

## Temperature Shocks and Industry Earnings News

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Climate scientists project an increase in both the mean and volatility of global temperatures, suggesting that exposure to more severe extreme weather events is a virtual certainty. In particular, the Intergovernmental Panel on Climate Change (IPCC) forecasts that extreme weather events will become more frequent, have longer duration, and exhibit stronger intensity over time. In the United States, climate scientists project that the frequency of heat waves has already more than doubled and that some locations will experience fourfold increases by mid-century (Lau and Nath, 2012). Accordingly, the topic of climate change has attracted the attention of economists interested in assessing its potential effects. For example, extreme temperatures have been shown to affect agricultural productivity, labor supply, and aggregate industrial output (Fisher et al., 2012; Graff-Zivin and Neidell, 2014; Jones and Olken, 2010; Hsiang, 2010).

More recently, Addoum, Ng, and Ortiz-Bobea (2019) examine the impact of exposure to extreme temperatures at economic establishments in the United States. Using a large sample yielding precise estimates, they find no evidence that temperature exposures significantly affect establishment-level sales or productivity. These findings are consistent with those of Dell, Jones, and Olken (2012), who show that the negative effects of temperature on aggregate economic growth are concentrated among developing countries and are tenuous in richer economies.

Motivated by these observations, the aim of this paper is to examine heterogeneity in how extreme temperature events affect industry-level earnings and stock prices in the United States. Specifically, we estimate the industry-level profitability effects of time-variation in quarterly temperature exposures at firms' establishment locations. We also examine whether key market participants, sell-side analysts and investors, understand the relationship between extreme temperatures and corporate profitability.

We begin by building a detailed panel of U.S. firms' temperature exposures (i.e., time spent at different temperatures). We utilize a set of granular climate data that documents daily temperatures across 481,631 16-square-kilometer (i.e., 4x4km) grids covering the continental United States from 1981 to 2015. We obtain these data from the PRISM Climate Group, the U.S. Department of Agriculture's official climatological database. We then combine the PRISM climate data with detailed data on U.S. public firms' geographic footprints to generate measures of weather exposure over the course of firms' fiscal quarters. To capture firms' geographic footprints, we obtain establishment-level data from the NETS database. This database provides addresses for every U.S. establishment owned by each public firm over the period from 1990 to 2015.

We ask several questions regarding the role of extreme temperature events in financial markets. First, we ask how extreme temperature exposure affects firm profitability in the United States. Specifically, is the level of exposure to extreme temperatures a useful predictor of quarterly firm earnings? If so, are the predictive effects of extreme temperatures confined to agriculture-related firms, or do they extend across a wider set of industries?

We examine the effect of temperature extremes on the profitability of companies in 59 different industries and find that earnings exhibit sensitivity to extreme temperatures in over 40% (24 out of 59) of the industries. The effects of temperature extremes apply to a wide range of industries and we show that hot and cold temperature extremes affect industries in varying ways during different seasons.

## Democracy Underwater: Public Participation and Technical Expertise in Climate Adaptation Infrastructure Planning in New York City

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Large portions of coastal cities around the U.S. face the threat of being underwater. City governments in wealthy urban centers are experimenting with large scale flood infrastructure as a way of adapting in place. Scholars and policymakers alike have emphasized the importance of public participation in infrastructure plans, noting the desirability of including residents and other civil society actors to legitimize and bolster the procedural justice dimensions of government initiatives. Yet a challenge in the coming decades will be to understand the possible roles for residents, community groups, and the state in collectively preparing for our warmer, wetter future: How, and to what extent, should large-scale climate policy be guided by democratic principles, and to what extent should it be guided by technical experts with specialized knowledge such as climate scientists or engineers?

Through an in-depth case study of planning the largest coastal protection project in the U.S., “The BIG U,” I narrate the social production of resistance to climate change infrastructure by showing how the state sidestepped public input and exercised authority through appeals to the rationality and objectivity of technical expertise. After a lengthy participation process wherein participants reported satisfaction with how their input was included in designs, city officials switched decision-making styles and enrolled the expertise of engineers and climate scientists to render the publicly-supported plan unfeasible, while continuing to involve residents in the process. As a result, conflict arose between activists and public housing representatives, bitterly dividing the neighborhood over who could legitimately claim to represent the interests of the “frontline community.” By documenting the experience of participants in the process before and after the switch in decision-making styles, this article emphasizes the importance of public *influence* in policy to legitimize large-scale climate adaptation plans: The ability for participants in a planning process to recognize their own input reflected in finished plans.

## **Can Energy Policy Help Low-Income Families Cope with Hot Weather?**

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Low-income populations are more likely to live in areas of California that experience a greater number of extremely hot days. And, unfortunately, the frequency of extremely hot days is only likely to increase with projected climate changes. This hot weather can harm population health via cardiovascular stress among other health channels, but air conditioning has been shown to be an effective tool for mitigating such risks. Low-income households face a difficult tradeoff when considering whether to protect themselves from hot weather using air conditioning. On one hand, households could decide to cool their households with air conditioning (assuming they even have access to air conditioning). But, the ensuing high energy bills could financially derail some families. Households may delay paying their energy bills, incur late fees, and enter into delinquency, which could cause long-lasting harm. On the other hand, households could avoid using air conditioning, but this would expose them to more physiological stress and increase serious morbidity and mortality risks. The extent that public policy could be used to address this inequity, and encourage energy consumption during stressful weather events, is an open question.

This study will investigate both the extent of financial stress experienced by households related to hot weather events, and how energy subsidies might encourage households to self-protect during those events (e.g. via air conditioning). The policies of interest are: the California Alternate Rates for Energy (CARE) and the Family Electric Rate Assistance government programs (FERA). Both policies could help offset the financial stress of air conditioning by subsidizing some of the cost of the energy bills. No previous study has explored the effectiveness of energy subsidies at helping families cope with heat waves.

## **Anticipating Water Distribution Service Losses from Climate Change Impacts**

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With projected temperature increases and extreme events due to climate change for many regions of the world, characterizing the impacts of this new hazard to water distribution systems is necessary to identify and prioritize adaptation strategies for ensuring reliability. To aid decision-making, models should consider both the direct effect of temperature change to hardware (pumps and pipes fail more frequently with increasing temperatures), and estimate the magnitude and duration of resulting service losses. To this end, we present the model *Perses*, a program that joins the network hydraulic solver EPANET with hardware reliability models to estimate failures and resulting service outages into the long term. A proof-of-concept case study is developed using Phoenix, Arizona, a city with relatively hot temperatures and extremes. By 2099 under hotter futures characterized by General Circulation Models, there is projected to be 5-8% more pump failures, 13-50% more iron pipe failures, and 5-21% more PVC pipe failures (RCP 4.5-8.5) than a baseline recent historical temperature profile. Service outages, which constitute inadequate pressure for domestic and commercial use, are evaluated using a realistic network and are projected to increase by up to 3% above the baseline by 2099. The exceedance of baseline failures reveals potential challenges for budgeting, management, and maintenance. An exploration of the mitigation potential of adaptation strategies within the model, however, shows that improved preventative maintenance and repair times are capable of offsetting 100% of the additional failures from climate change, at an additional cost.

## **Moral Hazard, Wildfires, and the Economic Incidence of Natural Disasters**

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Worsening wildfires are among the most salient impacts of climate change in North America. This study measures the degree to which large public expenditures on wildfire protection subsidize development in harm's way. Using administrative firefighting data, we calculate geographically-differentiated implicit subsidies to homeowners throughout the western USA. We first examine how the presence of homes affects firefighting expenditures. These results are used to reconstruct the implied historical cost of protecting each home and to perform an actuarial calculation of expected future protection cost. The expected net present value of this subsidy can exceed 20% of a home's value. It increases with fire risk and decreases surprisingly steeply with development density. A simple model is used to explore effects on expansion of developed areas, density, and private risk-reducing investments. These results demonstrate how policy and institutions influence the costs imposed by a changing climate.

## **Socioeconomic Impacts of Flooding in the U.S.**

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Flood losses continue to rise dramatically around the world, with multi-billion-dollar events becoming common. Communities in coastal regions are expected to face more frequent and intense coastal hazards. As communities weigh options for adaptation there is a need for more comprehensive understanding of disaster impacts on communities. At present, disaster impact assessments tend to be limited to property and infrastructure damage. These evaluation methods often result in omission of broader socioeconomic costs of disasters. Additionally, most disaster aid and recovery programs are oriented towards property damage, which might not address the needs of those struggling with unaccounted for impacts.

This study focuses on community impacts of flooding by statistically assessing consumption changes. Using high resolution, consumer spending we analyze weekly changes during and after flood events. This provides a more detailed view of disaster impacts and recovery compared to economic studies of disasters that rely on annual information. We create a panel dataset of consumption at the week-county level for years 2006-2018. Disaster occurrence is indicated by FEMA and NOAA disaster events data, while Census information captures socioeconomic characteristics.

Changes in consumption are assessed using a difference-in-differences approach, which compares consumption in flooded counties to both consumption pre-disaster and in counties not inundated. In addition, fixed effects models evaluate the short- and long-term effects of flooding. We assess how flooding impacts consumption overall as well as spending on consumable and durable goods. A test case of Hurricane Ike finds significant increases in consumption. Sales of consumable goods increase by 11% on average, while durable goods increase by 24%.

These greater out-of-pocket expenses represent financial costs within affected communities and can place additional strain on household budgets. Future work will extend this analysis nationwide in order to understand the distribution of disaster impacts across socioeconomic groups. Improved understanding can provide opportunities for incorporating distributive justice issues in disaster risk management.

## The Mortality Cost of Carbon

**R. Daniel Bressler | Columbia University**

A large body of scholarly literature has projected that climate change is expected to cause a significant number of excess deaths over the 21<sup>st</sup> century. However, no studies have yet quantified the number of excess deaths caused by marginal emissions. This is crucial because the effect of marginal emissions today is more important for informing both policy and individual decision-making than the total effect resulting from the emissions of all global economic activity in aggregate across time. This study determines the effect of marginal emissions on excess deaths by creating a coupled climate-economy-demographics integrated assessment model called DICE-EMR that includes a climate-mortality response function estimated from an interdisciplinary systematic research synthesis of 100 studies. The impact of marginal emissions on excess deaths is captured in a new metric introduced in this paper -- the mortality cost of carbon (MCC) -- that avoids many of the pitfalls that plague discussion of the social cost of carbon (SCC) because it measures the marginal mortality impact of climate change in units of excess deaths without discounting or valuing lives. We find that due to widespread estimates of a nonlinear relationship between temperatures and mortality, marginal 2020 emissions have a surprisingly large mortality impact over the 21<sup>st</sup> century: in a baseline emissions scenario, the 2020 MCC is  $2.35 \times 10^{-4}$  excess deaths per metric ton of 2020 emissions. This implies that on the current margin, the lifetime emissions of 3.3 average Americans cause one excess death globally between 2020-2100. In addition, DICE-EMR updates the climate policy prescribed by Nobel Prize-winning economist William Nordhaus by extending his influential DICE model to include the effect of climate change on human mortality, which has largely been left out of previous integrated assessment models including DICE. Before incorporating mortality costs, the 2020 SCC in DICE is \$37 per metric ton in the baseline emissions scenario and optimal climate policy involves an emissions plateau and then gradual reductions starting in 2050. After incorporating mortality costs in DICE-EMR, the 2020 SCC increases over seven-fold to \$265 per metric ton in the baseline emissions scenario and optimal climate policy involves large immediate emissions reductions and full decarbonization by 2050.

