over liability continue.

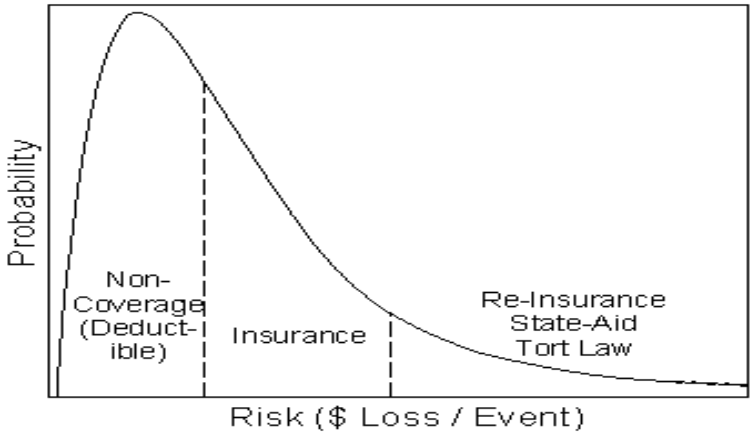


Figure 3. Financing climatic loss at different levels of risk.

Events leading up to non-coverage and the effects of non-coverage can be seen in the Saint Bernard Parish district of New Orleans after Hurricane Katrina (Ferguson 2008). Total insured losses of at least $41 billion occurred; the risk to insure parts of New Orleans is extremely high and lack of understanding of these risks also plays a part in keeping premiums too high to afford (King 2008). Contrasting interpretations of significant natural catastrophe risk, due to differences in assumptions and design of catastrophe models and minimal understanding of catastrophes, can lead to a large amount of uncertainty (King 2008). Many insurance agencies chose not to provide coverage in New Orleans as a result; a similar situation could occur in other places as more extreme events occur and flood plain maps are redrawn. The probability of non-coverage will be reduced with mutual adaptation and communication as well as increased understanding of the impacts of climate change.

## 4. Policymaking and Litigation Feedbacks

The insurance industry has a role in influencing public policy (Kunreuther 2013, Attali 2006; Kleindorfer and Kunreuther 1999). Government policies affect the industry directly by exempting parties from liability, subsidizing insurance deductibles or premiums, engaging in reinsurance, or providing coverage that competes with private sector insurance (Mills 2005). The role of government has decreased over the last 20 years as insurance coverage of natural disaster relief has increased from 20% to 40% in developed countries (Kunreuther and Michel-Kerjan 2007). While developed economies have a buffer from widespread loss, the ability of this buffer to protect nations from crippling loss effects is dwindling as the rate and severity of natural disasters increases (Kunreuther et al. 2013; Kunreuther and Michel-Kerjan 2007). As the need for more effective relief becomes apparent, many governments are using insurance to provide a reliable system for their citizens (Kunreuther et al. 2013; Kunreuther and Michel-Kerjan 2007; Tucker 1997). The insurance industry interacts with the public sector in providing protection against risks, although there is always disagreement over the allocations of costs (Mills 2005). The lack of cohesion in the response to Hurricane Katrina is one example of non-optimized risk allocation that resulted in $109 billion in post-disaster assistance and $8 billion in tax relief provided by the government (McCoppin 2014). For insurance and government to be more efficient

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and effective at disaster adaptation, mitigation, and relief, there must be more highly coordinated policy. Due to the immense costs from climate change, significant disagreements over the distribution of costs between the two sectors are not in the best interests of either party (Piketty 2014).

Litigation from insurance to government has been the result of ineffective policy or failure to reasonably foresee and adapt to the impacts of climate change. In 2013, The Farmers Insurance Co. sued the city of Chicago, Illinois for damages caused by storm water and sewage overflow because local municipalities knew that the drainage systems were inadequate but failed to take reasonable action to prevent damages (Sullivan 2014). The suit was eventually withdrawn, stating that the important issues were brought to the attention of the respective cities and counties and with the hope that policyholders' interests will be protected in the future (Sullivan 2014). As climate change impacts are further researched and understanding grows, more government entities and businesses may be held responsible via similar law suits for damages caused by climate change if proactive action is not taken to increase system resiliency (Sullivan 2014; Sustainable Brands 2017).

Coordination of efforts between government and insurers is crucial in developing a strong plan to provide affordable, adequate insurance coverage in the face of increasing risk from climate change (Glaas et al. 2016). Collaboration of building codes and standards, sharing of data, and better communication are all examples of action that can provide the knowledge and means necessary for policy-holders to adopt mitigation and adaptation measures and allow insurers to offer rewards or lower premiums for these measures. These actions can also provide direct feedback between the public, the government, and private insurers on how best to reduce risk and decrease costs for all stakeholders involved.

## 5. Conclusion

Increased losses from climatic catastrophes will challenge insurance systems to adapt and offer affordable coverage (Botzen 2013). Risk financing systems, including insurance, will need to be cautious of downside risks that can cause disincentives, market failures, and decrease equity (Botzen 2013). We must bear in mind that market-based insurance and its associated feedbacks are not a panacea, should not be expected to work well in all circumstances, and may even produce negative outcomes. Like all firms, insurance companies are vulnerable to agency problems and conflicts of interest such as those described by Jensen and Meckling (1976). While mechanisms exist within firms to mitigate such conflicts, they are imperfect and sometimes the social costs of a firm's actions outweigh the benefits. In addition, there are numerous contexts in which insurance markets simply fail to form despite the fact there are real human needs or problems to be addressed. The failure to form can arise from problems such as adverse selection (Rothschild and Stiglitz, 1976), moral hazard (Smith and Stutzer, 1995) or even a lack of perceived risks on the part of the public. In the absence of market-based insurance, the feedback mechanisms described in this paper will fail to develop. In these instances, alternative mechanisms must be established, which may include mutual aid or cooperative insurance arrangements (Smith and Stutzer, 1995), public-private partnerships or direct government intervention among many other new and/or novel solutions. In addition, the scale of insurance feedbacks affects their viability as a factor in adaptation and mitigation measures. Some risks need to be addressed on a scale larger than an individual and the feedbacks discussed will be less effective without external forces and other factors (USGCRP, 2018).

Through improved research, the interactions between the insurance industry and society can create more efficient and effective risk management strategies for public and private interests to address the challenges associated with climate change (Botzen 2013). Future avenues of research should include the complexity of these feedback loops and insurers' response to the discussed risk factors, including both climate and other risks. Specific interactions among these risks is not well understood and further empirical work on the dependencies of these risk factors is necessary. Another key challenge facing insurers is how to integrate climate change into their existing business models and including underwriting procedures that help to integrate these climate risks. Similarly, we do not look at specific methods for incentivizing risk reduction and empirical analysis of the efficacy of practices on risk reduction will help to provide a more detailed understanding of which elements of the feedback processes work best. Encouraging proactive cooperation between private insurers and government can increase the probability that mitigation techniques and adaptation can align incentives to protect assets. The insurance industry will continue to be a forceful

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and systemic mechanism to drive adaption and mitigation to climate change impacts in the absence of, and alongside, effective government policies, but further research is needed to clarify these relationships. Insurance can serve as a market-based approach to climate change that exists alongside policy-based approaches, a diversity that can shore-up the weaknesses of policy-based approaches and provide new and potent avenues for climate change adaptation and mitigation.

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## Competing Financial Interests

The authors declare no competing financial interests.

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