I Z A Institute
of Labor Economics
Initiated by Deutsche Post Foundation

DISCUSSION PAPER SERIES

IZA DP No. 16715

Extreme Weather Events and Climate Change: Economic Impacts and Adaptation Policies

Susana Ferreira

JANUARY 2024

I Z A Institute
of Labor Economics

Initiated by Deutsche Post Foundation

DISCUSSION PAPER SERIES

IZA DP No. 16715

Extreme Weather Events and Climate Change: Economic Impacts and Adaptation Policies

Susana Ferreira
University of Georgia and IZA

JANUARY 2024

ISSN: 2365-9793

IZA – Institute of Labor Economics

Schaumburg-Lippe-Straße 5–9
53113 Bonn, Germany

Phone: +49-228-3894-0
Email: publications@iza.org

www.iza.org

ABSTRACT

Extreme Weather Events and Climate Change: Economic Impacts and Adaptation Policies*

This article reviews the literature on the economic impacts of disasters caused by extreme weather and climate events to draw lessons on how societies can better manage these risks. While evidence that richer, better governed societies suffer less and recover faster from climate extremes suggests adaptation, knowledge gaps remain, and little is known about the efficiency of specific adaptation actions. I review various "no or low" regrets adaptation options which are recommended when uncertainties over climate change impacts are high. I discuss how governments can play an important role in adaptation by directly providing public goods to manage disaster risks or by facilitating private agents' adaptation responses, but also highlight the political economy of policy and coordination failures.

JEL Classification: Q54, Q56, O13, O44, I30

Keywords: climate change policy, natural disasters, climate adaptation, risk management, climate extremes

Corresponding author:
Susana Ferreira
University of Georgia
313 Conner Hall
Athens, GA 30602-7509
USA

E-mail: sferreir@uga.edu

* When citing this paper, please use the following: Ferreira S. 2024. Extreme Weather Events and Climate Change: Economic Impacts and Adaptation Policies. Annu. Rev. Resour. Econ. 16: Submitted. https://doi.org/10.1146/annurev-resource-101623-095314.

1. Introduction

The ten warmest years in the historical record have all occurred since 2010 (NOAA 2023a). In 2023, following the hottest June on record, July was the hottest month ever measured worldwide, with devastating heat waves in large areas of the US, Mexico, Southern Europe, and China that broke many local high temperature records, and that would have been "virtually impossible" without human-induced climate change (Zachariah et al. 2023). In August 2023, the island of Maui experienced the deadliest wildfire in the past 100 years in the US, where in 2023 there were twenty-five "billion-dollar" weather and climate disaster events (severe storms, flooding, tropical cyclone, drought, wildfire), each with losses exceeding $1 billion –the highest number of such events since the record starts in 1980 (NOAA 2023b). Record-breaking extreme weather and climate events have become the new normal.

Global temperatures are expected to continue to increase and with them the frequency and intensity of extreme weather and climate events (IPCC 2023).[1] Under any realistic climate policy scenario, atmospheric greenhouse gases (GHG) concentrations will continue to grow. Even if we could quickly and drastically reduce GHG emissions (which seems unlikely in the current economic and political reality), due to the high residence time of GHGs and lagging climate response, temperatures will continue to rise from past increases in GHG emissions, making it likely that a 2°C warming cannot be avoided (Tol 2018, Pindyck 2022).[2]

Aggressive mitigation of GHG emissions remains the most important prescription of climate policy, especially to insure against low-probability, high-impact catastrophes (Weitzman 2009), but climate is projected to change regardless of current GHG mitigation efforts, and climate extremes are affecting societies today. The World Economic Forum's 2023 Global Risks Report considers the failure to mitigate climate change, failure of climate change adaptation, and natural disasters and extreme weather events to be the top three greatest risks in the next 10 years (World Economic Forum 2023). While in the past there has been some reluctance to discussing adaptation due to concerns about moral hazard (Aldy and Zeckhauser 2020), it has become painfully evident that climate policy must include strategies to alleviate the negative impacts of climate change (Khan 2016, Aldy and Zeckhauser 2020, Pindyck 2022). Adaptation has the potential to significantly reduce the damages from climate extreme events but remains one of the least explored areas of climate economics (Burke et al. 2016).

This paper reviews the empirical literature on the economic impacts of climate extremes to learn how we can better manage their risks to prevent, as well as prepare for, cope with, and recover from disasters when they occur. I draw from two distinct branches of literature: one examining the economic costs of natural disasters –previously reviewed by Cavallo and Noy (2011),

[1] The distinction between weather and climate extremes is related to their specific time scales, but it is not precise. Extreme weather events are often short-lived (e.g., heat waves, freezes, tropical cyclones, floods). Extreme climate events persist longer and can be the accumulation of several weather events over a longer period (e.g., droughts or wildfire outbreaks) (IPCC 2012, p.117). For simplicity and following IPCC (2012) in this paper I refer to both as climate extremes.

[2] If GHG concentrations in the atmosphere reach 700 ppm (parts per million) a rise of temperatures between 1.5 and 4.5°C is most likely, but the distribution of possible temperature increases possesses "fat tails" implying a non-negligible, 10% probability that temperatures will increase by 6°C (Wagner and Weitzman 2015).

Kellenberg and Mobarak (2014), and Botzen et al. (2019) - and the other examining the economic impacts of climate change –reviewed by Dell et al. (2014), Carleton and Hsiang (2016), Tol (2018), and Auffhammer (2018). A key focus of the latter has been the study of impacts of climate on agriculture (see e.g., Mendelsohn et al. 1994, Fisher et al. 2012, Carter et al. 2018), but similar to Kousky (2014), my focus in this review is on weather- and climate-related disasters. Climate extremes do not always result in disasters; they do when they cause widespread damage and severe alterations to the normal functioning of communities or societies (IPCC 2012). And those impacts depend on the characteristics and intensity of the extremes themselves, as well as on the exposure and vulnerability of those affected.[3]

The literature reviewed in sections 2 and 3 suggests overall negative consequences of climate disasters on economies and societies, but it shows that the impacts are heterogenous, offering insights into adaptation to climate extremes. A consistent finding is that rich countries fare better, supporting Schelling's (1992) argument that developing countries' best defense against climate change may be their own continued development. Beyond this, somewhat generic, macro-level recommendation, decision makers are faced with limited resources and a potentially large portfolio of adaptation options and need to prioritize among them.

In section 4, I discuss the role of governments in adaptation, which in the context of climate extremes entails managing disaster risk. Among the portfolio of adaptation actions, some help reduce exposure or vulnerability to climate hazards, while others transfer risk (e.g., through insurance), or help manage the remaining residual risk. Some require the provision of public goods (e.g., early warning systems, flood-risk protection through "hard" infrastructure or nature based-solutions), while others, undertaken by households or firms (e.g., protective investments, insurance purchase, relocation) can be facilitated by policies that address market failures and the cognitive biases and behavioral barriers that are typical of decisions made in contexts of deep uncertainty. In Section 4, I review several specific adaptation strategies that have been recommended as "no regrets" or "low regrets" but also discuss policy and coordination failures that may prevent optimal public adaptation responses. Section 5 concludes and highlights the many areas of promising future research, given that research on the efficiency of adaptation policies is still in its infancy.

2. Impacts of climate extremes on the economy

Human-caused climate change is affecting weather and climate extremes across the world leading to widespread losses and damage to people and nature (IPCC 2023). Figure 1 shows the increase in the number of weather- and climate-related disaster events worldwide and associated inflation-adjusted losses from 1980 to 2022. During this period, disasters caused by droughts, wildfires, floods, landslides, tropical cyclones, severe storms, and extreme temperatures killed almost 1.6 million people and caused damages exceeding $4.6 trillion (in 2021 US dollars). Since 2010, global damage every year has exceeded $100 billion, with the last two years each above $200 billion. For comparison, Figure 1 also shows the number of geophysical disasters

[3] In fact, observed increases in disaster damages worldwide can be mainly explained from the growth in population and economic activities in hazardous areas, although climate change is expected to increasingly contribute to that trend (Hoeppe 2016).

caused by earthquakes, tsunamis, and volcanic eruptions, for which a positive trend is not observed.

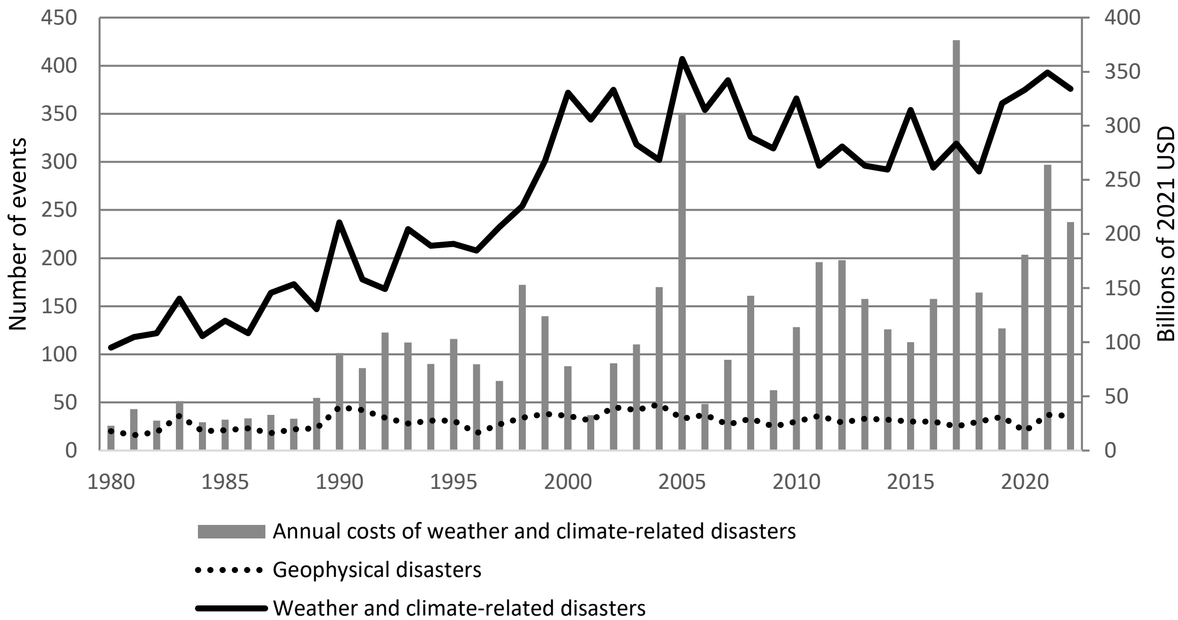

Figure 1. Evolution of weather and climate-related disaster events worldwide: Number of events and annual costs

Notes: Data come from the emergency events database EM-DAT, maintained by the Centre for Research on the Epidemiology of Disasters at the Catholic University of Louvain (www.emdat.be). Natural Disasters are recorded in EM-DAT if they fulfill one of these criteria: (1) at least 10 deaths; (2) at least 100 people reported affected; (3) declaration of state of emergency and/or appeal for international assistance. Information is compiled from various sources (UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies). Weather- and climate-related disasters are caused by droughts, wildfires, floods, landslides, tropical cyclones, severe storms, and extreme temperatures. Geophysical disasters are caused by earthquakes, tsunamis, and volcanic eruptions. Annual costs are the total estimated damages and economic losses directly or indirectly related to the disaster. In practice they typically include direct losses (e.g., damage to housing, infrastructure, and crops).