## A Social Cost of Carbon for Global Energy Consumption

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The global marginal damage caused by emitting a single ton of carbon dioxide (CO<sub>2</sub>), or its equivalent, is key to climate policy, but our current understanding of its value is based on spatially-coarse theoretical-numerical models that are not tightly linked to data. We develop the first architecture that integrates best-available data, econometrics, and climate science to estimate climate damages worldwide at the local level, as well as aggregated global marginal damages. Here we apply this architecture to construct the first global empirical estimates of the impact of climate change on total non-transport end-use energy consumption, one of the most uncertain impacts in current models. At end-of-century, we project annual global electricity consumption to rise roughly 4 EJ (1100 TWh, 6% of current global consumption) for each 1°C increase in global mean temperature, reflecting increased cooling demand, while direct consumption of other fuels declines 10.1 EJ (6% of current global consumption) per 1°C, reflecting reduced heating. Together, these estimates indicate that emission of 1 ton of CO<sub>2</sub> today produces global net savings in future aggregate energy consumption of about \$1 in net present value (3% discount rate). This finding is largely driven by a sharply nonlinear relationship between income and temperature-induced energy consumption, which indicates that for most of the 21<sup>st</sup> century, much of the world is expected to remain too poor to increase energy consumption in response to warmer temperatures. By end-of-century, emerging economies in the tropics (e.g. India) are projected to increase electricity consumption dramatically, but these rising costs are offset by heating reductions in the wealthy economies of North America and Europe.<sup>1</sup>

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<sup>1</sup> This project is an output of the Climate Impact Lab consortium.



## Are Infrastructure Under-designed for Climate Change?

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Every day, engineers, planners, and stakeholders, make choices for infrastructure that must directly consider weather and environmental variables. As evidence accumulates on the effects of climate change on current infrastructure, stakeholders are being forced to reconcile how to continue to keep their systems reliable over multi-decadal service lives in the face of growing climatic uncertainty. The crux of the challenge lies in the implicit acceptance of climate certainty in the infrastructure design process. Put simply, design of infrastructure and what it is able to withstand (heat, precipitation, water flows, cold, wind, fire, etc.) is largely based on historical environmental conditions. However, much of our infrastructure was designed at times (mid-20<sup>th</sup> century) when limited and highly uncertain data existed about local environmental conditions. As such, some infrastructure assets were under-designed while others were over-designed. Combine this dynamic with largely ad-hoc reconstruction over decades that likely targeted problem areas, and the uncertainty inherent in future timing and magnitude of climate change impacts, then several regimes emerge that describe the potential vulnerabilities in infrastructure. Given the limited resources available to upgrade infrastructure, a critical reconciling of infrastructure performance from past design goals to future climate uncertainty is necessary for strategically investing for resilience. Strategic investment in climate adaptation must acknowledge that climate uncertainty and non-stationarity are inimical to current infrastructure design processes which largely codify the use of past conditions as predictors of the future. Emerging design approaches that embrace Deep Uncertainty, Robust Decision Making, and Safe-to-Fail thinking, and deeper collaboration between the climate science and engineering communities will be needed to reimagine the infrastructure design process and manage the potential consequences of failure.

## **Rx for Hot Cities: Climate Resilience Through Urban Greening and Cooling in Los Angeles**

**Edith de Guzman | TreePeople and University of California, Los Angeles**

Extreme heat and its health impacts are on the rise. Globally, the five warmest years on record all occurred since 2015, and in Los Angeles average temperatures are expected to rise 3 to 7°F in coming decades. Annually, extreme heat already causes more deaths in the United States than all other weather-related causes combined, with heat-health risks being most pronounced in urban areas due to the heat-island effect. Reducing urban heat exposure is an equity issue, as low-income communities and communities of color are more likely to live in neighborhoods with older buildings, low tree cover, more heat-retaining surfaces, and limited access to coping mechanisms such as air conditioning. In Los Angeles, mortality increases fivefold from the first to the fifth consecutive day of a heat wave; after the fifth day, mortality risk increases 46% in Latino communities and 48% in elderly black communities.

The Los Angeles Urban Cooling Collaborative (LAUCC) is a multi-disciplinary, national partnership of researchers and expert practitioners working with communities and government toward the goal of understanding and implementing urban cooling strategies in Los Angeles. LAUCC recently completed a two-year modeling study of current and projected heat in Los Angeles County that:

1. Identifies geographic areas with the highest vulnerability to heat-related death;
2. Quantifies at the county level and more granularly how various tree cover + albedo scenarios (or “prescriptions”) would impact heat-related mortality, temperature, humidity, and oppressive air masses that lead to elevated mortality;
3. Quantifies the number of years that climate change-induced warming could be delayed as a result of implementing these prescriptions.

Using synoptic climatology, we use meteorological data for four historical summer heat waves and classify each day into discrete air mass types. We analyze those data against historical mortality data from California's Office of Statewide Health Planning and Development to determine excess, heat-related mortality. We then use the Weather Research and Forecasting model to explore the effects that tree cover + albedo prescriptions would have, correlating the resultant meteorological data with standardized mortality data algorithms to quantify potential reductions in mortality.

We find that 1 in 4 lives currently lost during heat waves could be saved, most in low-income communities and communities of color. We also find that climate change-induced warming could be delayed approximately 25 to 60 years under RCP business-as-usual and moderate mitigation scenarios, respectively.<sup>1</sup>

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## **Climate Adaptation and Innovation: Evidence from the Double-Cropping Boom in Brazil**

**Gilherme DePaula | Iowa State University**

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Firms can adapt to climate change by altering production inputs and adopting new technologies. Although understanding the climate change–innovation link is central to assessing global warming damage, empirical evidence of how innovation affects climate change adaptation is scarce. In this paper, we identify the returns and speed of climate change adaptation by modeling a unique climate change event, the change in the soy growing season climate caused by the Soybean Asian Rust (SAR) in Brazil, and the resulting innovation process, the design and adoption of soy-corn double-cropping systems using early-maturing seed varieties.

Starting in 2007, the soy growing season in the savanna was delayed and shortened to control the development of the fungi *Phakopsora pachyrhizi* that causes SAR, a severe soybean disease that can spread by wind over large distances. SAR was first observed in Brazil in 2001 and spread rapidly, affecting 60% and 90% of soybean plantations in the 2001/2002 and 2002/2003 seasons, respectively.

The incidence of SAR in Brazil changed the growing season in two ways. First, the Brazilian government created a soybean-free period to stop the development of the fungi during the off-season, changing the start of the season. Second, farmers started harvesting earlier to reduce their losses as the SAR fungi develops, strengthens, and spreads throughout the season. The change in the soy growing season induced a race for the experimentation, development, and diffusion of early-maturing soy varieties and double-cropping.

Our empirical strategy departs from the literature by using an exogenous temporal variation in climate in a panel fixed-effects model. The exogenous source of climate variation is the incidence of SAR in Brazilian soy plantations. We model the innovation process to capture the effect of climate change on productivity, double-cropping diffusion, and revenues using a unique panel dataset that combines acreage, yield, and prices for three crops: soy, first-crop corn, and second-crop corn.

We make three main findings. First, climate change accelerated the diffusion of double cropping, increasing the annual double-cropping diffusion rate by 13%, which explains 70% of the expansion in double cropping in the period. Second, we find a small but positive climate change effect on combined soy–corn revenues, suggesting that adaptation compensated for the expected damage from changing the growing season climate by raising yields for the second crop. Climate change increased the annual growth rate in the relative productivity of second-crop and first-crop corn by 5%. Finally, the climate change effects on diffusion and productivity were significantly higher in soils with higher water retention capability, leading to different climate change impacts across Brazil. Hence, constraints to innovation may compound climate change impacts.

The most important policy lesson from the double-cropping boom in Brazil is the interlinkage of development, technology, agricultural, and environmental policies. The innovation and diffusion processes underlying double-cropping systems have resulted from a series of technology policy decisions, such as integrating public and private research organizations early in the process, regulating seed patenting, and opening agricultural and technology markets to private investment.

## **The Effect of Media Coverage on Financial Aid in the Aftermath of a Disaster**

**Tatyana Deryugina | University of Illinois**

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Communities affected by natural disasters often get financial aid from both the government and private donors. If such aid is largely determined by need, then charitable donations and government disaster aid could become an increasingly important form of social insurance as extreme events become more frequent due to climate change. Media attention to a natural disaster has been anecdotally identified as an important non-need-based determinant of aid, but rigorous empirical evidence on this question is lacking. Using rich databases of news media coverage, of the universe of donations to the American Red Cross, and of US federal disaster aid, we estimate the effect of the news media on aid given in the aftermath of floods and tornadoes. We show that the occurrence of other newsworthy stories—as measured by the content share devoted to the top ten percent of non-disaster news stories in a given week—reduce the amount of charitable donations to the American Red Cross in the aftermath of a tornado or flood but have no effect on federal disaster aid. We then show that the occurrence of other newsworthy stories reduces media coverage of the floods and tornadoes themselves, suggesting that media coverage is an important determinant of charitable giving but not of federal disaster aid.

## **Preparing for Rising Seas: How the State Can Help Support Local Coastal Adaptation Efforts in California**

**Rachel Ehlers | The California Legislative Analyst's Office**

California's coastline could experience as much as seven feet of sea-level rise by 2100, which could have extensive and expensive impacts on the state's residents, economy, and natural resources. Most responsibility for preparing for and responding to these threats lies with local coastal communities. Several strategies for moderating the impacts of sea-level rise exist, however waiting too long to initiate such efforts likely will make responding effectively more difficult and costly. Despite the significant threats and compelling reasons to take action soon, most coastal communities still are only in the early stages of preparing for sea-level rise.

This report provides recommendations designed for policymakers in the California Legislature on how to help support and expedite progress in preparing for rising seas at the local level. Our findings and recommendations were informed by interviews with over 100 individuals. These interviewees represented local governments from across the state, academic researchers, community groups, nongovernmental organizations, federal agencies, and state departments. We also reviewed relevant reports and academic literature, including several statewide surveys.

We found that local governments' progress in adapting to the impacts of sea-level rise is constrained by a number of key challenges. These include funding and capacity constraints, a lack of key information, limited public awareness about the topic, and few forums for shared planning and decision-making across jurisdictions. We find that the state can play an important role in increasing the pace and scale of sea-level rise preparation efforts across California.

