ISSUE BRIEF

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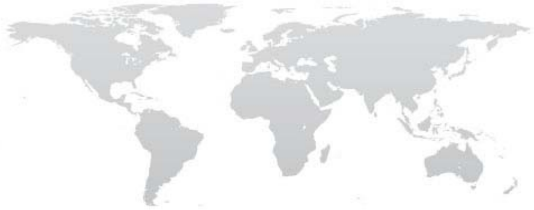

Climate Dependencies and Risk Management: Microcorrelations and Tail Dependence

Roger Cooke and Carolyn Kousky[1]

As defined by the Intergovernmental Panel on Climate Change, adaptation includes a set of actions to moderate harm or exploit beneficial opportunities in response to climate change. To date, little research has addressed public policy options to frame the nation's approach to adapt to a changing climate. In light of scientific evidence of extreme and unpredictable climate change, prudent policy requires consideration of what to do if markets and people fail to anticipate these changes, or are constrained in their ability to react. This issue brief is one in a series that results from the second phase of a domestic adaptation research project conducted by Resources for the Future. The briefs are primarily intended for use by decisionmakers in confronting the complex and difficult task of effectively adapting the United States to climate change impacts, but may also offer insight and value to scholars and the general public. This research was supported by a grant from the Smith-Richardson Foundation.

Summary

- Microcorrelations are tiny correlations between variables (for example, insurance policies, mortgages, and bonds) that are easily overlooked but can undermine traditional diversification strategies. Ignoring these could lead to undercapitalization and unintended risk taking.
- Tail dependence refers to the tendency of dependence between variables to concentrate in the tails of a distribution, or in the extreme values. More simply, it means bad things

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can happen together. Ignoring tail dependence can also lead to undercapitalization and unintended risk taking. Mitigation strategies should target tail dependencies.

- Further research should investigate shifts in patterns of microcorrelations and tail dependence induced by climate changes.

Unexpected Climate Correlations

Weather events in different parts of the world can sometimes be correlated. A good example comes from El Niño. In normal years, winds blow westward in the tropical latitudes across the Pacific Ocean, bringing warm water to the western edge of the Pacific. In an El Niño year, however, the winds weaken, and warm water spreads eastward. The warm water brings with it precipitation and suppresses the upwelling of nutrient-rich, cold water in the eastern Pacific. Thus, in an El Niño year, precipitation is likely to be more extreme in California, leading to mudslides and floods; nutrient-poor water is likely to cause fish-catch declines in Peru; and drier conditions are more likely in Australia, increasing the chance of bushfires. One might not initially think such diverse weather-related impacts are correlated, but El Niño induces this relationship.

As other examples of dependencies in the climate system, Atlantic tropical cyclone activity is strongly correlated with atmospheric dust from the Saharan Air Layer (Evan et al. 2006), as are the landfall of intense hurricanes in the United States and rainfall in the Western Sahel region of West Africa, possibly because both are driven by global oceanic thermohaline processes (Gray 1990). Some other dependencies are not as well understood, such as multiple events tending to occur together, sometimes referred to as “clustering” (Risk Management Solutions 2008). Active hurricane seasons in 1995 and 2004–2005 are good examples, as are the two severe windstorms that caused damage in Europe in 1999 (Riker 2004). These intricate dependencies should make us cautious of simple or ad-hoc consideration of climate-related risks.

Climate scientists use the word “teleconnections” to refer to the connection of weather events in different parts of the globe. These teleconnections can transform local impacts into global impacts. For instance, climate change–induced collapse of the thermohaline circulation in the Atlantic Ocean could affect the distribution and structure of ecosystems far from the northern Atlantic (Higgins and Vellinga 2004). Some research also suggests that climate change could potentially alter certain teleconnections; for example, climate change may be altering El Niño cycles (Timmermann et al. 1999).

Apart from correlations in the climate system itself, dependencies between socioeconomic variables, such as insurance policies, can arise when all the variables are correlated with a climate variable. This is discussed further below and suggests that even if the teleconnections are not being altered by climate change, the observed and predicted changes in precipitation, storm intensity, and sea-level rise could introduce dependencies about which insurers and other risk managers should be concerned. Here, we consider two specific types of dependencies: microcorrelations and tail dependence. We believe these two types of dependence deserve special attention because they are not very well understood or appreciated by risk managers.