Climate-related disasters have direct, negative impacts on factors of production and ecosystems. For example, floods can kill people, destroy buildings, crops, roads and bridges, and erode soils; heat waves increase mortality. Disasters disrupt economic activity (e.g., through business interruption), resulting in additional indirect, higher-order effects whose estimation is typically done through computational models such as input-output or computable general equilibrium models (Okuyama 2022 and Botzen et al. 2019 review these models).

Economic theory yields competing hypotheses for the trajectory of output following the initial disaster shock (Hsiang and Jina 2014, Botzen et al. 2019). In neoclassical growth models with exogenous technological progress, if the shock lowers capital-labor ratios, positive rates of growth following the shock return the economy to the steady state. This is the “recovery to trend" hypothesis.[4] Endogenous growth models offer additional possibilities for post-disaster dynamics. For example, vintage capital models predict that replacement of capital after a disaster updates the technology which, in turn, increases productivity and growth, providing the intuition for "build-back-better" or Schumpeterian "creative-destruction" hypotheses. In AK models (A denoting productivity, K capital stock), where output and output per worker depend on the level of accumulated capital, a shock that destroys capital has a lasting impact on output per worker, lowering post-disaster income permanently. This is consistent with a "no recovery" hypothesis. Additionally, the impact of disasters in the short-run may depend on business-cycle dynamics, with the shock providing a Keynesian-like stimulus during a recession but driving up inflation rather than output during a boom, when capacity is tight (Tol and Leek 1999, Hallegate and Ghil 2008).

2.1. Econometric methods and data

Given conflicting theoretical predictions, the question of whether and how climate extreme events affect economic growth has been posed as, ultimately, an empirical question (Cavallo et al. 2013, 2022). To empirically estimate their causal effect is difficult, however. It requires comparing the observed outcome to a counterfactual, unobserved outcome that would have occurred absent the shock. In practice, lacking a natural experiment to compare one population exposed to the climate extreme (i.e., "treated") with an identical "control" population not experiencing the event, most empirical studies have estimated variants of a general specification like equation (1):

$$Y_{it} = \alpha D_{it} + \boldsymbol{\beta}' \boldsymbol{X_{it}} + \boldsymbol{\gamma}' D_{it} \boldsymbol{X_{it}} + \theta_i + \theta_t + \varepsilon_{it} \, , \quad (1)$$

where *i* denotes a geographical unit (e.g., a country, region) or a firm or household, and *t* denotes time (typically a year). Y_{it} is the outcome of interest (e.g., income, GDP per capita, or their growth rates). D_{it} denotes contemporaneous or lagged disaster incidence. It can be a dummy for disaster occurrence, or a variable accounting for disaster frequency, intensity, or damage (e.g., wind speed of hurricanes, share of population killed or affected by a disaster). In most cases, researchers include additional controls $\boldsymbol{X_{it}}$ (e.g., indicators of education, openness, or institutional quality) that may mitigate the effect of a disaster to shed light on potential adaptation mechanisms. θ_i and θ_t are spatial and time fixed effects, respectively, which are needed to plausibly estimate a causal effect of the disaster on the outcome of interest. In specifications like (1) the population just before an event serves as "control" for itself right after the event (i.e., the "treatment").

[4] Existing literature suggests that depreciation effects to physical capital are larger than population effects in most cases. Possible exceptions are heatwaves, which cause more deaths than other climate extremes -although concentrated on the elderly (NWS 2023) and act as a negative labor productivity shock (Bilal and Rossi-Hansberg 2023), and disasters affecting the poorest, most vulnerable countries where the human toll tends to be disproportionally high and capital-labor ratios disproportionally low (Fankhauser and Tol 2005). An implicit assumption to return to the same steady state is that savings rates remain constant, but they may change after a disaster, if e.g., a potential drive to "enjoy life while it lasts" dominates over a precautionary tendency to self-insure, lowering savings rates (Filipski et al. 2019) or vice versa.

To model the temporal dynamic effects of climate shocks, researchers have used distributed lagged models or vector autoregressions, where additional lags of the disaster variable or the dependent variable are included in the right-hand side of equation (1). In contrast, the spatial spillovers of shocks remain understudied. In a highly interconnected world, climate shocks spread across regions through trade and financial flows, flows of people (i.e., migration), and flows of resources (e.g., water). Even without shocks, the economic performance of a region is influenced by that of its neighbors. Thus, areas not directly affected by a shock may be subject to spillover effects, which would violate the stable unit treatment value assumption and threaten causal identification (Kolak and Anselin 2019). To date, few studies (Strobl 2011 and Lima and Barbosa 2019 being exceptions) explicitly incorporate spatial dependence into econometric models of disaster effects.

An important consideration of empirical studies estimating versions of equation (1) is that in panel fixed-effect models, identification arises from within-unit year-to-year fluctuations in weather and the outcome of interest, which isolates the effects of disaster *strikes*, but does not tell us much about long-run adaptation responses to disaster *risk* (Auffhammer 2018, Bakkensen and Barrage 2023). Cross-sectional specifications, on the other hand, allow for long-run adaptation, but are subject to potential omitted variable bias, which has led most researchers to favor panel data –or a combination of both approaches (Auffhammer 2018). Insights about adaptation in panel studies have typically come from specifications that include interactive terms $\boldsymbol{\gamma}' D_{it}\boldsymbol{X_{it}}$, as described above. A promising, novel, alternative approach feeds results from the empirical estimation of panel versions of (1) to structural models of the economy to yield general equilibrium effects that allow to directly model long-run endogenous adaptation through, for example, migration, savings, and capital investment (Bakkensen and Barrage 2023, Bilal and Rossi-Hansberg 2023).

Most studies estimate equation (1) using ordinary least squares (OLS), which imposes a linear relationship between the intensity of the shock and the dependent variable; an assumption that may be inappropriate for fat-tailed damage distributions. Coronese et al. (2019) show that while their OLS estimates of disaster impacts over time are small and statistically insignificant, quantile-regression estimates increase exponentially with disaster intensity.

Regarding data, most multi-country studies have used the publicly available EM-DAT global dataset to construct the disaster variables in (1). (Please refer to the notes to Figure 1 for a description of EM-DAT). Alternative datasets maintained by reinsurance companies (Swiss Re's Sigma and Munich Re's NatCatSERVICE) provide a shorter time coverage and limited access and have been used less frequently. Disaster variables in these three datasets may not be exogenous, however. Because monetary damages of disasters are larger in richer economies, damage-based disaster intensity measures are correlated with GDP per capita. Felbermayr and

Gröschl (2014) show that the likelihood of a disaster being reported in EM-DAT, conditional on its physical magnitude, depends strongly on the affected country's GDP per capita.[5]

In contrast, indicators of the intensity of the underlying hazard events are plausibly exogenous to the economic variables of interest (at least in the short run) and have been used directly or as instruments of disaster intensity. Early examples are Hsiang (2010) and Strobl (2011 and 2012), who use tropical cyclone track data and wind field models to reconstruct local exposure to tropical cyclones.[6] As for data sources, some countries maintain publicly accessible databases for natural hazards and disasters. For example, the US National Centers for Environmental Information maintains a "billion-dollar" weather and climate disasters database for disasters exceeding $1 billion damages within US borders, as well as several databases for natural hazards, some of them global in scope, like the International Best Track Archive for Climate Stewardship for tropical cyclones.[7] Academic-driven publicly available global datasets with granular spatial and temporal resolutions include the Standardised Precipitation-Evapotranspiration Index (SPEI) database for droughts, or the Dartmouth Flood Observatory for floods.[8] A wider and growing availability of geo-spatially referenced climate and hazard data offers much promise by expanding the range of data that can be tailored to specific research questions.

2.2. Effects of disasters on GDP and GDP growth in multi-country studies

The consensus is that disasters, especially those most severe or affecting developing countries have, on average, negative impacts on GDP and GDP growth in the short run.[9] In their meta-analysis of more than 750 estimates from 22 primary studies, Klomp and Valckx (2014) report a negative "genuine" effect of natural disasters on economic growth, with climate disasters in developing countries having the most adverse impacts. However, they also report much variation in the estimates, with an important fraction being not significant or positive (38%) and note a publication bias in the reporting of negative estimates. The heterogeneity in the estimates suggests that the type and characteristics of the disaster as well as the responses across countries and economic sectors are important determinants of their impacts (Loayza et al. 2012), but there may also be sample composition effects (Bakkensen and Barrage 2023). In addition, Felbermayer and Gröschl (2014) find non-linearities with the worst 5-percent disaster years reducing GDP per capita by 0.46%, and those in the top 1-percentile by at least 6.8%.

[5] Kousky (2014) highlights two additional drawbacks of damage-based disaster indicators: (i) small events are not recorded although their frequent occurrence can be costly; (ii) potentially highly destructive hazards with low impact (e.g., due to pre-existing effective adaptation strategies) are not recorded either, although they would be very informative to assess which risk-management strategies drive the low impact.

[6] Felbermayr and Gröschl (2014) developed and used a global disaster events database (ifo GAME: https://www.ifo.de/en/ifo-game-geological-and-meteorological-events-database) with primary information on the physical strength of the hazards associated with disasters (e.g., hurricane track data, wind speed, precipitation) for the period 1979-2010.

[7] See https://www.ncei.noaa.gov/products/natural-hazards.

[8] More details at https://spei.csic.es/database.html and https://floodobservatory.colorado.edu/, respectively.

[9] The short run is defined as 1-5 years post-disaster. Most studies using conventional panel fixed-effects model specifications estimate immediate (next year) impacts.

Of the estimates reviewed by Klomp and Valckx (2014), less than 10 percent explain the long-run impact of disasters (after 5 years), reflecting a paucity of studies concerned with this question, partly because of the difficulty for causal identification. An early, influential study by Skidmore and Toya (2002) reports positive correlations between climate disasters and average annual growth rates of GDP and TFP between 1960 and 1989. Their result has been interpreted as evidence for Schumpeterian creative destruction dynamics, although Cuaresma et al. (2008) found that the relationship between technology absorption and disasters that would support this argument only held for high-GDP countries. Cuaresma (2022) revisits Skidmore and Toya's (2002) basic specifications with updated data and Bayesian model averaging techniques and finds that disasters are not robust predictors of long run economic growth.

Cross-sectional approaches like Skidmore and Toya (2002)'s provide long-run estimates that allow for adaptation but have the caveat of potential omitted variables. Using synthetic control methods to build a counterfactual for affected countries, Cavallo et al. (2013) report that even extremely severe disasters do not significantly affect short or long run economic growth.[10] In contrast, Hsiang and Jina (2014), using a panel distributed lag model, estimate a negative effect of tropical cyclones on GDP growth that persist 15-20 years following an event, arising from a small but persistent suppression of annual growth rates.