To this end, our report includes several recommendations for how the State Legislature can help alleviate some of the key barriers to coastal adaptation that local governments are experiencing. Our recommendations fall into four categories: (1) fostering regional-scale adaptation efforts; (2) supporting local planning and adaptation projects; (3) providing information, assistance, and support; and (4) enhancing public awareness about the potential risks and impacts of sea-level rise. Specific recommendations include making state contributions to support planning efforts and project implementation at both a local and regional scale, as well as establishing a statewide network for providing technical assistance and information on effective climate change adaptation practices.

## Why and How Do Cities Plan for Extreme Heat?

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Cities – home to nearly 63% of Americans and 76% of those in the western United States – are emerging as central actors in climate adaptation planning (Cohen 2015; Woodruff and Stults 2016). There is some evidence about why and how U.S. cities engage in climate adaptation efforts generally. Municipalities actively planning for climate adaptation have higher municipal expenditures per capita, greater exposure to local climate impacts, and more committed local officials (Shi, Chu, and Debats 2015). Cities plan for adaptation in both specialized plans and comprehensive plans, with those taking a narrower focus on specific risks proving more effective (Lyles, Berke, and Overstreet 2018). We know little, however, about why and how cities plan specifically for extreme heat.

Moreover, while scholars and practitioners have presented adaptation strategies for extreme heat, there is limited evidence about how cities are applying these strategies. These practices include lighter colored “cool” roofing and paving materials, urban greening, tree planting and other shade provision, building envelope design, cooling centers, early warning systems, and heat response plans (Burgess and Foster 2019; Stone et al. 2019; Stults and Woodruff 2017).

In this paper, we answer two questions about adaptation planning for extreme heat in California. What characteristics influence whether California municipalities adopt policies and plans for heat? What policies do California municipalities most commonly adopt to mitigate high heat days and heat waves?

The first part of the paper employs regression analysis of the factors associated with municipal adaptation of urban heat island policies and climate adaptation. We specify three sets of logistic regression models. Our binary outcome variables – from the state’s 2018 Annual Planning Survey – are (1) whether the city has adopted climate adaptation plans and strategies, (2) whether the city addresses climate adaptation in its General Plan, and (3) whether the city has adopted urban heat island policies. Our independent variable of interest is projected extreme heat days at the city level. We also control for local government, community, and intergovernmental characteristics that may influence city heat planning.

For climate adaptation generally, several factors are correlated with policy adoption. Political factors – leadership support and the share of registered Democratic voters – are associated with adaptation plans and strategies. Adaptation plans are less likely in cities with higher shares of Hispanic residents. Leadership support is the only variable that is significantly associated with climate adaptation in the General Plan. For urban heat island policies, future projections of extreme heat are associated with adopted policies. Additional correlates include the same political factors as above. Again, however, the share of Hispanic residents is negatively associated with urban heat island policies.

The second part of our paper employs content analysis methods to analyze adopted plans. We develop an inventory of mitigation strategies based on the literature and professional publications. We assess the presence of 14 characteristics in four types of plans for the six California cities with populations of at least 500,000. We review these cities’ general plans, climate action plans, climate adaptation plans, and local hazard mitigation plans to assess the degree to which cities have adopted the mitigation strategies in the inventory.

California’s largest cities are addressing urban heat in a variety of ways. First and fundamentally, nearly all plans identify extreme heat as an issue, although most do not include data about the extent of the problem or future projections. The most common strategy, urban tree canopy, was addressed by every city and the second most common, urban greening, was addressed by nearly all cities. Many plans also include recommendations for roofing and paving materials intended to reduce urban heat. Cities commonly engage in other risk management-focused responses to extreme heat, including operating cooling centers and education and outreach programs, but while these are generally mentioned in local hazard mitigation plans, they are seldom mentioned in general plan documents.

## Can Social Protection Reduce Environmental Damages?

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The costs of environmental degradation depend critically on how damage functions will evolve with increases in income. Causal investigation of this question has been challenging since the research design would require not only a large enough geographic area to estimate marginal effects from environmental damages but also meaningfully large exogenous variation in income/wealth that is unrelated to environmental factors and varies over the same large geographic area. Using a discontinuity in a location-specific eligibility criterion for a nation-wide cash transfer program, we demonstrate that cash transfers attenuate one-half to two-thirds of the effects of higher same-day temperatures on homicides. Our results not only suggest that social protection programs can help the poor adapt to rising temperatures, but also demonstrate causally that income can explain much of the heterogeneity in the marginal effects of higher temperatures with important implications for environmental justice.

## **Resilience from Below: Community Visions of Just Urban Climate Futures in Post- Hurricane Sandy New York City**

**Kian Goh | University of California, Los Angeles**

Urban resilience is often understood as the ability of cities to adapt to the environmental and socioeconomic impacts of climate change. But the concept is contested. On the one hand, resilience is celebrated as a positive characteristic of people and places to “bounce back” from shocks and stresses, exemplified by the book *The Resilience Dividend* by former Rockefeller Foundation president Judith Rodin (2014). This version of resilience has infused urban and development policies, evident in the Obama White House-promoted National Disaster Resilience Competition in 2014 and programs on resilience by USAID and the World Bank. On the other hand, researchers have critiqued the vagueness of the term (Vale 2015; Cutter 2016), and challenged the ways in which resilience is used to promote and protect status quo socioeconomic systems (Davoudi et al. 2017; MacKinnon and Derickson 2012).

How might urban researchers and policymakers conceive of a just and progressive notion of resilience? Can that notion of resilience be developed and practiced from within the marginalized communities that are most threatened by climate impacts? This paper challenges both dominant, mainstream views of resilience as well as overly reductive critical views that dismiss its potential to offer progressive lessons for advocates, researchers, and policymakers. It details the experiences and points of view of community organizers who face and surmount social and environmental challenges, in their own words, to develop a concept of urban resilience that centers marginalized urban communities in a framework of transformative political change. It poses the possibility of urban resilience from the ground up.

The paper investigates resiliency efforts in two neighborhoods in New York City after Hurricane Sandy in 2012, both considered exemplary cases of community-based recovery after the storm. The first is Red Hook, Brooklyn, and the work of the Red Hook Initiative (RHI), a community center serving residents of the Red Hook Houses public housing project. The second is the Lower East Side in Manhattan, and the work of Good Old Lower East Side (GOLES), a community organizing and housing justice organization, also involved with public housing residents. This mixed-methods research relies substantively on multiple, in-depth interviews with two key informants, Jill Eisenhard, founder and executive director of RHI, and Damaris Reyes, executive director of GOLES, as well as participant observation of the organizations and photographic and cartographic analyses of the physical spaces of the neighborhoods.

This research finds that practices of transformative community-based resilience are place-based – that is, bound to specific physical spaces in the city – and dependent on shared histories of socioeconomic struggle, and institutional bases of collective knowledge building (such as the development of organizing movements among residents in public housing). These findings reinforce the importance for researchers and policymakers not only to look to community participation and local knowledge – often cited in more just climate responses – but also to pay attention to the intertwined relationships between physical, spatial conditions in cities and the institutional contexts through which residents make sense of their past and future social and environmental challenges.



## Natural Disasters, Poverty and Inequality: New Metrics for Fairer Policies

**Stephane Hallegatte | The World Bank**

Worldwide, natural disasters pose a growing threat to economic and political stability. According to Munich Re, economic losses to natural disasters averaged US\$187 billion per year from 2009-2018, a 30 percent increase over the inflation-adjusted 30-year average. But in a world of massive inequalities within and across countries, the increase in aggregate economic losses cannot inform us on the real impact of these disasters.

In the conventional practice of disaster risk management, the severity of disasters is measured by their direct damages, or the replacement cost of assets damaged or destroyed by a shock. Other dimensions--such as the impact on health, education or quality of life--are not usually incorporated into disaster loss estimates or in cost-benefit analysis of possible risk reduction interventions. One implication of the use of economic or asset losses as a measure of disaster impacts is that Disaster Risk Management (DRM) strategies tend to favor the wealthy, central business districts, and other clusters of valuable assets. Interventions targeting poor people, who have few assets to start with, cannot generate large gains in terms of avoided asset losses and are therefore discouraged by this metric. And while this prioritization makes sense from a pure monetary perspective, it dis-incentivizes attractive investments in the poorest areas, even when small interventions could significantly reduce the stunting of children (Dercon and Porter 2014), disease transmission (Yonson 2018; Erman et al. 2019), absenteeism from work and school, lost wages, and many other types of disaster impacts on well-being.

Disasters have complex and diverse consequences that can be measured (and, increasingly, anticipated) in terms of recovery times, economic (income and consumption) losses, poverty incidence, or welfare or well-being losses, among other metrics. Each of these metrics provides a different perspective on disaster costs. In contrast to direct damages, many of these impacts of natural disasters accrue disproportionately to poor households. This is because income shocks can force the poor to make difficult decisions between food, housing, education and healthcare, and reconstruction. As a result of these tradeoffs, poor households take longer to recover from disasters, and are more likely to face long-term consequences.

This paper reviews the evidence for the impacts of disasters on poverty, accounting for both human and economic costs, which are well documented in case studies. Then, it flips the perspective, and consider the ways in which poverty exacerbates the effects of natural disasters. Finally, it introduces the concepts of well-being losses and socioeconomic resilience and quantified metrics to measure them. It then uses these concepts to explain how these metrics can lead to risk management strategies that are more efficient and fairer.

## **Rising Groundwater as a Significant Constraint on Adaptation to Sea Level Rise**

**Kristina Hill | University of California, Berkeley**

Sea level rise predictions indicate that coastal flooding will increase. The State of California has provided guidance to public agencies that recommends sea level scenarios and probabilities. But this guidance omits consideration of rising coastal groundwater that will result from higher relative sea levels. Previous research has shown that rising groundwater will create flooding, health and water quality impacts well beyond the areas that experience saltwater flooding.

In the absence of previous maps, we created an interpolated surface of depth to shallow, unconfined groundwater for the San Francisco Bay Area as an assessment tool for risks related to rising groundwater levels. We found that approximately 58 square miles of land around the Bay is vulnerable to potential impacts from rising groundwater, as a result of relatively flat topography. In bowl-shaped topographic zones, groundwater can be expected to rise at the same rate as sea level. As it rises, groundwater can infiltrate cracked pipes and reduces their capacity, increase liquefaction risks during seismic events, put new pressures on buried foundations and existing drainage pumps, and remobilize legacy soil pollution before it eventually emerges at the surface as flooding.

In order to access vulnerabilities across multiple systems and issues, we used a case study approach to identify the impacts of groundwater on adaptation scenarios for Marin City, a low-income community with a significant proportion of people of color in Marin County. We reviewed the configuration of drainage pipes and projected new groundwater levels with sea level rise. Our results indicate that the risk of flooding and health impacts in Marin City are seriously underestimated in the key sea level rise vulnerability maps that have been developed and used by public agencies. Using an adaptation pathways method to review adaptation scenarios, we also identified several key risks of negative path dependencies in the current proposals for new pump stations and levees. The results of this case study and the methods we used are broadly relevant to all low-lying communities within a mile of the coast.