Microcorrelations

Microcorrelations are very tiny, positive correlations between variables. With traditional statistical approaches, microcorrelations would often be imperceptible, but this does not mean they are nonexistent. We shall see that when variables are aggregated, these tiny correlations can undermine traditional diversification strategies of risk managers, such as insurance companies.

Microcorrelations could arise in various ways. First, if every variable is correlated with some sporadically occurring event, it could introduce microcorrelations between the variables themselves. For instance, El Niño occurs once in 2–7 years. If we simply look at yearly fish catches in Peru and yearly mudslides in California, we would only see a very tiny correlation, since in most years they are uncorrelated. However, if we conditionalize on El Niño events—that is, if we consider only El Niño years—the correlation will be much stronger.

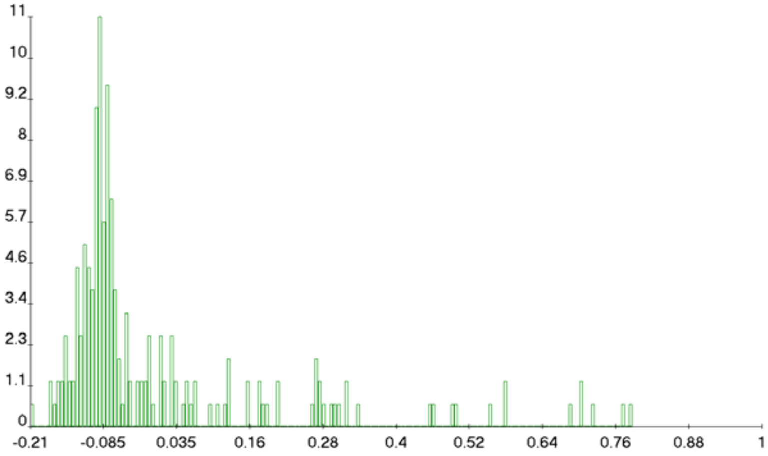
Second, continuously increasing variables, like sea-level rise or, potentially, hurricane intensity, could induce correlated changes in damage variables in locations that were previously uncorrelated. Finally, instead of a common, small, positive correlation among all the variables, each pair of variables may have a different correlation: small or large, positive or negative. A positive average correlation can have the same effect.

The problem with microcorrelations is that they balloon as the correlated variables are aggregated. Flood claims from the National Flood Insurance Program (NFIP) provide an example. Suppose we draw two random counties in the United States and look at the correlation in their yearly flood claims over the past 30 years. Figure 1 plots the histogram that results from computing the correlation for 500 random pairs of U.S. counties. A few have a high positive correlation, such as neighboring counties that are on the same river or share the same precipitation patterns. The average correlation is about 0.02. Most, however, are around zero, and some even have a negative correlation. Based on the most common statistical test, 91 percent of these correlations would be considered negligible.

The problem with microcorrelations arises in aggregation. Aggregation is a common tool for risk managers. Firms hold many insurance policies, banks hold many mortgages, and reinsurers write policies around the globe. If there was no correlation between the policies or assets, holding aggregations of them would provide diversification benefits and stabilize losses. This is because as independent risks are bundled, fluctuations around the mean become very small, relative to the mean.

If the average correlation between variables, such as flood claims, really was zero, when the variables were aggregated, the correlation between aggregations would remain zero. This is seen in Figure 2, which shows independent variables (zero correlation). The sample correlations between any two variables, based on 30 realizations of each variable, will fluctuate around zero; 500 such sample correlations are shown in green. The sample correlations between sums of 500 variables are shown in red. The histograms are effectively the same.