2.3 Subnational analyses of economic disaster impacts

The unit of analysis in studies of disaster impacts on economic growth is typically the country. This level of aggregation may mask significant impacts at a subnational level, particularly in large countries, missing potentially important regional distributional effects. In addition, national macroeconomic aggregates do not account well for the detrimental effects of climate extremes on the poor –who have fewer assets to lose and may participate more in the informal economy - which misses additional distributional effects of climate extremes within countries (Hallegatte and Rozenberg 2017). Equation (1) can still be used to estimate the effects of climate extremes on spatial units other than the country. Moving beyond country-level analyses, however, requires systematic collection of statistical information at the subnational level, which may be challenging, especially for low-income countries.

For coastal counties in the US, Strobl (2011) finds that an average hurricane lowers a county's annual economic growth by 0.45 percentage points the year it strikes but that this effect does not manifest at the state or national levels, highlighting the importance of a disaggregated level of analysis. In the longer run (8 years out) and for all US counties, Roth Tran and Wilson (2023) find that disasters increase income per capita by 0.6% in counties affected, with offsetting negative effects on other counties within the region. In one of the few studies to explicitly model spatial spillovers of climate extremes, Lima and Barbosa (2019) show that per capita GDP declined an average 7.6% in Brazilian municipalities affected by a flash flood, while those affected indirectly also experienced a decline of about 0.54 to 1.98%.

[10] This is after controlling for two events where radical political revolutions followed the disaster. (The causality of this link is not assessed).

Studies at a micro, firm level have shed light on post-disaster reconstruction dynamics. Leiter et al. (2009) find evidence that in the short run companies in regions hit by a flood grow physical capital and labor at a higher rate than firms in unaffected regions, but that this increase does not translate into higher productivity. This contrasts with Cole et al. (2019) where, conditional on firm survival to the 1995 Kobe earthquake, firms experienced a temporary increase in productivity consistent with "build back better" effects. Consistent with a "cleansing" hypothesis, Basker and Miranda (2018) find that less-productive firms exited in the aftermath of Hurricane Katrina, and that even after controlling for productivity, small, credit constrained firms were disproportionately affected. In Sri Lanka, De Mel et al. (2012) show that following the 2004 tsunami a lack of access to capital inhibited the recovery process, with firms receiving randomly allocated grants recovering profit levels almost 2 years before other damaged firms.

Weather risk is an important source of income volatility for the rural poor and the subject of a vast literature within development economics. This literature offers insights for adaptation by investigating households' ability and strategies to prepare for and cope with climate extremes including risk sharing and self-insurance via savings (often in the form of grain or cattle assets), or adoption of lower-risk, often lower-return technologies (see, e.g., Kazianga and Udry 2006, or Dercon and Christiaensen 2011, and Castells-Quintana et al. 2018 for a review). Few studies, however, study the effect of climate extremes on income or consumption *growth* in developing countries using micro-level household data, largely because suitable panel datasets have not been available. One early exception is Dercon (2004) who, using data from the Ethiopian Rural Household Survey, shows that rainfall shocks had a substantial negative impact on consumption growth in the period 1989–1997, which persisted for many years.

The lack of socio-economic data at a subnational level is a chronic constraint to study the impacts of climate extremes on regional, local, or individual household outcomes in poorer countries, where this information is arguably most needed. The average interval between nationally representative economic surveys in half African nations is above 6.5 years, compared to a subannual frequency in most wealthy countries (Burke et al. 2021). The long intervals between surveys make it difficult to link climate extremes to changes in economic and social outcomes. High-frequency household surveys and systematic post-disaster surveys with anonymized georeferenced data to assess hazard exposure are expensive, time-consuming and may require deploying enumerators to remote and dangerous locations, but they are needed to better assess the role of climate shocks in development and poverty reduction (Hallegate and Rozenberg 2017, Burke et al. 2021).

To overcome the paucity of survey-based, spatially disaggregated socioeconomic data, satellite images of night-time light intensity have been used as a proxy for local economic activity (Bertinelli and Strobl 2013, Elliott et al. 2015, Klomp 2016). Recent advances in satellite-based methods combine night-time light data with high-resolution daytime satellite images (both publicly available) for a more accurate approximation to household consumption and wealth (Yeh et al. 2020). These new approaches offer the promise to complement and enhance primary-data collection. They can also assist with quick preliminary damage estimation that would take much longer with conventional damage and loss assessments.

2.4 Effects of disasters on other economic and social outcomes

An important limitation of the focus of empirical research on GDP and its growth is that GDP measures the monetary value of economic output, not welfare. Evaluating the efficiency of adaptation measures necessitates a full accounting of *all* the impacts of climate extremes on *welfare* including those that are difficult to monetize (e.g., fatalities, morbidity, psychological damage, or biodiversity loss) and that markets do not capture well. In addition, Bakkensen and Barrage (2023) argue that because economic growth in macroeconomic climate-economy models is endogenous, empirical research should quantify disaster impacts on the structural determinants of growth: human capital, physical capital, and productivity, and not just on growth itself to account for macroeconomic adaptation through endogenous adjustments in savings and investment. For example, Bilal and Rossi-Hansberg (2023) use reduced-form estimates of the impacts of severe storms and heat waves on wages, employment, population, and investment to calibrate a general equilibrium model of the US economy, which they use to quantify long-term adaptation responses through migration and investment mobility.

2.4.1 Effects on Human Capital

Climate extremes affect human capital in multiple ways. Firstly, they kill and injure people. Excess mortality and morbidity can occur immediately, through drowning or injuries –as with tropical cyclones, severe storms, or floods, or with a lag, through malnutrition or disease including pathogenic disease (Mora et al. 2022) –as with floods or droughts. In addition to physical health, climate extremes can have significant negative consequences for mental health (Obradovich et al. 2018).

Studies explaining disaster fatalities have estimated versions of equation (1) finding, generally, that countries with higher incomes and better institutions suffer fewer deaths from disasters (Kahn 2005, Noy 2009, Fankhauser and McDermott 2014). More frequent exposure to tropical cyclones reduces fatalities (Hsiang and Narita 2012), which suggests adaptation. The intensity of the storms may matter for the extent of adaptation, however –Bakkensen and Mendelsohn (2016) find similar results but only for strong storms- as well as the timing of the exposure. For floods, Miao (2019) finds that it is recent past floods that reduce fatalities of current events. Heat waves are among the most lethal climate extremes (NWS 2023), and here there is also evidence of adaptation. Barreca et al. (2016) show that, in the US, mortality on days with mean temperature exceeding 80°F is lower in hot climates than in cooler climates. They further document a 75% decline in heat-related mortality over the 20th century due to the adoption of residential air conditioning. Climate control can also mitigate the effects of extreme heat on workers' productivity (Somanathan et al. 2021).

Monetization of mortality risks has relied on empirical estimates of the Value of a Statistical Life (VSL) and the Value of a Life Year, but studies tailored to climate extremes and developing countries have not been forthcoming. This contrasts with the large magnitude of the potential losses. The central VSL-based estimate of excess mortality from heat waves in France between 2015 and 2019 is €23.2 billion (Adelaide et al. 2022). Globally, Carleton et al. (2022) estimate the mean increase in mortality risk from extreme temperatures under a high-emissions scenario at 3.2% of global GDP in 2100—but as high as 27.5% and 18.5% of GDP in Pakistan and Bangladesh, respectively.

Additional, complementary estimates of the welfare costs of climate extremes are provided by studies directly estimating their effect on measures of subjective well-being (e.g., self-reported life satisfaction) that are used as proxies for experienced utility. Luechinger and Raschky (2009) and Ahmadiani and Ferreira (2021) report impacts of floods on life satisfaction that are sizeable and that yield monetary estimates comparable to price discounts in housing markets. Their findings also suggest that risk transfer mechanisms, disaster relief, and social support reduce the adverse effects of flood disasters.

Climate extremes can affect human capital accumulation in other important ways. For example, the 2010 Pakistan floods lowered literacy and increased school drop-out rates. Khan and Hussain (2022) show that in addition to destroying nearly 11,000 schools, the floods lowered employment and incomes of many households that self-insured by sending children to work. Similar disinvestments in human capital are observed following typhoons in the Philippines, especially for girls (Anttila-Hughes and Hsiang 2013, Deuchert and Felfe 2015). Maccini and Yang (2009) show that rainfall shocks even if experienced well before schooling age –around the time of birth - can have persistent, long-term impacts on adult socioeconomic status and suggest they operate through effects on infant health and educational attainment. They are only significant for women, which is consistent with gender bias in the allocation of resources in response to environmental shocks.[11] Even before birth, the fetal origins hypothesis applied to economic outcomes posits that shocks in utero can impact later-life health, educational attainment, and income (Currie and Rossin-Slater 2013, Sotomayor 2013). Further, shocks can transmit intergenerationally, with children of women exposed to disasters exhibiting lower education (Caruso 2017).

Fast-onset extreme weather events such as hurricanes or floods can displace people suddenly and involuntarily, often temporarily and over short distances.[12] If they cause permanent migration, it is likely to be internal, within a country's borders. Slow-onset events such as droughts can also result in migration but one that is perceived as voluntary and economically driven (Cattaneo et al. 2019). Clement et al. (2021) project that the number of internal climate-migrants by 2050 will be over 216 million, an increase of 73 million over similar estimates just 3 years older (Rigaud et al. 2018). Much of that migration will occur from rural to urban areas where, if unplanned could overwhelm a city's ability to cope with the inflow of residents and increase risks of, for example, extreme heat or flooding (Dodman et al. 2022). International migration is costlier and less common than internal migration and may exacerbate brain drain in developing countries by involving the migration of highly skilled people (Drabo and Mbaye 2015). Sheldon and Zhang (2022) find that in response to hurricanes, floods, and coastal storms in the US, high-income households are more likely to (mostly internally) emigrate than low-income households who are in some cases less likely to emigrate than they would have been in the absence of the shock. This highlights that although climate shocks create an incentive to move, moving costs act as a

[11] See also Neumayer and Plumper (2007).

[12] In 2022 there were a record 32.6 million people displaced by disasters, mostly by floods (Internal Displacement Monitoring Center, IDMC, 2023).

significant barrier that may become unsurmountable after experiencing a disaster, and "trap" vulnerable population in riskier areas (Cattaneo et al. 2019, Kaczan and Orgill-Meyer 2020).

2.4.2 Effects on physical and financial capital, competitiveness, and innovation

Disasters destroy and damage physical, man-made capital, including residential, commercial, government buildings and their contents, vehicles, public infrastructure, and agricultural assets. As in the case of fatalities, studies estimating equation (1) with natural disaster damages on the left-hand side generally find that countries with higher incomes and better institutions suffer fewer losses from disasters (Kahn 2005, Noy 2009, Fankhauser and McDermott 2014), which again suggests adaptation as income increases.

Recovery and reconstruction in the aftermath of climate disasters requires potentially large flows of financial capital, but climate disasters can destabilize financial markets. Climate change risk is systemic and not "hedgeable" with standard financial instruments (Bolton et al. 2021). The financial sector itself is exposed to climate risks through the effect of disasters on the solvency of borrowers as well as their effect on the value of real estate assets used as collateral for bank loans (Hernández de Cos 2021).