## **Labor Supply in a Warmer World: The Impact of Climate Change on the Global Workforce**

**Solomon Hsiang | University of California, Berkeley**

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Numerous laboratory, factory, and military studies indicate that worker behavior and performance are affected by temperature (Hancock et al., 2007; Somanathan et al., 2018), but it is not understood whether these results are generalizable or if they portend an economically important effect of climate change when workers may adapt to gradual shifts in their local conditions. In this paper, we answer these questions by exploiting millions of daily, individual worker records from time use and labor force surveys in eight countries, spanning many economic contexts and climates and representing more than half of the global population. The worker records are matched with high-resolution climate data to determine a) whether temperature affects labor supply (Graff Zivin and Neidell, 2014) and b) the extent to which adaptations might mitigate these effects. We then use these empirical findings to develop the first internally consistent, micro-founded, global estimates for how future climate change will affect global labor supply, accounting for and demonstrating the importance of workforce composition. Interpreting the labor supply impacts of climate change through a simple theoretical framework, we monetize the implied disutility to workers of a warmer climate, a welfare cost not captured by existing productivity estimates (Dell et al., 2012; Burke et al., 2015; Hsiang et al., 2017). This allows us to construct an empirically-derived global labor disutility damage function by indexing worker disutility costs against global mean surface temperature (GMST) for every climate realization (Hsiang et al., 2017). Finally, we employ a simple climate model to simulate how the release of an additional ton of CO<sub>2</sub> affects GMST (Millar et al., 2017), and apply the damage function to calculate the global welfare cost to workers from now until 2300 resulting from the emission of one additional ton today (i.e. social cost of carbon from labor disutility).

## **Waterfront Laws and the Adaptability of Urban Shorelines: A Boston Case Study**

**Courtney Humphries | University of Massachusetts Boston**

Adapting cities to climate change will require transformations in the built environment, but these transformations will be influenced by existing legal and regulatory structures that have limited and shaped the physical evolution of cities. In the past, many coastal cities in the United States altered their shorelines in order to create new land. However, this practice declined by the late 20th century due to the implementation of environmental laws and other waterfront regulations designed to preserve the integrity of coastal waters. Addressing the threats of 21<sup>st</sup> century sea level rise and increasing flood risks in dense urban coastal areas, however, may prompt renewed interest in filling areas of the shoreline to create new land—both horizontally extending the shoreline as well as raising its height—as a cost-effective way to protect existing neighborhoods and municipal infrastructure. Through a qualitative case study of Boston, Massachusetts, this research applies a law and policy analysis and to examine these issues. It first considers the historical evolution of the shoreline through the system of laws and policies that evolved over time to regulate land-making, such as the public trust doctrine and state and federal environmental laws. Using published documents and interviews with waterfront stakeholders (including nonprofit advocates, developers, designers, engineers, legal and permitting consultants, and regulators), it then explores how the current regulatory regime governing the waterfront impacts the ‘adaptability’ of the shoreline in terms of potential climate adaptation solutions involving fill as part of protective coastal infrastructure. It next considers where and how climate adaptation aligns or conflicts with existing laws and policies, focusing on solutions that have recently been designed or implemented along the Boston waterfront, or proposed by government agencies, professional experts, and academic groups. The findings contribute to a growing body of research on the historical evolution of laws and regulations governing the built environment that shape the ability of urban areas to adapt to changing environmental conditions.

## **Bank Lending Networks and the Propagation of Natural Disasters**

**Ivan Ivanov | Federal Reserve Bank**

In this paper, we study the propagation of natural disasters by large banks in the syndicated loan market, which is the main source of funding for mid-sized and large companies. Even though large banks have deposit-taking and lending activities that are geographically diversified, they still propagate local natural disasters to unaffected regions. They do so by increasing funding to corporations located in regions affected by natural disasters, while reducing credit to corporations located in unaffected regions. Shadow banks attenuate but do not fully offset such reduction in credit supply. As a result, total credit to borrowers in unaffected regions still falls by approximately three percentage points.

Our first set of tests confirms that natural disasters lead to an increase in the demand for credit in affected regions. We show that natural disaster shocks translate to approximately 2 percentage points increase in total syndicated commitments to the average borrower in affected regions. These effects are substantially larger when we focus on more severe natural disasters, in which case average borrower commitments increases by approximately 5-7 percentage points.

Our investigation into how banks meet the increase in credit demand shows that banks reduce credit in unaffected regions concurrently with increasing lending in the region affected by natural disasters. Consistent with this result being supply-driven, we find evidence of a larger network effect among banks with lower tier 1 capital-to-assets ratio. We also find that banks manage these network effects and reduce credit in those unaffected regions that are relatively less important for their corporate lending business.

Finally, we find that shadow banks attenuate but do not fully offset the reduction in credit supply associated with the network shocks in unaffected regions. Specifically, we show that non-bank investors increase their investment in syndicated loans following network shocks, thereby leading to increase in the syndicate concentration of non-bank investors by more than one percentage point. This offset is only partial and, as a result, total credit commitments of borrowers facing bank network shocks still fall by approximately three percentage points.

In robustness tests, we consider additional channels through which banks may respond to natural disasters. To the extent that banks are able to raise sufficient deposits to accommodate the increase in credit demand following a natural disaster, we should not expect to see a reduction in bank credit supply to unaffected regions. We find that banks raise additional deposits only in the regions affected by natural disasters, and only by 40 cents for each dollar of damages. Importantly, banks do not appear to raise additional deposits or increase deposit rates in unaffected regions in response to natural disasters elsewhere.

Our findings also highlight a novel spillover effect of natural disasters, one that is likely to grow in importance given the rise in frequency and magnitude of the natural disasters with the climate change.

## **Approaching Adaptation Systematically in Southern California with Flexible Adaptation Pathways: Opportunities and Barriers**

**Robert Kay | ICF**

**Maggie Messerschmidt | ICF (Respondent)**

*Additional authors: Judsen Bruzgul, Maya Bruguera, Tommy Hendrickson, Maggie Messerschmidt, Joanne Potter, Beth Rodehorst, and Cole Wheeler*

Flexible Adaptation Pathways is a rapidly emerging approach in California to the design and implementation of climate change adaptation strategies. The approach provides an opportunity to address key problems in supporting adaptation implementation programs, namely:

- How to address short-term resilience imperatives and long-term adaptation challenges simultaneously; and
- How public and private-sector decision makers seeking cost-effective, equitable adaptive outcomes so that their communities or shareholders feel confident that the decisions they make today are the right ones to make, and will stand the test of time.

Currently the dominant paradigm for supporting adaptation decision making is “predict-and-plan,” that is trying to predict the future to the best of our ability and then plan a single course of action to adapt to those predicted changes. Underpinning the predict-and-plan approach is a reductive premise that reducing future uncertainty will correlate to a reduction in decision-making uncertainty.

In contrast, Flexible Adaptation Pathways embrace uncertainty. The approach involves identifying different adaptation measures that, when sequenced together over time, form pathways. Pathways-based adaptation planning recognizes that the climate will change in often uncertain and unpredictable ways. In addition, as the climate changes so do other factors that influence transparent and effective decision-making, including societal needs, technology innovations, and policy and regulatory environments. Signposts, triggers and “sell-by dates” are integral to the development of adaptation pathways and are used to monitor a measure’s effectiveness and the need to change paths from one adaptation measure to another.

Flexible Adaptation Pathways are gaining traction in California. In 2018 the report of the State’s Climate Safe Infrastructure working group was entitled *Paying It Forward: The Path Toward Climate-Safe Infrastructure in California*. In addition, Executive Order B-30-15 guides State agencies “where possible” that “flexible and adaptive approaches should be taken to prepare for uncertain climate impacts.” CalOES’s current effort to update the Adaptation Planning Guide for local governments highlights flexible adaptation pathways as an emerging tool for adaptation planning.

However, there are considerable challenges to implementing pathways-based adaptation planning including:

- The approach is new in the State and reflects a departure from current planning approaches. Institutional buy-in and implementation of the approach requires additional time to account for its novelty.
- The approach embraces the notion that the future is inherently uncertain, which can be confronting to decision-makers and stakeholders alike. Without proper explanation, the approach is open to criticism that tough adaptation decisions are “being kicked down the road” into the future.
- Pathways relies on signposts, triggers and pathway sell-by dates to monitor when to change paths. What and how to monitor can range from changes in regional climates through to internal organizational parameters, such as the number of service interruptions due to extreme heat.
- Currently, there is no regional governance framework that helps standardize signposts of change.
- The approach is unproven in California for shaping policy around a variety of climate hazards, given its application to date has primarily been for adaptation to sea-level rise impacts.

The presentation will explore the challenges and opportunities of using pathways-based adaptation planning in Southern California using examples drawn both from the literature and our practical experience. Importantly, the presentation will stress the need for discussion between climate adaptation scientists and policy academics, practitioners and decision-makers to realize the potential of Flexible Adaptation Pathways.

## The Design of Resilience and Adaptation Indicators

**Jesse M. Keenan | Tulane University**

As resilience and adaptation considerations become mainstreamed into public policy, there is an overarching desire among practitioners to measure and quantify metrics and indicators that seek to evaluate the efficiency, effectiveness and justness associated with outcomes derived from such processes. While much research has sought to develop specific indicators that may serve as proxies for these considerations, less research has focused on those normative aspects of indicator design that support a variety of goals associated with the accuracy, reproducibility, proxy value and multi-stakeholder translation, among various other goals and values. This presentation sets forth a range of potential considerations that may be useful for those who seek to design and develop novel resilience and adaptation indicators (“RAIs”). These considerations are explored through a range of hypothetical examples that may be applicable to coastal communities. In light of the practical necessity to qualitatively and quantitatively customize indicators for particular places, communities, and public policies, this presentation seeks to address the practical challenges facing the design, execution, management and modification of RAIs. The methods supporting this analysis are combination of literature review, semi-structured interviews with state and federal government officials and a series of focus groups among relevant producers and consumers of indicators.<sup>1</sup>

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## **Planning for Extreme Heat: A Review**

**Ladd Keith | University of Arizona**

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Climate change and the urban heat island (UHI) effect are increasing the risk of extreme heat in cities across the world. Extreme heat impacts public health, economies, urban infrastructure, and urban ecology, all areas within the concern of the urban planning profession. To better understand the current state of scholarship and practice in urban planning for extreme heat, we conducted a systematic literature review of peer-reviewed papers. We found that the majority of the current literature focuses on UHI mapping and modeling, while less studies explore extreme heat planning and governance processes. An in-depth review of this literature reveals common institutional, policy, and informational barriers and strategies for overcoming them. We identify challenges for planning for extreme heat including siloed heat governance and research that limit cross-governmental and interdisciplinary collaboration; complex, context-specific, and diverse heat resilience strategies; the need to combine extreme heat “risk management” strategies (focused on preparing and responding to extreme heat events) and “design of the built environment” strategies (spatial planning and design interventions that intentionally reduce urban temperatures); and the need for extensive, multidisciplinary data and tools that are often not readily available. These challenges point to several areas of need for future extreme heat planning research. We argue that urban planners have an important role to play in increasing heat resilience and identify areas where scholars and practitioners can work together to advance our understanding of extreme heat planning.