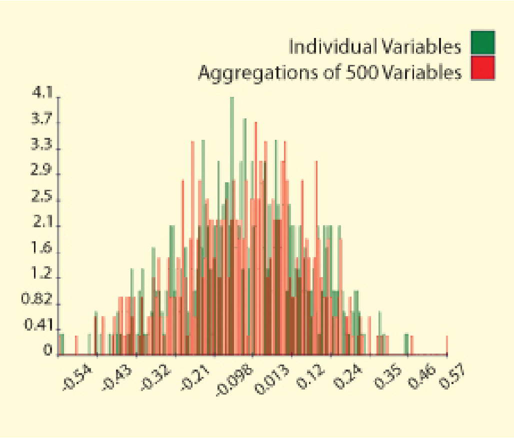
Figure 1. Correlations in Monthly Flood Claims between U.S. Counties



Note: The vertical axis is proportional to the number of pairs of counties having the correlation on the horizontal axis.

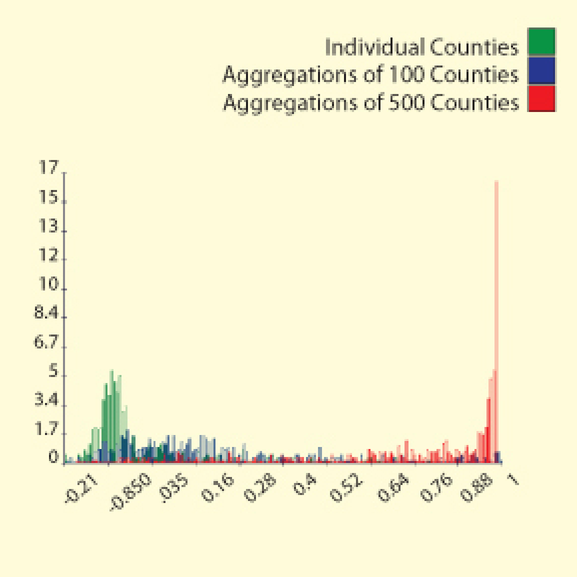
When variables with a tiny, positive average correlation are aggregated, the correlation between aggregations always balloons. Examine the flood claims. Instead of looking at the correlations between two randomly chosen counties, look at the correlation between sums of 100 randomly chosen counties. If we repeat this 500 times, the blue histogram in Figure 3 results; the average of 500 such correlations of 100 is 0.23. The red histogram depicts 500 correlations of 500; their average value is 0.71. This dramatic increase in correlation is a result of the microcorrelations between the individual variables. Aggregation amplifies microcorrelations.

Figure 2. Correlations between Individual, Independent, Uniform Variables and Sums of 500



Note: The vertical axis is proportional to the number of sums of counties having the correlation on the horizontal axis.

Figure 3. Correlations between Aggregations of Average Monthly Flood Claims by County



Note: The vertical axis is proportional to the number of pairs of counties having the correlation on the horizontal axis.

A numerical example of a hypothetical insurance company demonstrates the difficulty microcorrelations pose. Assume the insurance company is holding 10,000 policies, each with a 0.01 probability of a claim of $10,000. The firm wants to have a 99 percent probability of staying solvent. If the policies are independent, the firm can set its prices to ensure it has enough capital to cover losses that would occur with a 99 percent probability. Using standard models based on the normal distribution, this means charging about 1.23 times the expected loss per policy. Since this expected loss is $100, the charge would be $123. Now suppose a microcorrelation exists between policies equal to the average correlation in Figure 1 (0.02). The charge should then go up from $123 to $333. If the firm neglects this correlation, the probability of it not having enough capital to cover claims is not 1 percent but 41 percent! Neglecting microcorrelations causes unintended risk taking.

Insurers will need accurate information on what types of insurance lines, types of damage, and what areas of the world are likely to have such tiny correlations. To mange natural-disaster risk going forward, insurers and/or reinsurers may need specially targeted, global diversification. But before we can improve our management of climate-related dependencies through such actions, more information is needed. Insurance companies and other risk managers will need to investigate where microcorrelations exist that could be harmful to risk management.

Tail Dependence

Tail dependence describes the situation in which the dependence between two variables concentrates in the tails. Simply, with tail dependence, extreme events are more likely to happen together. This was observed in Hurricane Katrina, where insurance lines that are usually independent from each other all experienced severe losses, including cargo, inland marine and recreational watercraft, floating casinos, onshore energy, automobile, worker’s compensation, health, and life insurance (Risk Management Solutions 2005). Tail dependence can compound losses for an insurance company or society as a whole. Further, certain extreme events, when occurring together, can cause much more damage than the sum of damages from the two events occurring independently. For example, when extreme heat and humidity occur together, the effects on human health are much greater than if either occurs on its own.