Existing evidence suggests that both public finances and private capital flows are negatively affected by disasters. Major disasters often increase government debt by increasing public spending –in disaster relief response and in the repair and reconstruction of damaged public infrastructure, while lowering tax revenues (Lis and Nickel 2010, Melecky and Raddatz 2015, Deryugina 2022). In the US, hurricanes increase non-disaster government transfers such as employment insurance and public medical payments in affected counties in the decade after the hurricane (Deryugina 2017). At the same time, climate risk vulnerability and climatological disasters increase the cost of government debt financing, especially for local governments (Jerch et al. 2023) and in developing countries (Cevik and Jalles 2022, Fisera et al. 2023), and increase the probability of a sovereign debt default (Klomp 2017). Credit ratings are already lower in developing countries; and updating beliefs about climate threats (due to e.g., more frequent climate extreme events) could lead to "capital flight" from most vulnerable countries (Ferriani et al. 2023). Yang (2008) shows that only two forms of international financial flows to poor countries increase after they experience hurricanes: foreign aid and migrants' remittances – although David (2011) does not corroborate the findings for aid flows following climatic disasters. Moreover, humanitarian aid is typically a small fraction of the magnitude of the destruction (Becerra et al. 2014), and sometimes is reallocated from aid that had already been committed to other sectors of the affected country (Becerra et al. 2015).

Large disasters that destroy production capabilities may reduce competitiveness. While the effects on imports are ambiguous, the consensus is that exports decrease (Osbergaus 2019). The response of the export sector (and the overall recovery) is bigger and faster in flexible exchange rate regimes (Ramcharan 2007). Pelli and Tschopp (2017) show that exporting sectors are affected differentially across the spectrum of comparative advantage, reminiscent of a Schumpeterian process of creative destruction of shifting resources towards higher comparative advantage industries. Miao and Popp (2014) ask whether disasters spur "risk-mitigating innovation" that facilitates coping with and building resilience to future shocks (e.g., new techniques for flood control or new drought-resistant crops). They find that patents increase following domestic disasters –and foreign floods, suggesting (reactive) adaptation by the private sector.

3. Lessons for adaptation

Adaptation is the process of adjustment to the effects of actual or expected climate, to moderate harm or exploit beneficial opportunities (IPCC 2012, p.556). In the context of climate extremes, it entails disaster risk management –as defined in the Sendai framework for Disaster Risk Reduction – including actions to prevent new disaster risk, reduce existing risk and, acknowledging that not all disaster risk can be eliminated, manage residual risk (UNDRR 2015). Figure 2 characterizes the range of adaptation options for reducing disaster losses and strengthening resilience.[13]

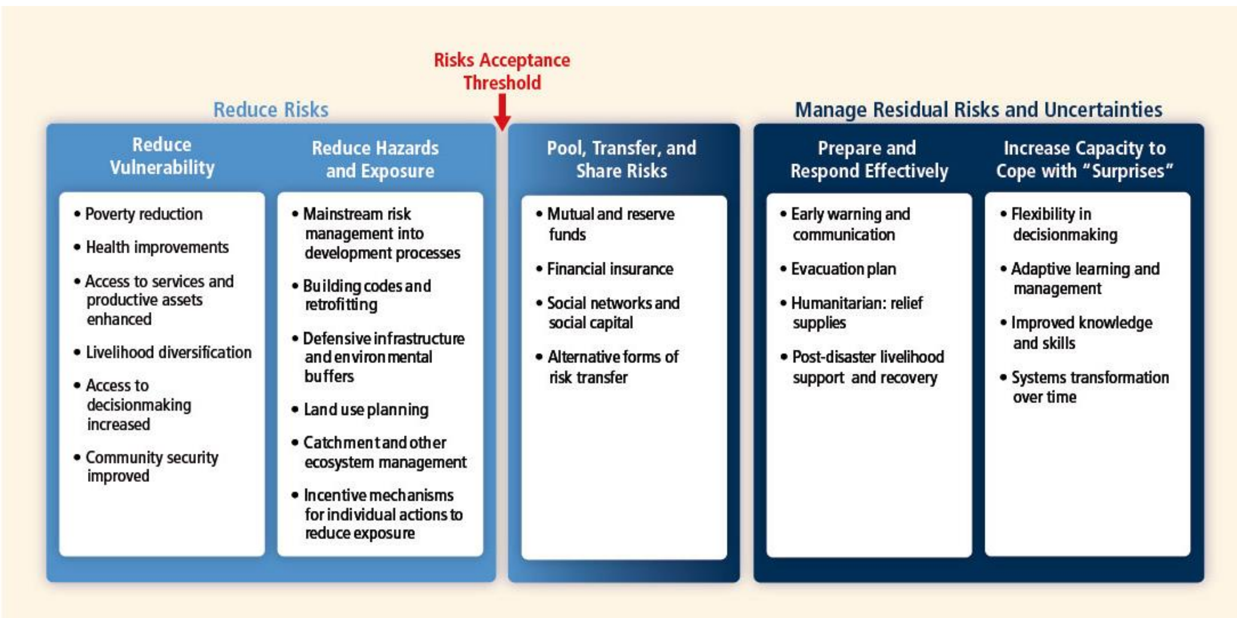

Figure 2: Risk management and adaptation options.

Notes: Reproduced with permission from IPPC 2012, p.361 – Figure 6.3 Complementary response measures for observed and projected disaster risks supported by respective institutional and individual capacity for making informed decisions.

The empirical literature reviewed in section 2 does not explicitly measure adaptation activity. Adaptation is inferred from how the response to climate extremes varies according to exposure and to a series of economic, social, and political characteristics that explain vulnerability (captured by $\boldsymbol{X_{it}}$ in equation 1). One key such factor is the level of economic development. In

---

[13] Note that the risk management and hazards literatures use the term mitigation, rather than adaptation, to describe reduction of climate risks. In the climate literature, mitigation is the reduction of GHG emissions. Resilience is defined as the ability to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner (IPCC 2012).

Fankhauser and McDermott's (2014) model of adaptation, demand for adaptation increases with income per capita. On the supply side, economic development strongly correlates with the capacity to handle climate risks, financially (e.g., through access to credit and insurance), institutionally (e.g., through effective planning regulations and building codes, good public services), and technically (e.g., by providing hazard information and early warning systems). Richer countries with better institutions tend to suffer lower human and economic losses from climate disasters (Kahn 2005, Noy 2009, Felbermayr and Gröschl 2014). At a micro level, poor people are disproportionally adversely affected by natural disasters (Hallegate et al. 2020). Beyond the generic recommendation of getting richer and better governed, some studies have started to identify more specific factors and interventions that mitigate adverse disaster impacts and speed up recovery, offering practical lessons for adaptation.

3.1. Post-disaster support and risk transfer

Richer countries fare better partly because, financially, they can mobilize significant resources for reconstruction (Cavallo and Noy 2011). Countries with more developed debt and insurance markets experience lower output declines from disasters (Melecky and Raddatz 2015). Moreover, they tend to follow counter-cyclical fiscal policy in the aftermath of disasters in contrast to developing countries whose procyclical behavior exacerbates adverse macroeconomic outcomes (Noy and Nualsri 2011). Availability of disaster relief funds facilitates the rapid deployment of post-disaster liquidity. For example, FONDEN, Mexico's indexed Natural Disasters Fund, financed the reconstruction of federal infrastructure, which accelerated recovery (Del Valle et al. 2020) and, by restoring access to health services, mitigated mortality impacts of disasters, with a benefit-cost ratio above 3.2 (Del Valle 2023).

Overall financial development helps coping with disasters; in the case of insurance without increasing the fiscal burden (Melecky and Raddatz 2015). Timely insurance payments help speed up recovery at both macro and micro (household and firm) levels (Kousky 2019, Nguyen and Noy 2020). The role of insurance in promoting risk-mitigation is, however, less clear. First, the costs of insurance may be high, preventing adoption (Kousky 2019). Second, government-sponsored programs that encourage adoption through subsidized premiums could create moral hazard (Annan and Schlenker 2015). Similarly, expectations of disaster aid might discourage ex-ante risk management (including purchasing insurance). In the US Deryugina and Kirwan (2018) show that farmers reduce crop insurance coverage in anticipation of government disaster relief while Kousky et al. (2018) find only a small reduction in the quantity of flood insurance purchased in Florida after receipt of FEMA individual assistance grants, and no impact on take-up rates, likely because there is a requirement that disaster-aid recipients purchase insurance. Using a macro model calibrated with data on US storms, disaster aid, and cyclone wind speed, Fried (2022) finds that disaster aid reduces adaptation, but that federal subsidies for adaptation more than offset this moral hazard effect.

In developing countries, insurance provision allows farmers to invest more in production activities that yield higher expected returns but are also riskier –for example, more sensitive to deficient rainfall (Cole et al. 2017). It is often assumed that insurance premiums can incentivize risk reduction and location choice; that is, premium discounts for hazard mitigation can reduce risks and aligning premiums with actual risks can deter floodplain development. However, empirical work in this area is scarce; limited by data availability and lack of exogenous changes to allow causal identification (Kousky 2019).

In developing countries, where resources to self-insure are few and risk transfer mechanisms remain uncommon (Surminsky 2022), foreign aid and migrants' remittances can lessen disasters' impacts (Hochrainer 2009). Remittances can help with both recovery and preparedness (by e.g., financing stronger houses and access to communication equipment) (Mohapatra et al. 2012). Internationally, sovereign states have created disaster insurance pools, such as the Caribbean Catastrophe Risk Insurance Facility, the African Risk Capacity, or the Pacific Catastrophe Risk Assessment and Financing Initiative. International risk pools would be even more effective if implemented globally instead of regionally (Ciullo et al. 2023).

3.2. Institutions and accountability

Democratic countries with better institutions experience fewer deaths and damages and recover more quickly from natural disasters (Kahn 2005, Noy 2009). Fellbermayr and Gröschl (2014) hypothesize that safer property rights in democracies encourage foreign and domestic investment which speeds up recovery after a disaster, and Kellenberg and Mobarak (2011) that governments in democracies are more accountable for disaster preparations and post disaster assistance. Besley and Burgess (2002) show that (democratic) state governments in India are more responsive to extreme rainfall conditions where newspaper circulation, political competition and electoral accountability are larger. In section 4.3 I return to other aspects of the political economy of government adaptation policy.

4. Government Adaptation Policy: Public vs Private Adaptation

Economic development is not a sufficient condition for climate resiliency. As economies grow, exposure to climate extremes might increase if people and economic activity move to poorly planned urban centers in vulnerable coastlines (Glavovic et al. 2022). Effective adaptation is not automatic, either; it requires knowledge of the risks and potential mitigating actions, resources for implementation, coordinated planning, and foresight (Fankhauser 2017).

The Sendai Framework for disaster risk reduction recognizes that the State has a primary role in reducing disaster risk, but that responsibility should be shared with local government, the private sector, and other stakeholders (UNDRR 2015). Moreover, given the international transmission of disaster impacts and responses, adaptation can be conceptualized as a multi-level public good with domestic, transboundary, and global dimensions (Banda 2018, Persson 2019, Carter et al. 2021).