## **Relocation Outcomes for Participants in U.S. Property Buyouts: A Nationwide Analysis**

**Carolien M. Kraan | University of Miami**

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As the climate continues to change, retreat as an adaptation option will become increasingly important and inevitable in some locations. Buyouts of flood-prone properties funded by the U.S. Federal Emergency Management Agency (FEMA) are among the longest-running and largest examples of managed retreat globally. In such buyouts, the property owner voluntarily sells their property to the government, and the land is restored to open space. While over 40,000 buyouts have occurred in 49 different states, little is known about how buyouts affect the overall wellbeing of participating households. Questions that to date remain unanswered include: Where do buyout participants move to, and how does the post-relocation neighborhood compare to where homeowners lived before the buyout? Here, we present an analysis of the relocation destinations for participating homeowners. This analysis combines address-level data for 34,000 buyout properties with a nationwide real-estate dataset of property deed transactions. It is the largest assessment of buyout outcomes for participating homeowners to date. We examine the nature of the move for participating homeowners. In particular, we determine the distance of the move and the ways in which the relocation changes the flood risk and neighborhood-level social vulnerability for participating homeowners. We establish social vulnerability of neighborhoods using American Community Survey Census data for income, racial diversity, and population density, among other metrics. Initial results suggest that most buyout participants stay within the same county or neighboring counties, that the majority of the homeowners relocate out of the floodplain, and that newly-purchased properties are, on average, of similar value to the bought-out properties. Importantly, when the resident of a buyout is not a property owner who can be tracked in the real-estate dataset, the relocation address cannot be determined. This is the case for at least 4,500 buyouts of manufactured homes (i.e., mobile homes) and rentals, which may involve households at greater risk of adverse outcomes associated with relocation and displacement. This analysis represents a first crosscutting analysis of how buyouts affect the participating households. In addition, our results identify common relocation destinations, enabling further investigation of how those receiving communities are affected. Assessment of the full experience of retreat for all affected communities is critical for improving buyout processes and programs, including at potentially greater scales into the future.

## **What to Expect When It Gets Hotter: The Impacts of Prenatal Exposure to Extreme Temperature on Maternal Health**

**Ajin Lee | Michigan State University**

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We use temperature variation within narrowly-defined geographic and demographic cells to show that exposure to extreme temperature increases the risk of maternal hospitalization during pregnancy. This effect is driven by emergency hospitalizations for various pregnancy complications, suggesting that it represents a deterioration in underlying maternal health rather than a change in women's ability to access health care. The effect is larger for Black women than women of other races, suggesting that the projected increases in extreme temperatures over the next century may further exacerbate racial disparities in maternal health.

## **Adapting to Extreme Heat in California: A Review of State-level Policies, Funding Opportunities, and High Priority Gaps**

**Lolly Lim | University of California, Los Angeles**

*Additional authors: J.R. DeShazo, University of California, Los Angeles*

The State of California's governance capacity for adapting to extreme heat impacts is currently relatively limited and in need of considerable policy development.

The motivating questions of this study are: What is the degree to which State-level heat adaptation efforts are underway for selected key settings of importance (e.g., residential, workplace, schools) when considering heat vulnerable populations? What State resources and funding opportunities are currently available to local entities (e.g., households, schools, local governments) to make adaptive changes? What are gaps that could be filled by the State to facilitate adaptation and build resilience to the impacts of heat, particularly in the context of protecting vulnerable populations and communities?

We seek to answer these questions through a review of existing State regulations, funding resources, and known adaptation efforts. Preliminary findings from this ongoing study will be shared.

## **Beating the Heat: Temperature and Spatial Reallocation over the Short and Long-run**

**Christos Makridis | Arizona State University/Massachusetts Institute of Technology**

*Additional author: Tyler Ransom | University of Oklahoma*

Does temperature affect real economic activity? Using the annual Current Population Survey between 1963 and 2015, we show that there is no association between temperature and earnings, hours, or output after controlling for time-invariant spatial heterogeneity and time-varying demographic factors. These results are robust to five separate sources of micro-data, different sampling horizons, functional forms, spatial measures of temperature, and subsets of the data. Motivated by these null results, we develop a spatial equilibrium model where temperature can affect not only firm productivity, but also individual locational choice. After calibrating the model, we use it to disentangle the role of reallocation versus actual productivity losses in the U.S. economy between 1980 and 2015. Nearly all of the variation is driven by reallocation. We subsequently use the model to evaluate a counterfactual climate scenario and recover a new spatial equilibrium for the U.S. economy by 2050.

## Re-Imagining Infrastructure Design Storm Criteria for the Challenges of the 21<sup>st</sup> Century

**Samuel A. Markolf | Arizona State University**

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Design storm criteria (i.e., the specific intensity and/or frequency to which infrastructure systems are designed to withstand) are a critical part of resilience efforts within urban and infrastructure systems. However, factors like climate change and increasing complexity within our urban systems call into question the viability of current approaches to and implementation of design storm criteria moving forward. Using a combination of literature review/synthesis and conceptual framing, this work outlines challenges to existing infrastructure design storm criteria and considers design practices and strategies that appear well-suited for the increasingly complex and rapidly changing contexts in which our cities and infrastructure operate. More specifically, a review of historical documents and reports is conducted in order to trace the history and evolution of stormwater infrastructure design storm criteria in the United States. Next, a review of academic literature and governmental policies and standards was used to evaluate and compare design storm criteria across different hazards (precipitation, temperature, and wind) and infrastructure systems (water, power, and transportation). Finally, we outline the major challenges currently facing design storm standards, and posit new and/or complementary approaches for addressing these challenges and moving toward more resilience-based design standards.

The comparison of design criteria across different hazards revealed that standards related to precipitation tend to adopt a 'Return Period' approach (i.e., designed to withstand hazards with a specific probability of occurrence), while standards related to temperature and wind tend to adopt a 'Threshold' approach (i.e., designed to withstand hazards of a specific magnitude – regardless of probability of occurrence). The return period approach appears to be more incongruent with recent and expected changes in climate. However, moving forward, both approaches likely warrant continual monitoring and updating in order to maintain the expected/required level of performance and reliability. Additionally, none of the explored infrastructure sectors appear to have design storm criteria for all three hazards (precipitation, temperature, and wind). Therefore, development of integrated, multi-hazard design criteria merits additional consideration and exploration. Finally, our analysis revealed that the major challenges currently facing design storm standards include climate non-stationarity, increasing complexity within and among urban/infrastructure systems, and the prospect of concurrent hazards and/or propagating failures as a result of interconnectedness between and across different systems.

Overall, we posit that the advancement of a multi-scalar perspective on resilience will be increasingly necessary in response to the growing challenges our cities and infrastructure face. At the scale of single components/sub-systems, return periods and/or thresholds (or similar criteria) will likely remain a necessary element of the design process. At the scale of the entire system(s), approaches like safe-to-fail, robust decision making, and enhanced sensing/simulation appear well suited for complementing existing approaches by more explicitly considering failure consequences in the design and management processes. Ultimately, this work seeks to spur continual research and advancement of these topics in order to facilitate the evolution of the design storm process for an increasingly complex and non-stationary world.

## **A Decision-Support Tool to Reduce Negative Public Health Outcomes from Wildfire Smoke Exposure in Equatorial Asia**

**Miriam E. Marlier | University of California, Los Angeles**

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The increasing severity and frequency of wildfires in many locations around the world has drawn renewed focus on the consequences of fires for natural ecosystems, climate, and public health. In Indonesia, a hotspot of global fire activity, fire emissions associated with land management practices release particulate matter that contributes to severe regional air pollution and associated negative public health outcomes. In this study, we map the interconnections between land use management, fires, and public health in Indonesia, along with implications for health outcomes in the coming decades.

Fires in Indonesia are tied to regional climate variability, the clearing of natural ecosystems for agricultural activities, and the location of fuel-rich peatlands that contribute disproportionately to emissions. We integrate satellite-based information on the location and timing of fire activity with atmospheric transport modeling to assess population-level exposure to particulate matter concentrations across Indonesia, Singapore, and Malaysia. Our analysis finds that unless comprehensive land conservation policies are enacted, exposure to particulate matter associated with Indonesian fires will lead to an average of 36,000 excess deaths per year across the region for the foreseeable future. However, our analysis shows that these deaths can largely be prevented by enacting various conservation efforts. For example, enacting comprehensive peatland restoration activities that prevent fires from occurring in these areas would prevent approximately 24,000 excess deaths per year.

As part of this study, we translated our interdisciplinary scientific framework into a publicly available decision-support tool through the Google Earth Engine platform. The SMOKE Policy Tool allows stakeholders to rapidly evaluate the public health benefits of various land management strategies. We have engaged with regional stakeholders, including the Indonesian Peatland Restoration Agency, to prioritize land management strategies that maximize benefits for public health.

## Housing Adaptation: Behaviors and Resources in Post-Katrina Greater New Orleans

**Carlos Martín | Urban Institute**

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A home's quality and value, its capacity as defensive and healthful shelter, and its connection to neighbors are conditions that define a household's exposure to climate-related hazards. Of all places, post-Katrina Gulf communities know how housing can nurture shared wellbeing or exacerbate inequality. Housing equity complicates adaptation; gaps in housing access and segregation are common stressors in the face of expected climate shocks. For vulnerable families, then, a house is not just a home: it is resilience made durable.

Despite the truism, we know little about how households of different kinds reduce vulnerability, and whether the access and quality of tools and services is equitable. With support from the National Academies of Sciences' Gulf Research Program, the Urban Institute has explored how housing behaviors and resources shape climate adaptation on five fronts:

- 1) hazard and property insurance availability, access, and costs;
- 2) hazard information and property risk disclosures;
- 3) resources for and use of property mitigation techniques;
- 4) awareness of actual and projected site-based risks to climate, including perceptions of risk reductions from regional infrastructure upgrades; and
- 5) household participation in adaptation-related planning that protects residences.

The overall work relies on numerous data sources, including: FEMA flood maps, Census demographic data, property assessment and purchase data, focus groups, and in-person interviews. However, this paper presents the preliminary findings from a massive, multimodal survey effort fielded over two years of a representative sample of homebuyers who purchased in the post-Katrina era (after 2008 to the present) in the seven-parish area of Greater New Orleans area because of the region's potential as a harbinger for future climate adaptation behavior.

The survey instrument includes questions relevant to all five studies but focuses on the homeowner's property selection process, the sources and types of information disclosed to the buyer about past damages and risks of exposure to climate-related and other environmental hazards, detailed insurance policy coverage and costs, take-up of formal property mitigation programs and self-funded mitigation actions, and personal experiences with climate-related events and risk perceptions of future ones. Descriptive frequencies from the final survey responses to be completed in March 2020 will be shared, including cross-tabulations by geography, flood risk, and select demographic characteristics.

The work expands the empirical evidence base to support the focus on housing as a critical dimension of climate adaptation and individual wellbeing, while providing tools for residents to consider their current housing contexts and future climate risks.