Another, perhaps unexpected, example of tail dependence comes from considering the damage distributions associated with computer networks and some highly infectious diseases, which are predicted to spread as the climate warms. Events in the tail of the damage distribution associated with potential computer network problems include network failure and malicious attacks. Events in the extreme tail of the tropical-diseases damage distribution not only include rising infection and mortality rates, but also mass quarantines. These negative outcomes, however, are not independent. If people are quarantined at home, the number of people telecommuting will increase dramatically, stressing computer networks and leading to failures and vulnerabilities that could be exploited. That is, if society is in the tail of disease impacts, it is also more likely to be in the tail of computer-security damages.

These examples demonstrate that tail dependence among distributions related to climate change could arise in distinct ways. Two variables could be causally linked such that when one variable takes on an extreme value, it pushes the other variable to do so as well. Pandemics and network security provide an example. For policy, it is important to note that this type of dependence will often be unidirectional. That is, a disease pandemic increases the likelihood of network failure, but not vice versa. Tail dependence could also arise because a third variable that is normally dormant or latent pushes both variables into extremes when activated (Lescourret and Robert 2006). This is the case of the insurance lines during hurricane Katrina. If all lines experience losses when a certain magnitude event occurs, tail dependence will arise.

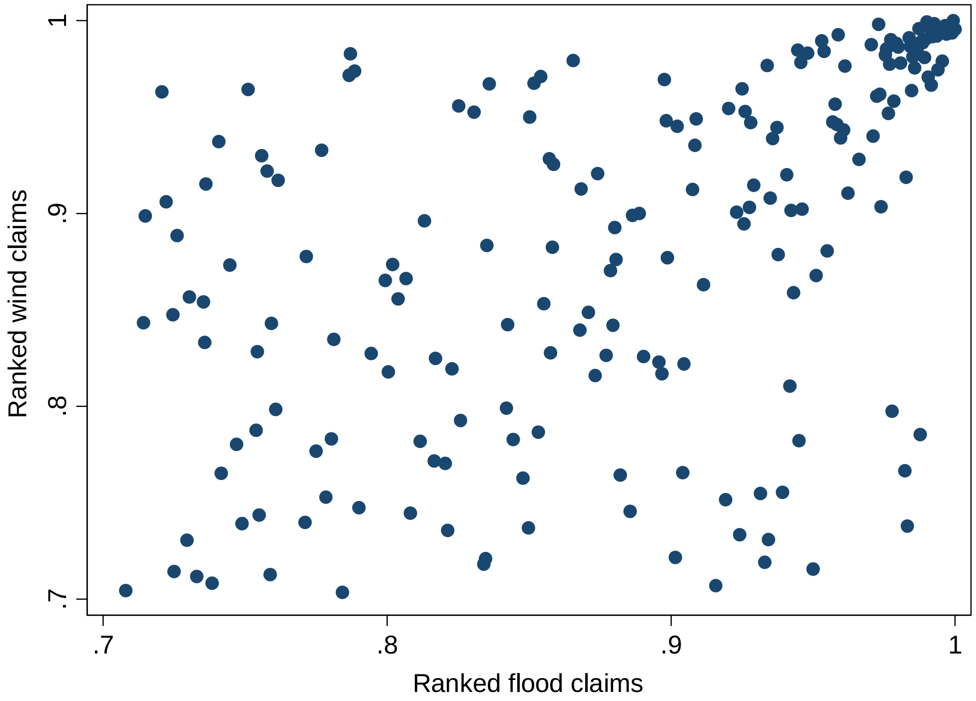
More than two variables can have tail dependence, as seen in the European heat wave in the summer of 2003. The temperatures for the summer were extremely far out in the tail of the temperature distribution (Schär et al. 2004), leading to extreme losses across multiple sectors. The heat wave led to uninsured crop losses of nearly $12.3 billion, extensive fires that burned 647,069 hectares across Europe, the shutdown of nuclear power plants in France from lack of river water for cooling, soaring electricity spot market prices, rockfalls from melting permafrost, decreased yields and lower quality harvests, excess deaths of between 22,000 and 35,000 people across Europe, and excess human mortality from higher ground-level ozone and particulate matter concentrations (De Bono et al. 2004; Schär and Jendritzky 2004; Stedman 2004). With more heat waves from climate change, events in the tail of the distributions related to mortality, crop yields, wildfires, and electricity pricing are more likely to occur together.