National governments are critical to providing public goods related to risk management (e.g., flood risk protection through infrastructure, early warning systems) and are responsible for much of the public infrastructure and assets at risk (e.g., bridges, roads). They control budgetary allocations and through disaster relief they are often the 'insurer of last resort' (Priest 1996). Through institutional arrangements, policies and regulations they create the environment in which other stakeholders make decisions (Lal et al. 2012). An important role of public policy in this regard is to facilitate effective private adaptation by incentivizing the right actions and removing potential distortions (Fankhauser 2017).

Most countries in the world have established adaptation plans, strategies, laws, and policies, to implement actions such as those in Figure 2, but the financing of adaptation actions in developing countries is 5-10 times below the estimated need and the adaptation gap is widening (UNEP 2022). Prioritizing adaptation actions becomes necessary, but it is difficult. First, their efficacy is hard to assess because adaptation responses are frequently motivated by both climatic and non-climatic drivers simultaneously, and interact with other socio-economic processes (e.g., urbanization, economic growth) that also affect risk (O'Neill et al. 2022). Measuring adaptation is difficult as there are no common reporting systems and many actions that reduce climate risk may not be labelled as climate adaptation (Lempert et al. 2018). Second, adaptation decisions are made in a context of ambiguity or deep uncertainty, as the scientific uncertainty in climate models is particularly acute for spatially and temporally localized climate extremes. In this context, the expected utility framework may be of limited use (see Heal and Millner (2014) and Fankhauser (2017) for an overview of alternative decision frameworks).

4.1 Provision of "no or low regrets" adaptation public goods

"No regrets" and "low regrets" adaptation options are recommended when uncertainties over future climate change directions and impacts are high. Although they may not be optimal for every future scenario, they provide benefits under any range of climate change scenarios (Lal et al. 2012). Prominent among them, ecosystem-based adaptation harnesses nature-based solutions (NbS) and ecosystem services to protect communities from climate extremes.

One example of NbS is mangrove forests, which protect 3.5 million people and GDP worth roughly US $400 million (Blankespoor et al. 2017). The 1999 super cyclone that struck Orissa, India caused fewer fatalities in villages with wider remaining mangroves than in villages with narrower or no mangroves, even though all villages benefited from early warnings (Das and Vincent 2009). Another example is coastal wetlands, which in the US reduced property damage caused by 88 tropical storms and hurricanes between 1996 and 2016 by an average $1.8 million/km^2 per year and a median value of $91,000/km^2 (Sun and Carson 2020). Across the entire continental US, each hectare (=0.01 km^2) of wetlands provided flood protective services in the order of $1,840 per year between 2001 and 2016 and over $8,000 in developed areas (Taylor and Drunkenmiller 2022). In the Gulf of Mexico, three NbS –restoration of wetlands, barrier islands and oyster reefs, would reduce flood risk cost-effectively, yielding average benefit-cost ratios above 3.5, with the combination of NbS and conventional ("grey") infrastructure being most cost-effective (Reguero et al. 2018). Tree canopy in cities reduces daytime urban air temperature (Edmonson et al. 2016) which in turn can reduce heat-related mortality (Kalkstein et al. 2022).

In addition to disaster risk reduction, NbS provide benefits such as carbon sequestration, air and water purification, soil erosion prevention and recreation, and it is often argued that NbS could outperform defensive grey infrastructure (such as levees) if all their benefits were considered.

Few studies, however, provide full economic or social evaluations of NbS, and analyses that explicitly compare NbS to conventional, grey measures are rare (Nelson et al. 2020).

Another example of “no or low regrets” adaptation strategy by national governments is early warning systems. They facilitate emergency preparedness to forecastable and actionable hazards, benefiting more than 5 billion people worldwide (New et al. 2022). Two recent studies suggest that the benefit-cost ratio of improving weather forecasts is well above one. Molina and Rudik (2022) report that improvements in short-term hurricane forecasts in the US over the period 2007-2020 reduced damages by 19%, about $5 billion per hurricane. Shrader et al. (2023) show that, in the US in the period 2005-2017, improving the accuracy of routine weather forecasts by 50%would reduce mortality from temperature by 2,200 lives generating a net value of $2.9 billion per year, of which $0.8 billion reflect their value in adapting to climate change. While most of this value comes from warm and cool days which are much more common than extreme heat or cold, mortality risk responds to forecast errors most strongly on extreme heat days (either because adaptation is more responsive or more consequential for mortality in extreme heat).

4.2 Facilitating effective private adaptation

Early warning systems can reduce mortality and other damages only if people respond to them, for example by pre-deploying emergency power generation or evacuating. In fact, effective climate risk management cannot happen without household-level adaptation (van Valkengoed and Steg 2019). Here, public policy can facilitate private adaptation by addressing market failures and behavioral barriers in a context in which individuals make decisions under risk and uncertainty. Insurance is a prime example.

It is well known that because damages from climate disasters are fat tailed and spatially correlated, climate risks cannot be pooled and are difficult to hedge, prompting governments to intervene in disaster insurance markets to guarantee availability and/or affordability of insurance coverage (Kousky 2022). In 2022, the global protection gap (i.e., the disaster losses not covered by insurance) was around $151 billion dollars (Banerjee et al. 2023). As damages from climate disasters increase, there is some evidence that private insurers are retreating from areas of high wildfire and hurricane risk (Dixon 2018, Botros 2023), a trend that will accentuate government’s participation in insurance markets or as insurer of last resort.

Government interventions can lessen the financial and economic repercussions of disasters, but should be carefully designed so that financial markets correctly price climate-related risks to encourage ex-ante risk management (Bolton et al. 2021). For example, an increase in insurance premiums to reflect increasing climate risks could be complemented with means-tested voucher programs coupled with loan programs for investments in hazard mitigation, to address affordability (Kousky and Kunreuther 2014). In addition, smart policy should acknowledge the heuristics and biases that guide individuals’ decision making regarding low-probability/high-impact climate risks (Kunreuther and Botzen 2022). Meyer and Kunreuther (2017) recommend using the principles of choice architecture in the design of measures that accept these biases as part of the choice process (e.g., bundling several low-probability risks into a single insurance policy, expressing disaster probabilities over longer time horizons, or using default options).

Implementation of this type of choice-architecture measures remains limited, however, and studying their effectiveness is an open area of future research.

Relocation often emerges as an alternative when other forms of adaptation are insufficient (Cattaneo et al. 2019), but also as a forward-looking adaptation strategy that substantially reduces the spatial variance in the welfare impacts of climate change (Bilal and Rossi-Hansberg 2023). As discussed in Section 2.4.1 vulnerable populations may be involuntarily "trapped" in hazardous areas and require government interventions to continue living in exposed locations or to remove obstacles to a safe and orderly migration (Cissé et al. 2023). The study of the effects of natural disasters on migration, and particularly of how government interventions can facilitate successful migration outcomes are promising areas of research.

The empirical study of individuals' optimal adaptation is complicated by the endogeneity of risk perceptions, risk preferences, and disaster risk itself: decisions regarding where to live, whether to purchase insurance and other concurrent adaptive actions are influenced by risk perceptions and risk preferences, with implications for climate risk capitalization in housing markets. Hedonic pricing studies report much variability on the effect of flood risk on house prices (Beltran et al. 2018). Hino and Burke (2021) find that in the US flood risk information is not fully capitalized into property values –more sophisticated commercial buyers and risk aware buyers respond more to flood risk information- which suggests that better risk communication could improve the efficiency of market outcomes. The prices of properties at risk have been found to fall after flood events, suggesting that floods provide new information that updates flood risk perceptions, but the effect is short-lived, consistent with an availability heuristic (Bin and Landry 2013, Atreya et al. 2013). In addition to the availability of information, differences in the degree of capitalization of climate risks reflect heterogeneity in beliefs about long-run climate change risks (Baldauf et al. 2020). Underestimation of such risks and sorting based on risk perceptions and amenity values can result in a significant overvaluation of vulnerable coastal properties (Bakkensen and Barrage 2022).

Risk perceptions and preferences are not only difficult to measure but, along with time preferences and prosocial behavior, they can be affected by disasters (Brown et al. 2018, Schildberg-Hörisch 2018). This is an active and contested area of research,[14] with important practical, policy implications, as the findings that risk perceptions and preferences may not be stable suggests that after a disaster there may be a window of opportunity to encourage adaptation behaviors, including the support of adaptation and GHG mitigation policies (Bakkensen and Conte 2022).

In a meta-analysis of factors motivating individual climate adaptation, van Valkengoed and Steg (2019) report that experiencing a natural hazard is moderately, positively associated with adaptation behaviors – which include preparatory action (e.g. buying an emergency kit), evacuation, buying insurance, information seeking and policy support - but they also show a large heterogeneity between studies, highlighting that the effects of "climate proximity" on

[14] Chuang and Schechter (2015) review research on the effect of natural disasters on risk and time preferences and prosocial behavior and report conflicting results along every dimension of preferences.

individual adaptation are more complex than commonly assumed (Brügger et al. 2015). In addition, the window of opportunity may be closing more rapidly as climate disasters become more commonplace. Temperatures initially considered remarkable become unremarkable (as captured by social media posts) with repeated exposure over, roughly, a 5-year timescale, suggesting a social normalization of extremes –but not adaptation, as disasters continue to induce negative sentiments (Moore et al. 2019).

4.3. Preventing policy failure

Existing (limited) evidence on the net benefits of specific adaptation measures suggests that they are efficient, with benefit-cost ratios of about four (Mechler 2016). The even scarcer evidence comparing the effectiveness of ex-ante hazard mitigation and ex-post public assistance programs suggests that the marginal return per dollar invested in ex-ante mitigation programs is larger than that of investing in recovery; Davlasheridze et al. (2017) find it to be double, which contrasts with a much lower allocation of federal monies to hazard mitigation (in the order of 1-to-4). A political-economy explanation is that voters are "myopic": they hold elected officials accountable for actions taken after a disaster but not for preparedness. Benefits of relief spending are highly salient, immediate, and attributable to the incumbent, but benefits of preparedness are difficult to observe and not immediate, which leads to public underinvestment in risk reduction (Healy and Malhotra 2009).

Investments in disaster relief and mitigation may not reach those who most need it (Noy et al. 2021), and may respond to additional political considerations. Garrett and Sobel (2002) showed that in the US, politically important ("battle-ground") states and those with greater representation in committees overseeing the Federal Emergency Management Agency had more disasters declared between 1991 and 1999. Following floods in India, Parida (2019) shows that fatalities are lower in states whose governments are politically aligned with the central government and in election years.

Because adaptation responses often involve agents at different decision levels (local, regional, national, and even international) coordination is required to avoid incentive misalignment and moral hazard across jurisdictions. Such misalignment could happen, e.g., when a local government implements a policy designed for short-term economic growth by encouraging development in hazardous areas without fully internalizing the risks as it can rely on federal aid if a disaster strikes (Bagstad et al. 2007). Liao and Kousky (2022), for example, show that California municipalities are insulated from the costs of wildfires. For a review of the politics of climate change adaptation see Dolšak and Prakash (2018).

5. Conclusions

Record-breaking disasters caused by extreme weather and climatic events have become a new normal. Research on the economic costs of past disasters and on the factors that mitigate those damages can help to better prepare for and cope with current and future climate extremes. Much of this research has relied on country-level analysis of global disaster datasets and has generally found that disasters have a negative effect on economic growth in the short term. Few studies have analyzed long-term impacts, spatial spillovers, the cumulative impacts of multiple smaller climate extreme events, or the implications of relaxing the linearity assumption implicit in OLS estimations, and these remain open areas for future research. Incorporating the results from reduced-form empirical models of disasters impacts into structural general equilibrium models of the economy is another promising area of research.