## Planning for Resilience to Extreme Heat in U.S. Cities

**Sara Meerow | Arizona State University**

Additional author: *Ladd Keith | University of Arizona*

Extreme heat is already the deadliest climate risk in the United States and negatively impacting communities around the world. The combination of climate change and the urban heat island effect is increasing the number of dangerously hot days in cities and the need for them to mitigate and plan for resilience to extreme heat. Given this increased focus and urgency, a better understanding of the current state of heat planning is needed. Most of the literature focuses on heat island mapping and modeling, while few studies delve into extreme heat planning and governance processes. We therefore surveyed planning professionals to examine how heat risk perceptions, current planning activities, and barriers to action vary across the country. The same survey was conducted on two different samples: 1) a stratified random sample of planners working for U.S. cities from different regions and of different population sizes (n=69); and 2) a convenience sample of planners who are members of relevant professional networks (n=98). The survey was co-produced with input from planners, designers, and climate service providers to establish important baseline information for a growing area of planning practice and scholarship. Survey results reveal that planners across the U.S. were generally quite concerned with extreme heat risks, particularly environmental and public health impacts of heat due to climate change. The majority of communities were impacted in some way by extreme heat, most commonly energy and water use, vegetation and wildlife, public health, and quality of life. Most planners claimed to be using information on heat risks, addressing heat in plans, and implementing strategies such as urban forestry and emergency response coordination. Communities that reported more heat impacts implemented significantly more strategies, as did larger cities. Planners nevertheless perceived many barriers to advancing heat resilience, with the most significant being those related to human and financial resources and political will.



## **Heterogeneity in the Recovery of Local Real Estate Markets After Extreme Events: The Case of Hurricane Sandy**

**Rachel Meltzer | The New School**

Additional authors: Ingrid Gould Ellen | New York University, Xiaodi Li | New York University

This paper examines the effect of Hurricane Sandy on local real estate markets in New York City. A natural disaster, like Sandy, generates two important shocks that can affect real estate markets: it creates physical blight and it provides new information about the risk of future damage. Unlike previous research, we consider how the information provided by the storm differs inside and outside of official flood zones and the role of localized economic conditions in mitigating storm-induced blight. We rely on a combination of several longitudinal, micro-datasets on property sales transactions, property and neighborhood characteristics, and mortgage application activity in New York City. We overlay these data with spatial information on flood zones, to capture the perceived risk prior to Hurricane Sandy, as well as spatially detailed data on storm surge heights to capture the storm's actual impact. We then compare prices and buyer characteristics across areas inside and outside of the flood zones, and across blocks of varying storm surge intensities.

Results indicate that the price of 1-3 family homes that were hit by high storm surges drop by about 16 percent and remain 12 percent lower than pre-storm levels six years after the storm. We show that these long-term effects are concentrated in areas outside of existing flood zones and in low-income neighborhoods. Properties in higher income neighborhoods experience large initial price shocks but then mostly recover, while those in lower income areas appear to experience a delayed response and exhibit no sign of recovery. Finally, the storm led to a change in the composition of homebuyers in storm surge areas that were low-income and outside the flood zone. After the storm, homebuyers in those areas were more likely to be black and Hispanic, suggesting that the flooding and damage may have shifted the nature of neighborhood change that was underway prior to the storm. Preliminary analyses of rebuilding activity suggest that any price decline is due more to new information about risk than persistent blight.

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## Social Cohesion and Climate Risk Resilience in East Boston

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For communities at risk of catastrophic events to be resilient, they have to *anticipate* such events during “Blue Sky” periods and *adapt* during “Dark Sky” phases. Whether the hazards are natural, technological, or man-made, and whether they materialize with or without warning, the stresses and disruptions to both engineered and social systems are often complex and cascading. Climate-related risks are particularly challenging: they blur the distinction between Blue Skies and Dark Skies, as evolving threats are not easily observed, and they force community leaders, planners, and residents to consider threats that are both cumulative (such as sea-level rise) and explosive (such as cyclonic activity and severe flooding events).

East Boston is a community at singularly high risk for such climate-related events. It is a peninsular community of 40,000 residents sitting as a breakwater between the Atlantic Ocean and the mainland and is composed of five islands connected by landfill. East Boston serves as a major transportation hub for the Northeast with Logan International Airport and three tunnels connecting Boston to Massachusetts’s northern shore, and it has been a destination port for immigrants for over a century. In terms of overall cost of damage, Boston is ranked as the eighth most vulnerable city in the world and fifth in the United States when it comes to climate-related flooding, according to a World Bank Study.<sup>1</sup> Among all the city’s neighborhoods, East Boston has the most exposed land area and is most susceptible to extreme flooding and sea level rise.

This study will describe a two-year partnership between researchers at New York University’s School of Global Public Health and the Neighborhood of Affordable Housing (NOAH). For over thirty years, NOAH, as a community development corporation focused on housing development and economic revitalization, has worked to bolster the financial capacity and community connectedness of many of the neighborhood’s residents, even as it has simultaneously concentrated on developing local leaders and strengthening organizational ties both within East Boston and across the greater city and region. As one of the major community organizations in the area and a key “boundary-spanner,” NOAH has bridged the gap among elected leaders, city and state agencies, community organizations, neighborhood associations and community groups through its multiple and diverse array of programs, projects, and services, including environmental youth initiatives.

We will present data from our neighborhood survey (n=271) that estimates residents’ readiness for climate risks; their interest, ability, willingness, and barriers to engage in readiness and preparedness measures; and, their sense of social cohesion, collective efficacy, and sense of community. We will then describe how we have started to use these findings to inform a practical climate resilient community model (East Boston Resilience Network) that aims to foster systems thinking among community and organizational leaders, and increase the neighborhood’s capacity to deliver solutions around climate risk.

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<sup>1</sup> Duc, T.V. (2013, August 11). Which Coastal Cities Are at Highest Risk of Damaging Floods? New Study Crunches the Numbers. Retrieved July 20, 2018, from The World Bank Website: <http://www.worldbank.org/en/news/feature/2013/08/19/coastal-cities-at-highest-risk-floods>

## Heat Exposure in the Southwest: Exploring Mitigation Strategies from a Pedestrian Perspective

Ariane Middel | Arizona State University

Heat is the leading climatic stressor in Southwestern U.S. cities and a major threat to public health. Various strategies to mitigate urban heat have been proposed in the scientific literature and have been embedded in policy documents for climate adaptation and resilience, often with the goal to reduce air or surface temperature to meet a defined target. However, in hot, dry environments, outdoor human thermal exposure is primarily driven by mean radiant temperature (MRT), a synthetic parameter that integrates the longwave and shortwave radiation a body receives into a temperature value. This presentation explores the impact of two heat mitigation strategies – active shade management and cool pavement -- on pedestrian thermal exposure in the Southwest using the biometeorological instrument platform *MaRTy*.

The first study expands the “right tree in the right place” guiding principle of Tempe, Arizona’s Urban Forestry Plan to “right shade in the right place” by testing the efficacy of natural and engineered shade in various urban contexts and functions of space. Over a three-year period (2016, 2018, and 2019), *MaRTy* conducted hourly transects in Tempe on hot summer days sampling sun-exposed reference locations and 50 shade types classified by urban form (e.g., awnings, overhangs), engineered shade (e.g., shade sails, umbrellas), tree species, and ground surface cover. The shade efficacy was investigated using four thermal metrics: the difference between a shade type and sun-exposed reference location in MRT, incoming solar radiation, surface temperature, and air temperature. During the day, engineered shade from urban structures was most effective, followed by trees and lightweight artificial structures such as umbrellas and shade sails. Structural shade performed differently with changing orientation and produced characteristic diurnal shade performance curves (u-shaped vs. v-shaped). Trees varied widely in performance. Native trees (palo verde, mesquite) and palm trees were least effective, while pine and eucalyptus trees were most effective in reducing MRT. Findings will inform the City of Tempe’s active shade management practices and policies.

The second study investigates the thermal performance of solar reflective coating on asphalt concrete roads in two Los Angeles communities. *MaRTy* performed hourly transects in Pacoima and Sun Valley residential neighborhoods on July 30, 2019, a typical summer day with low wind speeds and maximum air temperature of 31°C. The surface temperature of the coated asphalt concrete was up to 6°C lower than that of the regular asphalt concrete, but coated surfaces reflected 118 Wm<sup>2</sup> more shortwave radiation on average and up to 168 Wm<sup>2</sup> more at noon. In the evening, *MaRTy* observed 20 to 30 Wm<sup>2</sup> of added reflected shortwave radiation on sidewalks next to the reflective pavement. MRT over reflective pavement was 4°C higher during midday. Although air temperature was reduced by 0.5°C in the afternoon, after-sunset cooling was negligible. Findings illustrate the benefits and disadvantages of reflective pavement with respect to various thermal performance metrics. Cities should weigh the tradeoffs of UHI mitigation, thermal exposure, implementation and maintenance costs, lifecycle, and other competing priorities in the context of space use.

## **Adaptation Infrastructure and its Effects in Property Values in the Face of Climate Impacts**

**Renato Molina | University of Miami**

*Additional author: David L. Kelly | University of Miami*

We evaluate the effect of climate adaptation infrastructure investments on property transaction prices, using data on over four hundred thousand property transactions and nearly two hundred adaptation infrastructure projects in the Miami-Dade County, an area that is highly vulnerable to sea level rise due to climate change. Using a difference-in-differences estimator, we find significant gains in property values after completion of infrastructure projects. These gains are concentrated in areas 0-200 meters from the boundary of the project polygon. We then calculate the return on investment for the adaptation infrastructure projects. Summing over a large number of properties protected by each project results in an aggregate benefit net of adaptation cost of about \$20 million per project, and about \$3 billion in aggregate net benefits for all projects. Most projects generated positive net benefits, indicating that the vast majority of adaptation efforts are being placed in areas of need that pass the benefit-cost test.

## **Noah's Ark on Rising Seas: Climate Change, Biodiversity, and Public Adaptation Costs in the United States**

**Frances C. Moore | University of California, Davis**

*Additional authors: Arianna Stokes | University of California Davis, Marc Conte | Fordham University, Xiaoli Dong | University of California Davis*

Climate change poses a growing threat to biodiversity over the 21st century, but the welfare consequences of this are not well constrained. Here we analyze the determinants of listing and spending decisions under the US Endangered Species Act (ESA), revisiting previous analyses by Metrick and Weitzman (1996, 1998) with a much longer and larger dataset spanning 21 years and over 1600 species. We show that scientific assessments of endangerment are strongly associated with the probability of listing, but also find bias towards vertebrate species for both listing and spending. Using these revealed conservation priorities, we estimate the effect of climate change on listing and spending under the ESA, a form of public adaptation. We find unmitigated warming (5°C above pre-industrial) would result in the listing of an additional 620 species and committed spending of \$19 billion. Several thousand more species, mostly plants and invertebrates, would be critically imperiled by climate change but remain unlisted, a form of residual climate damages. Finally, we provide a comparison with estimates of willingness to pay (WTP) for conservation of 35 listed species and find that aggregate WTP is almost always 1-2 orders of magnitude larger than direct ESA spending on those species.