Tail dependence can be seen in loss data by ranking two variables and comparing them. We do this with flood claims in Florida from the federal NFIP and wind claims from the Florida state insurer Citizens Property Insurance Corporation. Claims by county and month for the years 2000–2006 in constant 2007 dollars were ranked and plotted against each other. Flood damage and wind damage are often independent; a rising river does not necessarily mean terrible winds, and a storm with high winds may not have enough rain to cause flood damage. A severe hurricane, however, causes both. This suggests that wind and water insurance payments may be tail dependent in a hurricane-prone state such as Florida. The abundance of points in the upper right quadrant of Figure 4 shows that this is indeed the case.

As seen in these insurance examples, with tail dependence, insurance companies could face very large losses during an extreme event. This means they will need access to more capital to cover these claims, leading to higher prices. One way to access capital for these types of events more affordably is to transfer the risk to the financial sector through catastrophe (cat) bonds. Cat bonds could be designed specifically to cover tail-dependent losses. For instance, in April 2007, Swiss Re structured a cat bond covering flood risk in the United Kingdom that is triggered if there is flooding in at least 4 of 50 reference locations (Mitchell and Schnarwiler 2008). If firms knew which regions, lines, or damage types were likely to be tail dependent, they could use bonds such as these to help ensure access to sufficient amounts of capital.

With more extreme events, more damage distributions will become coupled in their tails. We need a better understanding of where such dependence is likely to arise. Thinking through the response of individuals and all sectors of the economy to an extreme event can help us identify and understand tail dependencies. An example again comes from Hurricane Katrina. Models of potential losses assumed that the pumps in New Orleans would keep flooding in the city to a minimum. However, the extreme nature of Katrina led to an evacuation of people, including pump managers, as well as a power outage, reducing pumping capacity and leading to much more extensive flood damage in the city than was expected (Risk Management Solutions 2005). This suggests that policies aimed at adapting to the potential increases in extreme weather events from climate change should consider adding redundancies in protective systems and thinking through the impact of not only loss of personnel and power, but damage to all critical infrastructure, including communications.

Figure 4. Tail Dependence in Wind and Water Claims, Florida 2002–2006



For some types of tail dependence, measures can also be adopted to effectively decouple the tails. An example comes from the 1906 earthquake in San Francisco. This event showed the tail dependence between earthquakes and fires. The earthquake ruptured gas lines, starting fires, and also broke water lines, such that the fires could not be put out. The fire burned for 3 days and devoured 28,000 buildings (Steinberg 2004). Decoupling the tails of these two risks involves the design and installation of pipes that can withstand extreme earthquakes. Once tail dependencies are understood, communities can adopt these types of mitigation measures.

Concluding Thoughts

We have effective risk-management tools for risks that are independent. It should not take Hurricane Katrina or the financial meltdown to remind us, however, that many risks we care about are not independent. The risk-management community has long acknowledged that natural-disaster risks create spatial correlations among insurance policies, a problem many thought could be addressed by (re)insurance companies combining policies from diverse geographic regions. Other types of dependencies that have been largely neglected, however, can pose problems for this type of risk management.

Microcorrelations are correlations so tiny that they are easily neglected. Doing so, however, can lead to unintended risk taking and undercapitalization. Similar effects can occur when tail dependencies are neglected. More research is needed to identify the presence of these types of dependencies and ways to effectively manage them. Mitigation and novel approaches to risk sharing look promising, as discussed above. When solutions such as these are identified for addressing dependencies arising from changes in the climate system, communities should incorporate them into adaptation plans.

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