Wider availability of high-resolution hazards data and advances in remote sensing have improved how we model exposure and, to some extent, vulnerability to natural hazards. However, more systematic collection of spatially referenced high-frequency household (and firm) surveys which include questions specific to the impacts of climate extremes would enable further study of their distributional implications (across space, economic sectors, and income groups) and, especially, their impacts on the poor, which are underrepresented in macroeconomic indicators such as GDP per capita.

Past studies consistently show that recovery from disasters is faster and fatalities and damages smaller in countries with higher incomes and better governance, indicating a strong link between adaptation and economic development. Adaptation –which in the context of climate extremes involves effective disaster risk management - does not happen automatically, however. Governments play an important role through the provision of public goods, such as defensive (conventional or nature-based) infrastructure or early warning systems, and through the implementation public policy that, ideally, facilitates effective private adaptation.

The opportunities for future research on the valuation and assessment of disaster risk-management options are enormous. Existing benefit-cost analyses suggest that the benefits outweigh the costs, particularly in the case of ex-ante risk mitigation programs, but the evaluation of adaptation actions is notoriously difficult for at least the three following reasons which suggest avenues of future research.

First, causal identification is hindered by data availability and endogeneity. Adaptation actions are not randomly distributed; they depend on the underlying hazards, on exposure and vulnerability, and on individual and societal preferences, all of which may in turn be affected by climate disasters and risks in ways that are not yet well understood. Longitudinal research designs that study actual adaptation actions and research designs with granular spatial data that exploit exogenous variation in adaptation actions across administrative boundaries would be helpful.

Second, the evaluation of the efficiency of adaptation actions requires a comprehensive assessment of their costs and benefits. Most studies on the economic costs of climate extremes focus on the effects on income or aggregate output. More attention should be paid to the quantification and monetization of all the effects of disasters on welfare, notably those on human life and suffering, and ecological services. A full accounting of net benefits of adaptation actions extends to their so-called “co-benefits” or “ancillary” benefits, which can be considerable in the case of ecosystem-based adaptation or nature-based solutions.

Third, decisions about adaptation to climate extremes are made in a context of deep uncertainty under which conventional decision-making approaches such as benefit-cost analysis are inadequate. At a micro level, individuals’ decisions with respect to low-probability, high-impact events are plagued with cognitive biases and behavioral failures that tend to preclude optimal adaptation. Governments can facilitate effective private adaptation by designing policies that correct market failure and cater to individuals' biases and heuristics. The study of adaptation by individuals and of how public policy can incentivize optimal adaptation are other promising areas of research.

This review must end with a disclaimer and on a cautionary tone. The empirical literature it covered analyzes the impacts of climate extremes observed in the last four, five decades, but the worst may be yet to come, particularly if global warming triggers climate tipping points. Moreover, the literature reviewed here estimates marginal impacts of observed disasters using statistical methods that assume linearity, and in drawing lessons from its findings, it implicitly assumes stationarity of socio-economic and climatic systems. In a world of increasing climate extremes and fat-tailed distributions of damages, economic research that relaxes these assumptions is important and urgent.

References

1. Adélaïde, L., Chanel, O. and Pascal, M., 2022. Health effects from heat waves in France: an economic evaluation. The European Journal of Health Economics, pp.1-13.
2. Ahmadiani, M. and Ferreira, S., 2021. Well-being effects of extreme weather events in the United States. Resource and Energy Economics, 64, p.101213.
3. Aldy, J.E. and Zeckhauser, R., 2020. Three prongs for prudent climate policy. Southern Economic Journal, 87(1), pp.3-29.
4. Annan, F. and Schlenker, W., 2015. Federal crop insurance and the disincentive to adapt to extreme heat. American Economic Review, 105(5), pp.262-266.
5. Anttila-Hughes, J. and Hsiang, S., 2013. Destruction, disinvestment, and death: Economic and human losses following environmental disaster. Available at SSRN 2220501.
6. Atreya, A., Ferreira, S. and Kriesel, W., 2013. Forgetting the flood? An analysis of the flood risk discount over time. Land Economics, 89(4), pp.577-596.
7. Auffhammer, M., 2018. Quantifying economic damages from climate change. Journal of Economic Perspectives, 32(4), pp.33-52.
8. Bakkensen, L.A. and Mendelsohn, R.O., 2016. Risk and adaptation: Evidence from global hurricane damages and fatalities. Journal of the Association of Environmental and Resource Economists, 3(3), pp.555-587.
9. Bakkensen, L.A. and Barrage, L., 2022. Going underwater? Flood risk belief heterogeneity and coastal home price dynamics. The Review of Financial Studies, 35(8), pp.3666-3709.
10. Bakkensen, L. and Barrage, L., 2023. Climate shocks, cyclones, and economic growth: bridging the micro-macro gap. The Economic Journal, conditionally accepted. Current version WP No. w24893, National Bureau of Economic Research.
11. Bakkensen, L. and Conte, M.N., 2022. Risk preferences and natural disasters: a review of theoretical and empirical themes. Handbook on the Economics of Disasters, pp.86-114.
12. Baldauf, M., Garlappi, L. and Yannelis, C., 2020. Does climate change affect real estate prices? Only if you believe in it. The Review of Financial Studies, 33(3), pp.1256-1295.
13. Banda, Maria L., Global Adaptation Law: Optimizing Legal Design for Multi-Level Public Goods after the Paris Agreement (May 1, 2018). Vanderbilt Journal of Transnational Law, 2018, Available at SSRN: https://ssrn.com/abstract=3134172
14. Banerjee, C., Bevere, L., Corti, T., Finucane, J., and Lechner, R., 2023. Sigma: Natural catastrophes and inflation in 2022: A perfect storm, Swiss Re Institute, 22 February 2023.
15. Barreca, A., Clay, K., Deschenes, O., Greenstone, M. and Shapiro, J.S., 2016. Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the twentieth century. Journal of Political Economy, 124(1), pp.105-159.
16. Basker, E. and Miranda, J., 2018. Taken by storm: business financing and survival in the aftermath of Hurricane Katrina. Journal of Economic Geography, 18(6), pp.1285-1313.
17. Becerra, O., Cavallo, E. and Noy, I., 2014. Foreign aid in the aftermath of large natural disasters. Review of Development Economics, 18(3), pp.445-460.
18. Becerra, O., Cavallo, E. and Noy, I., 2015. Where is the money? Post-disaster foreign aid flows. Environment and Development Economics, 20(5), pp.561-586.
19. Beltrán, A., Maddison, D. and Elliott, R.J., 2018. Is flood risk capitalised into property values?. Ecological Economics, 146, pp.668-685.

20. Bertinelli, L. and Strobl, E., 2013. Quantifying the local economic growth impact of hurricane strikes: An analysis from outer space for the Caribbean. Journal of Applied Meteorology and Climatology, 52(8), pp.1688-1697.
21. Besley, T. and Burgess, R., 2002. The political economy of government responsiveness: Theory and evidence from India. The quarterly journal of economics, 117(4), pp.1415-1451.
22. Bilal, A. and Rossi-Hansberg, E., 2023. Anticipating Climate Change Across the United States (No. w31323). National Bureau of Economic Research. https://www.nber.org/papers/w31323
23. Bin, O. and Landry, C.E., 2013. Changes in implicit flood risk premiums: Empirical evidence from the housing market. Journal of Environmental Economics and management, 65(3), pp.361-376.
24. Blankespoor, B., Dasgupta, S. and Lange, G.M., 2017. Mangroves as a protection from storm surges in a changing climate. Ambio, 46(4), pp.478-491.
25. Bolton, P., Kacperczyk, M., Hong, H.G. and Vives, X., 2021. Resilience of the financial system to natural disasters. Center for Economic Policy Research (CEPR) Press. https://cepr.org/system/files/publication-files/60025-barcelona_3_resilience_of_the_financial_system_to_natural_disasters.pdf
26. Botros, Alena. (2023) "Trouble awaits Florida's housing market as the state just lost another home insurer." Fortune.com. 7/22/2023 https://fortune.com/2023/07/22/housing-market-florida-trouble-as-home-insurers-pull-out/
27. Botzen, W.W., Deschenes, O. and Sanders, M., 2019. The economic impacts of natural disasters: A review of models and empirical studies. Review of Environmental Economics and Policy, 13(2) pp.167-188
28. Brown, P., Daigneault, A.J., Tjernström, E. and Zou, W., 2018. Natural disasters, social protection, and risk perceptions. World development, 104, pp.310-325.
29. Brügger, A., Dessai, S., Devine-Wright, P., Morton, T.A. and Pidgeon, N.F., 2015. Psychological responses to the proximity of climate change. Nature climate change, 5(12), pp.1031-1037.
30. Burke, M., Craxton, M., Kolstad, C.D., Onda, C., Allcott, H., Baker, E., Barrage, L., Carson, R., Gillingham, K., Graff-Zivin, J. and Greenstone, M., 2016. Opportunities for advances in climate change economics. Science, 352(6283), pp.292-293.
31. Burke, M., Driscoll, A., Lobell, D.B. and Ermon, S., 2021. Using satellite imagery to understand and promote sustainable development. Science, 371(6535), p.eabe8628.
32. Carleton, T.A. and Hsiang, S.M., 2016. Social and economic impacts of climate. Science, 353(6304), p.aad9837.
33. Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R.E., McCusker, K.E., Nath, I. and Rising, J., 2022. Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. The Quarterly Journal of Economics, 137(4), pp.2037-2105.
34. Carter, T.R., Benzie, M., Campiglio, E., Carlsen, H., Fronzek, S., Hildén, M., Reyer, C.P. and West, C., 2021. A conceptual framework for cross-border impacts of climate change. Global Environmental Change, 69, p.102307.