## **Managed Retreat May Be Unmanageable with Current Practices**

**Robert Moore | Natural Resources Defense Council**

Millions of Americans are increasingly vulnerable to flooding, sea level rise, and other climate-driven hazards. Managed retreat, which is the moving of people and property out of harm's way, is an oft-discussed strategy for how governments and individuals could adapt to such hazards. One of the most common tools for managed retreat in the US to date are the publicly financed purchase of hazard-prone private properties, more commonly known as buyouts.

Over the past 30 years, more than 43,000 properties have been removed and demolished through buyouts financed through FEMA, and thousands more have been financed through local and state governments and other federal agencies, such as the Department of Housing and Urban Development, the U.S. Army Corps of Engineers, and the Natural Resources Conservation Service.

Of the agencies listed above, FEMA is (and will continue to be) one of the primary sources of buyout funding, but its programs are already struggling to provide buyouts in a timely fashion in the aftermath of today's flood disasters.

At the agency's current pace and capacity, FEMA's current programs would support about 130,000 more buyouts over the next 90 years; a drop in the bucket compared to the millions of Americans who could see their homes inundated by sea level rise and increased inland flooding in the coming decades.

NRDC has looked closely at the various federal policies that govern buyouts and post-disaster recovery efforts and changes that could make assistance more readily available. This research has identified the time it takes for a typical buyout project to be applied for, approved, and completed; what some of the hurdles are for conducting buyouts in an efficient and more effective manner; and proposals for alternative ways of delivering equitable assistance for buyouts in the future.

## **Once Bitten, Twice Shy: Direct and Indirect Effects of Previous Weather Shocks on Input Use in Agriculture**

**Kelvin Mulungu | Colorado State University**

Extreme weather events have detrimental effects on smallholder farmers' incomes. This study looks at farmers' risky decisions after a drought. Existing evidence suggests that a loss can either increase or decrease risk aversion. In this study, we estimate the effect of previous shocks input use. Specifically, we determine whether farmers are more likely to use a high-risk, high-return input (fertilizer) or a low-risk, low-return input (improved seed) after experiencing a drought. Panel data collected from more than 6000 smallholder households in 2012 and 2015 in Zambia were combined with objectively measured rainfall data. We use fixed effects structural equation modeling to disentangle direct and indirect effects (through income). Results show that farmers who experience droughts are more risk averse. As a result, they are less likely to use fertilizer and more likely to use improved seeds the following season compared to those who did not experience droughts. The indirect effect accounts for about 7% of the total effect and the remainder of the effect is attributed to changes in risk-aversion. These results suggest that weather shocks affect the timing and type of technology adopted in the agricultural sector. This has important implications for climate change adaptation and food security in the developing world.

## **The Food Problem and the Aggregate Productivity Consequences of Climate Change**

**Ishan Nath | University of Chicago**

This paper integrates local temperature treatment effects and a quantitative macroeconomic model to evaluate the impact of climate change on sectoral reallocation and aggregate productivity. First, I use firm-level data from a wide range of countries to estimate the effect of temperature on productivity in manufacturing and services. Estimates suggest that extreme heat reduces non-agricultural productivity, but less so than in agriculture, implying that hot countries could adapt to climate change by importing food and shifting labor toward manufacturing. Second, I embed my estimates in an open-economy model of structural transformation covering 158 countries to investigate this possibility. Simulations suggest that subsistence food requirements drive agricultural specialization more than comparative advantage, however, such that climate change perversely pulls labor into agriculture where its productivity suffers most and reallocation exacerbates the global decline in GDP. The productivity effects of climate change reduce welfare by 1.5-2.7% overall and 6-10% for the poorest quartile. Trade reduces the welfare costs of climate change by only 7.4% under existing policy, but by 31% overall and 68% for the global poor in a counterfactual scenario that assigns all countries the 90th percentile level of trade openness.



## **Labor Market Frictions and Adaptation to Climate Change**

**R. Jisung Park | University of California, Los Angeles**

*Additional authors: Nora M.C. Pankratz | University of California, Los Angeles, A. Patrick Behrer | Harvard University*

In this paper, we examine the potential for adaptation in labor market settings by exploring the relationship between heat and workplace safety, and assessing the role of adaptation investments in mitigating this relationship. Using administrative data on 11 million US workers compensation claims combined with high-frequency weather variation over the period 2000-2018, we find that hotter temperature increases workplace injury risk substantially. Consistent with a model in which adaptation is technically feasible but costly, we find evidence for elevated accident risk in both indoor (manufacturing, warehousing) and outdoor (construction, agriculture) industries, and for types of injuries that are ostensibly unrelated to direct heat exposure (e.g. falling from heights, mishandling heavy equipment). We estimate that official statistics may understate heat-related injury burdens by a factor of four. Exploiting variation in mandated heat safety investments due to a California policy, we provide the first evidence that directed adaptation policy through the labor market can be effective at mitigating climate risk. Consistent with labor market frictions, we find no evidence that the policy led to significantly increased costs, reduced worker-hours, or reduced firm profitability.

## **Is Planning Worth It? Perspectives on the Utility of Planning for Adaptation and Hazard Mitigation**

**Elizaveta Barrett Ristroph | University of Hawaii**

Planning for climate change adaptation and hazard mitigation seems to be a cost-effective way that agencies can assist communities struggling with impacts such as severe flooding and erosion. Indeed, there are many grants available merely for adaptation and hazard mitigation planning, and relatively few for carrying out plans. This research draws on a study of hazard mitigation and adaptation-related plans for Alaska tribal communities, which considered residents' awareness of the plans and perspectives on whether they were useful. The original research was based on interviews and conversations with a diverse sample of residents and planning professionals across of Alaska, as well as a review of the plans for the 59 Alaskan tribal communities. This resulted in a review of about 70 plans written between 1990 and 2017. Findings from the original research indicate that there were plans by the same consultants that appeared very similar and were not representative of the communities, and many residents were not aware of them. Findings also suggested that those in the planning profession or outside of communities were more likely to consider planning useful than community residents subject to plans. The original research has been supplemented by practical experience working with Alaska Native Villages on planning, particularly with the relocation of Newtok, AK. Practical experience demonstrates the difficulty of futility of most consultant-led planning processes for these communities, except for hazard mitigation plans required for Federal Emergency Management Agency funding, and concrete, simple plans in which the local government is directly involved.

## **Climate Change and Adaptation in Global Supply-Chain Networks**

**Christoph M. Schiller | Arizona State University**

*Additional author: Nora M.C. Pankratz | University of California, Los Angeles*

This paper examines how firms adapt to climate-change risks resulting from their supply-chain networks. Combining a large sample of global supplier-customer relationships with granular data on local temperatures and flooding incidents, we first document that the occurrence of climate shocks at affected supplier firms has both a large direct and indirect negative effect on earnings and revenues of suppliers and their customers. Second, we show that customers are 10% to 20% more likely to terminate existing supplier-relationships when realized climate shocks at the supplier firms exceed ex-ante expected climate shocks. Further, customers subsequently switch to suppliers with lower heatwave and flooding exposure. Our results indicate that climate change affects the formation of global production networks.

## **Water, Violence, and Internal Displacement: Evidence from Somalia, 2007-2018**

**Justin Schon | University of Florida**

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A growing body of research is examining climate-conflict and climate-migration relationships. Since conflict and migration can influence each other and both may be influenced by climate triggers, careful analysis of their relationships is needed. A growing body of research observes that violence can cause migration and migration can cause violence. In addition, high violence can push people away from origin locations and low violence can pull them toward destination locations. Climate factors can motivate additional migration. We focus specifically on the role of water, both precipitation and surface water. Using analytical techniques that account for non-stationary time series and threshold effects, we examine monthly province-level fluctuations in water, violence, and internal displacement in three Somali regions—Banadir, Lower Shabelle, and Hiraa—from 2007-2018. We find that people move away from high violence locations and towards low violence locations. When conflict intensity subsides, people also move away from areas experiencing floods. Drought does not clearly precede violence or migration in the data. If drought does increase violence or migration, then it does so with about a one year lag. These findings advance existing research on the violence-migration cycle and add insight into how climate interacts with that cycle.

## Labor Market Adjustment to News

**Jeffrey G. Shrader | Columbia University**

*Additional authors: Mitch Downey | Stockholm University, Nelson Lind | Emory University*

Labor market adjustment costs are central to understanding the effects of labor productivity shocks, including those due to changes in the climate. Whether, and to what extent, labor is costly to adjust also matters for a wide range of labor-market policies including the effect of local income taxes, welfare consequences of environmental regulations, and minimum wage. This paper uses differential response of employment to forecastable versus unforecastable productivity fluctuations to identify the degree of rigidity in labor market adjustment. In particular, we use a global climate phenomenon which generates forecastable and differential rainfall conditions across commuting zones in the United States to estimate the response of employment to future labor productivity at different anticipation horizons. We find that news about future rainfall causes anticipatory reductions in construction employment. Moreover, the more time there is before the anticipated rainfall, the larger the response. These results cannot be reconciled without adjustment costs.

The empirical results focus on the construction sector, but they likely also informs us about fundamentals of labor adjustment in other sectors. Construction is a medium- skilled sector exhibiting wide variation in many of the factors widely perceived to drive labor adjustment costs (like unions and wrongful discharge laws). We explore the heterogeneity along these and other dimensions to better understand the source of the adjustment costs. The heterogeneity results suggest that both policy and non-policy factors are important drivers of adjustment costs.

Finally, we calibrate a multi-sector model of the local labor market to interpret the effects. We find that the empirical results imply large adjustment costs for workers moving into or out of the construction sector. These adjustment costs have important implications for the effect of productivity fluctuations on employment and output dynamics within the construction sector. For instance, if exit costs were reduced to be one-tenth the size of those implied by our empirical results, then forecasts would be half as valuable. Forecasts become more valuable as adjustment costs rise because workers and firms need more warning of upcoming fluctuations to be able to respond in the face of high adjustment costs. We also show that for a fixed level of adjustment costs, local labor market volatility increases as fluctuations become more forecastable. The results in the paper have important implications for the study of climate change. First, costly adjustment provides incentive for economic agents to adapt in advance of changes in the climate. The larger are adjustment costs, the more important such ex ante adaptation becomes and the more valuable are forecasts of future climate change. Second, costless adjustment is assumed in all major integrated assessment models, but transition costs might be a substantial fraction of total climate change damage. Estimates of the degree of rigidity in the labor market are key to quantifying these costs.

## **Social Inequalities in Flooding Inside and Outside of Floodplains during Hurricane Harvey**

**Kevin T. Smiley | Louisiana State University**

In the era of the Anthropocene, extreme weather events are increasing in likelihood and severity because of climate change. Adapting and mitigating these climate challenges is a central task of policymakers and residents alike. One such challenge of adaptation and mitigation concerns delineating risks from flooding from extreme weather events. Previous research shows that flood impacts frequently occur outside of the areas identified as risky by the most well-used metric and policy tool of flood risk in the United States, the FEMA 100 year floodplain. While much disasters research has studied unequal social vulnerabilities to natural hazards, few studies have studied how these vulnerabilities may vary inside and outside of the 100 year floodplain risk zones. This study analyzes flooding impacts from Hurricane Harvey inside and outside of the 100 year floodplain in an effort to uncover social vulnerabilities especially by race inside and outside of the floodplain.

Using novel data on more than 1 million residential properties in Harris County, Texas, I identify both what properties are located in the 100 year floodplain as well as the flood impacts using state- of-the-art data on the high water marks from Hurricane Harvey. Melding together the data on risk from floodplains and on impacts from the Harvey-specific data, these findings indicate that the vast majority – more than 4 in 5 – of properties that experienced flooding impacts during Hurricane Harvey were outside of the 100 year floodplain zone of risk.

To analyze this social problem, I use social and demographic data on neighborhoods to predict the likelihood of overall percent of flooded residential properties in a neighborhood as well as the percent of flooded residential properties inside and outside of the floodplain in each neighborhood. Results from spatial regression models are fourfold. First, there is no evidence for racial disparities in risk, that is in whether some racial groups are more likely to reside in the 100 year floodplain in Harris County. Second, there are large racial disparities in impacts from flooding during Hurricane Harvey, namely that neighborhoods with more black and more Hispanic residents had more properties that experienced flooding impacts. This second finding is in contradistinction to the first finding, and suggests that our 100 year floodplain maps may obscure unequal racialized impacts. Third, there is small and limited evidence of racial inequalities in the composition of flooded properties inside the floodplain. Fourth, and most central to the overall study, there are large racial inequalities in the impacts from flooding during Hurricane Harvey outside of the 100 year floodplains. The overall inequalities in the second finding are primarily driven by the inequalities found outside of the 100 year floodplain.

Discussion centers on how existing models of measuring flood risk may underestimate racial inequalities in risk exposures. Put simply, inaccurately identifying flood risk disproportionately disadvantages blacks and Hispanics in the Houston area. Implications focus on how subtle disparities in elevation, infrastructural inequalities in stormwater provision, and the policy making around flood plain maps intertwine to produce these inequalities.

## How Are Cities Planning for Heat? A National Assessment of Municipal Heat Plans

V. Kelly Turner | University of California, Los Angeles

*Additional authors: Emma French | UCLA and Nicole Cano | UCLA*

Heat is a central environmental, public health, and social justice concern in cities. Urban regions are already hotter than surrounding undeveloped areas due to the Urban Heat Island (UHI), extreme heat events are predicted to increase with climate change, and heat impacts disproportionately affect disadvantaged communities. In response, some cities have begun to incorporate cooling strategies into official planning documents as part of broader climate planning efforts. Outdoor cooling through urban design interventions like urban greening and cool surfaces is of central interest due to several potential co-benefits. These include mitigating UHI, improving pedestrian thermal comfort to encourage active transportation, and reducing indoor energy demand. Yet, heat is a multifaceted concept and the effectiveness of outdoor cooling strategies are scale, context, and regionally dependent. Lack of nuance in heat policy could promote “panaceas”: strategies that are likely to fail because they assume too much similarity in context.

Through a content analysis of 228 municipal planning documents spanning 50 cities across the United States, this study addresses three interrelated questions: (1) Which heat related **problems** are cities incorporating into planning documents? (2) Which hard (e.g., green infrastructure) and soft **strategies** (e.g., education, studies) are cities planning to implement to address those challenges? (3) How does problem framing and strategy selection vary by climate region (National Climate Assessment), plan type (Hazard Mitigation, Climate Action, Sustainability, Resilience, Infrastructure, General Plans, Other), and membership in national/international networks (Urban Sustainability Directors Network, Rockefeller 100 Resilience Cities, and Cities Climate Leadership Group, C40)?, and (4) To what extent do the strategies suggested actually address the problems invoked according to urban climate science? We hypothesize that strategies will conflate multiple dimensions of heat—land, air, and surface temperature—which operate differently across scales, leading to claims of co-benefits across heat related goals that are not scientifically supported. Moreover, we hypothesize that regional differences in urban heat dynamics will not be considered.

We found that more than half of the municipal planning documents analyzed contain at least one statement mentioning heat. The most pervasive goal statements pertained to adapting to extreme heat events or mitigating urban heat island. Soft interventions like education and outreach were more pervasive than infrastructure interventions, but many statements contained no soft or infrastructure intervention was prescribed at all. This reflects the fact that addressing urban heat was most frequently mentioned as a co-benefit of broader efforts to vegetate the city. Many documents addressed vulnerability, variously defined, but mostly focused on exposure as opposed to sensitivity or adaptive capacity, and mentions of equity were infrequent. Finally, while explicit misinterpretations of urban climate science were rare, vague generalizations were pervasive and could potentially lead to misinterpretations in translation to policy.

## **The Effects of Weather on Recreational Fishing Demand and Adaptation: Implications for a Changing Climate**

**Roger H. von Haefen | North Carolina State University**

*Additional author: Steven J. Dundas | Oregon State University*

Outdoor recreation is one of the most popular leisure activities in the United States, yet the potential impacts of climate change on the non-market aspects of this activity are largely unknown or poorly understood. We estimate the non-linear effect of temperature and precipitation on the demand for a significant segment of the outdoor recreation economy – shoreline marine recreational fishing in the Atlantic and Gulf Coast regions – from 2004-2009. Our econometric estimates suggest extreme heat significantly reduces recreation participation. We find declines in participation (up to 15 percent) and welfare (up to \$312 million annually) over a range of predicted climate futures. These impacts vary spatially and temporally, with warmer locations and times of year experiencing significant losses and gains possible in cooler areas. We also find evidence of climate-averting behavior as anglers shift their activities to nighttime rather than fish less frequently to mitigate the negative impacts from extreme heat.



## **Information, Prices, and the Distribution of Climate Risk: Evidence from the National Flood Insurance Program**

**Joakim A. Weill | University of California Davis**

Floods are among the costliest natural disasters worldwide, with estimated damages exceeding 40 billion dollars per year. Rising sea-levels and growing local precipitation intensity will further exacerbate these impacts, with projections estimating a global decline in welfare and economic growth.

In order to improve resilience to flooding, the US federal government provides flood insurance to homeowners and renters through the National Flood Insurance Program (NFIP). Flood insurance is mandatory for properties with a federally backed mortgage located within a 100-year flood zone. However, despite this mandate and the various subsidies offered through the NFIP, the demand for flood insurance has remained extremely low and the total number of active policies declined by 500,000 between 2010 and 2017.

In this paper, I combine new data on flood insurance policies with a model of flood risk in the United States to study the determinants of the demand for flood insurance. Leveraging the national roll-out of digital flood maps, I provide three main findings.

First, I provide new descriptive evidence showing that the digitization of flood maps, through changes in the boundaries of flood zones, led to the rezoning of more than three million individuals outside of the FEMA 100-year floodplain. While local reductions of the estimated flood risk can be warranted through better risk assessments and the placement of fills and levees, the observed widespread shrinking of the 100-year floodplain is inconsistent with the best available flood science.

Second, I find that the transition from a paper-based flood map to an updated digital map had large and significant impacts on insurance take-up, but that these impacts are extremely heterogeneous. Communities that tended to re-zone properties outside of the 100-year floodplain saw the largest reductions in the demand for insurance. In contrast, expansions of the 100-year floodplain caused a substantial increase in insurance take-up. These findings suggest that the updating of beliefs about flood risk and the mandate requirement have a greater combined effect on insurance demand than changes in insurance premiums induced by rezoning.

Finally, using an approach based on the estimation of local synthetic controls, I estimate that the digitization of flood maps caused about 190,000 properties to drop flood insurance coverage while leading about 110,000 individuals to take-up insurance. Communities with a higher share of African Americans and economically disadvantaged communities were more likely to experience negative treatment effects from the policy. Overall, digitizing flood maps caused both fiscal redistribution through changes in insurance premiums and risk redistribution through changes in insurance demand.

Taken together, these results suggest that a better characterization of flood risk and an expansion of the mandate requirement outside of the 100-year floodplain could substantially increase flood insurance coverage. They also provide a cautionary tale regarding the decentralized implementation of climate adaptation policies.

## **Can Access to Health Care Mitigate the Effects of Temperature on Mortality?**

**Corey White | Cal Poly, San Luis Obispo**

*Additional author: Jamie Mullins | University of Massachusetts Amherst*

Understanding the sources of heterogeneity in the health effects of environmental exposure is critical for optimal policy design. Differential access to health care is commonly cited as a potential source of such heterogeneity. We test this hypothesis in a causal framework by combining random year-to-year fluctuations in local temperatures with variation in access to primary care services resulting from the idiosyncratic roll-out of Community Health Centers (CHCs) across US counties in the 1960s and 1970s. We find that the improved access to primary care services provided by CHCs moderates the heat-mortality relationship by 14.2%, but we find little evidence that CHC access mitigates the harmful effects of cold. In a supplementary analysis we find evidence that acute care – in contrast to primary care – may be especially effective at mitigating the cold-mortality relationship. Our results suggest that differential access to health care does contribute to observed heterogeneity in environmental health damages, and that improving access to primary care may be a useful means of mitigating harm from a warming climate.

## **Are the Cooling Effects of Urban Greening Detectable from Space?**

**Bev Wilson | University of Virginia**

Cities across the United States and around the globe are embracing urban greening as a strategy for mitigating the effects of rising temperatures on human health and quality-of-life. In addition to lowering ambient air temperatures through evapotranspiration, trees can reduce energy demand when placed in proximity to buildings through the shading effect they have on their immediate surroundings. This exploratory research focuses on two related questions: (1) where has afforestation occurred and (2) what effect has afforestation had on intra-city heat exposure within a sample of large and mid-sized cities in U.S. In order to answer these questions, I rely on the most recent National Land Cover Dataset (NLCD) to identify areas that may have experienced a net gain in forest, then collect available tree canopy data and urban forest plans from local sources. Next satellite imagery is used to estimate land surface temperatures that predate and follow documented afforestation initiatives to test for a detectable and lasting impact (i.e., reduction in land surface temperatures) in and around the targeted areas. In addition to landcover, changes in albedo are also considered in order to account for potentially confounding factors like painting roofs and pavement white. The results of the analysis are used to highlight differences in outcomes across the cities considered and also discusses the implications of using land surface temperatures rather than air temperatures for heat mitigation planning.

## Does Climate Change Impact Sovereign Bond Yields?

**Michael Barnett | Arizona State University**

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This paper studies the impact of current expectations about long-term climate change damage on sovereign bond yields. Sovereign bond yields are particularly important from a policy perspective, as most climate change mitigation decisions are taken at the national level, and borrowing cost today may serve as a disciplining device. We use scientific projections of climate change damage, and compare the spread in yields between long and short term bonds. We find that projected climate change damage has large effects on yields for bonds with long maturities, but not for short term maturity bonds. The effect of projected climate change damage is monotonically increasing in maturity. We discuss the broader asset pricing and macroeconomics effects implied by our results.

We are grateful to numerous conversations with colleagues at the University of Chicago and Arizona State University for helpful comments and discussions. This draft is preliminary and incomplete and comments are welcome.