35. Carter, C., Cui, X., Ghanem, D. and Mérel, P., 2018. Identifying the economic impacts of climate change on agriculture. Annual Review of Resource Economics, 10, pp.361-380.
36. Caruso, G.D., 2017. The legacy of natural disasters: The intergenerational impact of 100 years of disasters in Latin America. Journal of Development Economics, 127, pp.209-233.
37. Castells-Quintana, D., del Pilar Lopez-Uribe, M. and McDermott, T.K., 2018. Adaptation to climate change: A review through a development economics lens. World Development, 104, pp.183-196.
38. Cattaneo, C., Beine, M., Fröhlich, C.J., Kniveton, D., Martinez-Zarzoso, I., Mastrorillo, M., Millock, K., Piguet, E. and Schraven, B., 2019. Human migration in the era of climate change. Review of Environmental Economics and Policy, 13(2), pp.189-206.
39. Cavallo, E. and Noy, I., 2011. Natural disasters and the economy—a survey. International Review of Environmental and Resource Economics, 5(1), pp.63-102.
40. Cavallo, E., Galiani, S., Noy, I. and Pantano, J., 2013. Catastrophic natural disasters and economic growth. Review of Economics and Statistics, 95(5), pp.1549-1561.
41. Cavallo, E., Becerra, O. and Acevedo, L., 2022. The impact of natural disasters on economic growth. In Handbook on the economics of disasters (pp. 150-192). Edward Elgar Publishing.
42. Cevik, S. and Jalles, J.T., 2022. This changes everything: Climate shocks and sovereign bonds. Energy Economics, 107, p.105856.
43. Chuang, Y. and Schechter, L., 2015. Stability of experimental and survey measures of risk, time, and social preferences: A review and some new results. Journal of development economics, 117, pp.151-170.
44. Cissé, G., R. McLeman, H. Adams, P. Aldunce, K. Bowen, D. Campbell-Lendrum, S. Clayton, K.L. Ebi, J. Hess, C. Huang, Q. Liu, G. McGregor, J. Semenza, and M.C. Tirado, 2022: Health, Wellbeing, and the Changing Structure of Communities. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1041–1170, doi:10.1017/9781009325844.009.
45. Ciullo, A., Strobl, E., Meiler, S., Martius, O. and Bresch, D.N., 2023. Increasing countries' financial resilience through global catastrophe risk pooling. Nature Communications, 14(1), p.922.
46. Clement, V., Rigaud, K.K., de Sherbinin, A., Jones, B., Adamo, S., Schewe, J., Sadiq, N., Shabahat, E. 2021. Groundswell Part 2: Acting on Internal Climate Migration. World Bank, Washington, DC. http://hdl.handle.net/10986/36248 License: CC BY 3.0 IGO.
47. Cole, M.A., Elliott, R.J., Okubo, T. and Strobl, E., 2019. Natural disasters and spatial heterogeneity in damages: the birth, life and death of manufacturing plants. Journal of Economic Geography, 19(2), pp.373-408.
48. Cole, S., Giné, X. and Vickery, J., 2017. How does risk management influence production decisions? Evidence from a field experiment. The Review of Financial Studies, 30(6), pp.1935-1970.

49. Coronese, M., Lamperti, F., Keller, K., Chiaromonte, F. and Roventini, A., 2019. Evidence for sharp increase in the economic damages of extreme natural disasters. Proceedings of the National Academy of Sciences, 116(43), pp.21450-21455.
50. Cuaresma, J.C., Hlouskova, J. and Obersteiner, M., 2008. Natural disasters as creative destruction? Evidence from developing countries. Economic inquiry, 46(2), pp.214-226.
51. Cuaresma, J.C., 2022. Natural disasters and economic growth: revisiting the evidence. In Handbook on the Economics of Disasters (pp. 134-149), edited by M. Skidmore, Edward Elgar Publishing.
52. Currie, J. and Rossin-Slater, M., 2013. Weathering the storm: Hurricanes and birth outcomes. Journal of health economics, 32(3), pp.487-503.
53. Das, S. and Vincent, J.R., 2009. Mangroves protected villages and reduced death toll during Indian super cyclone. Proceedings of the National Academy of Sciences, 106(18), pp.7357-7360.
54. David, A.C., 2011. How do international financial flows to developing countries respond to natural disasters?. Global Economy Journal, 11(4), p.1850243.
55. Davlasheridze, M., Fisher-Vanden, K. and Klaiber, H.A., 2017. The effects of adaptation measures on hurricane induced property losses: Which FEMA investments have the highest returns?. Journal of Environmental Economics and Management, 81, pp.93-114.
56. De Mel, S., McKenzie, D. and Woodruff, C., 2012. Enterprise recovery following natural disasters. The Economic Journal, 122(559), pp.64-91.
57. Del Valle, A., de Janvry, A. and Sadoulet, E., 2020. Rules for recovery: Impact of indexed disaster funds on shock coping in Mexico. American Economic Journal: Applied Economics, 12(4), pp.164-195.
58. Del Valle, A., 2023. Saving Lives with Indexed Disaster Funds: Evidence from Mexico. American Economic Journal: Economic Policy (forthcoming)
59. Dell, M., Jones, B.F. and Olken, B.A., 2014. What do we learn from the weather? The new climate-economy literature. Journal of Economic literature, 52(3), pp.740-798.
60. Dercon, S., 2004. Growth and shocks: evidence from rural Ethiopia. Journal of Development economics, 74(2), pp.309-329.
61. Dercon, S. and Christiaensen, L., 2011. Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. Journal of development economics, 96(2), pp.159-173.
62. Deuchert, E. and Felfe, C., 2015. The tempest: Short-and long-term consequences of a natural disaster for children′ s development. European Economic Review, 80, pp.280-294.
63. Deryugina, T., 2017. The fiscal cost of hurricanes: Disaster aid versus social insurance. American Economic Journal: Economic Policy, 9(3), pp.168-198.
64. Deryugina, T. and Kirwan, B., 2018. Does the Samaritan's dilemma matter? Evidence from US agriculture. Economic Inquiry, 56(2), pp.983-1006.
65. Deryugina, T., 2022. The fiscal consequences of natural disasters. In Handbook on the Economics of Disasters, edited by M. Skidmore, Edward Elgar Publishing, pp. 208-228
66. Dixon, L., Tsang, F. and Fitts, G., 2018. The impact of changing wildfire risk on California’s residential insurance market. California’s Fourth Climate Change Assessment. California Natural Resources Agency (available at: www. energy. ca. gov/sites/default/files/2019-07/Forests_CCCA4-CNRA-2018-008. pdf).

67. Dodman, D., B. Hayward, M. Pelling, V. Castan Broto, W. Chow, E. Chu, R. Dawson, L. Khirfan, T. McPhearson, A. Prakash, Y. Zheng, and G. Ziervogel, 2022. Cities, Settlements and Key Infrastructure. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 907–1040, doi:10.1017/9781009325844.008.
68. Dolšak, N. and Prakash, A., 2018. The politics of climate change adaptation. Annual Review of Environment and Resources, 43, pp.317-341.
69. Drabo, A. and Mbaye, L.M., 2015. Natural disasters, migration and education: an empirical analysis in developing countries. Environment and Development Economics, 20(6), pp.767-796.
70. Edmondson, J.L., Stott, I., Davies, Z.G., Gaston, K.J. and Leake, J.R., 2016. Soil surface temperatures reveal moderation of the urban heat island effect by trees and shrubs. Scientific Reports, 6(1), p.33708.
71. Elliott, R., Strobl, E., & Sun, P. (2015). The local impact of typhoons on economic activity in China: A view from outer space. Journal of Urban Economics, 88, 50–66.
72. Fankhauser, S., 2017. Adaptation to climate change. Annual Review of Resource Economics, 9, pp.209-230.
73. Fankhauser, S. and McDermott, T.K., 2014. Understanding the adaptation deficit: why are poor countries more vulnerable to climate events than rich countries?. Global Environmental Change, 27, pp.9-18.
74. Fankhauser, S. and Tol, R.S., 2005. On climate change and economic growth. Resource and Energy Economics, 27(1), pp.1-17.
75. Felbermayr, G. and Gröschl, J., 2014. Naturally negative: The growth effects of natural disasters. Journal of development economics, 111, pp.92-106.
76. Ferriani, F., Gazzani, A.G. and Natoli, F., 2023. Flight to climatic safety: local natural disasters and global portfolio flows. Available at SSRN 4497865.
77. Filipski, M., Jin, L., Zhang, X. and Chen, K.Z., 2019. Living like there's no tomorrow: The psychological effects of an earthquake on savings and spending behavior. European Economic Review, 116, pp.107-128.
78. Fisera, B., Horvath, R. and Melecky, M., 2023. Natural Disasters and Debt Financing Costs. Climate Change Economics, 14(03), p.2350015.
79. Fisher, A.C., Hanemann, W.M., Roberts, M.J. and Schlenker, W., 2012. The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather: comment. American Economic Review, 102(7), pp.3749-3760.
80. Fried, S., 2022. Seawalls and stilts: A quantitative macro study of climate adaptation. The Review of Economic Studies, 89(6), pp.3303-3344.
81. Garrett, T.A. and Sobel, R.S., 2003. The political economy of FEMA disaster payments. Economic inquiry, 41(3), pp.496-509.
82. Glavovic, B.C., R. Dawson, W. Chow, M. Garschagen, M. Haasnoot, C. Singh, and A. Thomas, 2022: Cross-Chapter Paper 2: Cities and Settlements by the Sea. In: Climate

Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2163–2194, doi:10.1017/9781009325844.019.
83. Heal, G. and Millner, A., 2014. Reflections: Uncertainty and decision making in climate change economics. Review of Environmental Economics and Policy, 8(1), pp.120-137.
84. Hallegatte, S. and Ghil, M., 2008. Natural disasters impacting a macroeconomic model with endogenous dynamics. Ecological Economics, 68(1-2), pp.582-592.
85. Hallegatte, S. and Rozenberg, J., 2017. Climate change through a poverty lens. Nature Climate Change, 7(4), pp.250-256.
86. Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Bangalore, M. and Beaudet, C., 2020. From poverty to disaster and back: A review of the literature. Economics of Disasters and Climate Change, 4, pp.223-247.
87. Healy, A. and Malhotra, N., 2009. Myopic voters and natural disaster policy. American Political Science Review, 103(3), pp.387-406.
88. Hernández de Cos, P. 2021. The role of central banks and banking supervisors in climate action. In Bolton, P., Kacperczyk, M., Hong, H.G. and Vives, X., 2021. Resilience of the financial system to natural disasters. Center for Economic Policy Research (CEPR) Press. https://cepr.org/system/files/publication-files/60025-barcelona_3_resilience_of_the_financial_system_to_natural_disasters.pdf, pp. 5-10.
89. Hino, M. and Burke, M., 2021. The effect of information about climate risk on property values. Proceedings of the National Academy of Sciences, 118(17), p.e2003374118.
90. Hochrainer, S., 2009. Assessing the macroeconomic impacts of natural disasters: are there any?. World Bank policy research working paper, (4968). http://hdl.handle.net/10986/4162 License: CC BY 3.0 IGO
91. Hoeppe, P., 2016. Trends in weather related disasters–Consequences for insurers and society. Weather and climate extremes, 11, pp.70-79.
92. Hsiang, S.M., 2010. Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. Proceedings of the National Academy of Sciences, 107(35), pp.15367-15372.
93. Hsiang, S.M. and Narita, D., 2012. Adaptation to cyclone risk: Evidence from the global cross-section. Climate Change Economics, 3(02), p.1250011.
94. Hsiang, S.M. and Jina, A.S., 2014. The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones (No. w20352). National Bureau of Economic Research.
95. IDMC (Internal Displacement Monitoring Centre), 2023. 2023 Global Report on Internal Displacement (GRID). Accessed at https://www.internal-displacement.org/global-report/grid2023/
96. IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L.

Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp

97. IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 36 pages. (in press).
98. Jerch, R., Kahn, M.E. and Lin, G.C., 2023. Local public finance dynamics and hurricane shocks. Journal of Urban Economics, 134, p.103516.
99. Kaczan, D.J. and Orgill-Meyer, J., 2020. The impact of climate change on migration: a synthesis of recent empirical insights. Climatic Change, 158(3-4), pp.281-300.
100. Kahn, M.E., 2005. The death toll from natural disasters: the role of income, geography, and institutions. Review of economics and statistics, 87(2), pp.271-284.
101. Kahn, M.E., 2016. The climate change adaptation literature. Review of Environmental Economics and Policy, 10(1), pp.166-178.
102. Kalkstein, L.S., Eisenman, D.P., de Guzman, E.B. and Sailor, D.J., 2022. Increasing trees and high-albedo surfaces decreases heat impacts and mortality in Los Angeles, CA. International journal of biometeorology, 66(5), pp.911-925.
103. Kazianga, H. and Udry, C., 2006. Consumption smoothing? Livestock, insurance and drought in rural Burkina Faso. Journal of Development economics, 79(2), pp.413-446.
104. Khan, Q. and Hussain, K., 2022. Gone with the Flood: Natural Disasters and Children's Schooling in Pakistan. The BE Journal of Economic Analysis & Policy, 23(1), pp.271-283.
105. Klomp, J., 2016. Economic development and natural disasters: A satellite data analysis. Global Environmental Change, 36, pp.67-88.
106. Klomp, J., 2017. Flooded with debt. Journal of International Money and Finance, 73, pp.93-103.
107. Klomp, J. and Valckx, K., 2014. Natural disasters and economic growth: A meta-analysis. Global Environmental Change, 26, pp.183-195.
108. Kolak, M. and Anselin, L., 2020. A spatial perspective on the econometrics of program evaluation. International Regional Science Review, 43(1-2), pp.128-153.
109. Kousky, C., 2014. Informing climate adaptation: A review of the economic costs of natural disasters. Energy economics, 46, pp.576-592.
110. Kousky, C., Michel-Kerjan, E.O. and Raschky, P.A., 2018. Does federal disaster assistance crowd out flood insurance?. Journal of Environmental Economics and Management, 87, pp.150-164.
111. Kousky, C., 2019. The role of natural disaster insurance in recovery and risk reduction. Annual Review of Resource Economics, 11, 399-418.
112. Kousky, C., 2022. Understanding disaster insurance: New tools for a more resilient future. Island Press.
113. Kousky, C. and Kunreuther, H., 2014. Addressing affordability in the national flood insurance program. Journal of Extreme Events, 1(01), p.1450001.

114. Kunreuther, H. and Botzen, W., 2022. The role of biases and heuristics in addressing natural disasters. In Handbook on the Economics of Disasters (pp. 72-85). Edward Elgar Publishing.
115. Lal, P.N., T. Mitchell, P. Aldunce, H. Auld, R. Mechler, A. Miyan, L.E. Romano, and S. Zakaria, 2012: National systems for managing the risks from climate extremes and disasters. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 339-392.
116. Leiter, Andrea M., Harald Oberhofer, and Paul A. Raschky. "Creative disasters? Flooding effects on capital, labour and productivity within European firms." Environmental and Resource Economics 43 (2009): 333-350.
117. Lempert, R., J. Arnold, R. Pulwarty, K. Gordon, K. Greig, C. Hawkins Hoffman, D. Sands, and C. Werrell, 2018: Reducing Risks Through Adaptation Actions. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1309–1345. doi: 10.7930/NCA4.2018.CH28
118. Liao, Y. and Kousky, C., 2022. The fiscal impacts of wildfires on California municipalities. Journal of the Association of Environmental and Resource Economists, 9(3), pp.455-493.
119. Lima, R.C.D.A. and Barbosa, A.V.B., 2019. Natural disasters, economic growth and spatial spillovers: Evidence from a flash flood in Brazil. Papers in Regional Science, 98(2), pp.905-924.
120. Lis, E.M. and Nickel, C., 2010. The impact of extreme weather events on budget balances. International Tax and Public Finance, 17, pp.378-399.
121. Loayza, N.V., Olaberria, E., Rigolini, J. and Christiaensen, L., 2012. Natural disasters and growth: Going beyond the averages. World Development, 40(7), pp.1317-1336.
122. Luechinger, S. and Raschky, P.A., 2009. Valuing flood disasters using the life satisfaction approach. Journal of Public Economics, 93(3-4), pp.620-633.
123. Maccini, S. and Yang, D., 2009. Under the weather: Health, schooling, and economic consequences of early-life rainfall. American Economic Review, 99(3), pp.1006-1026.
124. Mechler, R., 2016. Reviewing estimates of the economic efficiency of disaster risk management: opportunities and limitations of using risk-based cost–benefit analysis. Natural Hazards, 81, pp.2121-2147.
125. Melecky, M. and Raddatz, C., 2015. Fiscal responses after catastrophes and the enabling role of financial development. The World Bank Economic Review, 29(1), pp.129-149.
126. Mendelsohn, R., Nordhaus, W.D. and Shaw, D., 1994. The impact of global warming on agriculture: a Ricardian analysis. The American economic review, 84(4), pp.753-771.
127. Meyer, R. and Kunreuther, H., 2017. The ostrich paradox: Why we underprepare for disasters. University of Pennsylvania Press.

128. Miao, Q., 2019. Are we adapting to floods? Evidence from global flooding fatalities. Risk Analysis, 39(6), pp.1298-1313.
129. Miao, Q. and Popp, D., 2014. Necessity as the mother of invention: Innovative responses to natural disasters. Journal of Environmental Economics and Management, 68(2), pp.280-295.
130. Mohapatra, S., Joseph, G. and Ratha, D., 2012. Remittances and natural disasters: ex-post response and contribution to ex-ante preparedness. Environment, Development and Sustainability, 14, pp.365-387.
131. Molina, R., and Rudik, I.,2022. The Social Value of Predicting Hurricanes. CESifo Working Paper No. 10049, Available at SSRN: https://ssrn.com/abstract=4266614 or http://dx.doi.org/10.2139/ssrn.4266614
132. Moore, F.C., Obradovich, N., Lehner, F. and Baylis, P., 2019. Rapidly declining remarkability of temperature anomalies may obscure public perception of climate change. Proceedings of the National Academy of Sciences, 116(11), pp.4905-4910.
133. Mora, C., McKenzie, T., Gaw, I.M., Dean, J.M., von Hammerstein, H., Knudson, T.A., Setter, R.O., Smith, C.Z., Webster, K.M., Patz, J.A. and Franklin, E.C., 2022. Over half of known human pathogenic diseases can be aggravated by climate change. Nature climate change, 12(9), pp.869-875.
134. Nelson, D.R., Bledsoe, B.P., Ferreira, S. and Nibbelink, N.P., 2020. Challenges to realizing the potential of nature-based solutions. Current Opinion in Environmental Sustainability, 45, pp.49-55.
135. Neumayer, E. and Plümper, T., 2007. The gendered nature of natural disasters: The impact of catastrophic events on the gender gap in life expectancy, 1981–2002. Annals of the association of American Geographers, 97(3), pp.551-566.
136. New, M., D. Reckien, D. Viner, C. Adler, S.-M. Cheong, C. Conde, A. Constable, E. Coughlan de Perez, A. Lammel, R. Mechler, B. Orlove, and W. Solecki, 2022: Decision-Making Options for Managing Risk. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2539–2654, doi:10.1017/9781009325844.026.
137. Nguyen, C.N. and Noy, I., 2020. Measuring the impact of insurance on urban earthquake recovery using nightlights. Journal of Economic Geography, 20(3), pp.857-877.
138. NOAA, 2023a. Climate Change: Global Temperature accessed at https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature
139. NOAA, 2023b. National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters. https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73 accessed December 30, 2023.
140. Noy, I., 2009. The macroeconomic consequences of disasters. Journal of Development economics, 88(2), pp.221-231.

141. Noy, I. and Nualsri, A., 2011. Fiscal storms: public spending and revenues in the aftermath of natural disasters. Environment and Development Economics, 16(1), pp.113-128.
142. Noy, I., Nguyen, C. and Patel, P., 2021. Floods and spillovers: Households after the 2011 great flood in Thailand. Economic Development and Cultural Change, 69(2), pp.829-868.
143. NWS (National Weather Service), 2023. Weather Related Fatality and Injury Statistics https://www.weather.gov/hazstat/
144. Obradovich, N., Migliorini, R., Paulus, M.P. and Rahwan, I., 2018. Empirical evidence of mental health risks posed by climate change. Proceedings of the National Academy of Sciences, 115(43), pp.10953-10958.
145. Okuyama, Y., 2022. A few good models for economic analysis of disasters: can your model handle the truth?. Handbook on the Economics of Disasters, pp.30-49.
146. O'Neill, B., M. van Aalst, Z. Zaiton Ibrahim, L. Berrang Ford, S. Bhadwal, H. Buhaug, D. Diaz, K. Frieler, M. Garschagen, A. Magnan, G. Midgley, A. Mirzabaev, A. Thomas, and R. Warren, 2022: Key Risks Across Sectors and Regions. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2411–2538, doi:10.1017/9781009325844.025.
147. Osberghaus, D., 2019. The effects of natural disasters and weather variations on international trade and financial flows: a review of the empirical literature. Economics of Disasters and Climate Change, 3(3), pp.305-325.
148. Parida, Y., 2020. Economic impact of floods in the Indian states. Environment and Development Economics, 25(3), pp.267-290.
149. Pelli, M. and Tschopp, J., 2017. Comparative advantage, capital destruction, and hurricanes. Journal of International Economics, 108, pp.315-337.
150. Persson, Å., 2019. Global adaptation governance: An emerging but contested domain. Wiley Interdisciplinary Reviews: Climate Change, 10(6), p.e618.
151. Pindyck, R.S., 2022. Climate future: Averting and adapting to climate change. Oxford University Press.
152. Priest, G.L., 1996. The government, the market, and the problem of catastrophic loss. Journal of risk and Uncertainty, 12, pp.219-237.
153. Reguero, B.G., Beck, M.W., Bresch, D.N., Calil, J. and Meliane, I., 2018. Comparing the cost effectiveness of nature-based and coastal adaptation: A case study from the Gulf Coast of the United States. PloS one, 13(4), p.e0192132.
154. Ramcharan, R., 2007. Does the exchange rate regime matter for real shocks? Evidence from windstorms and earthquakes. Journal of International Economics, 73(1), pp.31-47.
155. Rigaud, K. K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, J., Adamo, S., McCusker, B., Heuser, S., Midgley, A., 2018. Groundswell: Preparing for Internal Climate Migration. World Bank, Washington, DC. http://hdl.handle.net/10986/29461 License: CC BY 3.0 IGO.

156. Roth Tran, B. and Wilson, D.J., 2023, November. The Local Economic Impact of Natural Disasters. Federal Reserve Bank of San Francisco Working Paper 2020-34. https://doi.org/10.24148/wp2020-34
157. Schelling, T.C., 1992. Some economics of global warming. The American Economic Review, 82(1), pp.1-14.
158. Schildberg-Hörisch, H., 2018. Are risk preferences stable?. Journal of Economic Perspectives, 32(2), pp.135-154.
159. Sheldon, T.L. and Zhan, C., 2022. The impact of hurricanes and floods on domestic migration. Journal of Environmental Economics and Management, 115, p.102726.
160. Shrader, J.G., Bakkensen, L. and Lemoine, D., 2023. Fatal Errors: The Mortality Value of Accurate Weather Forecasts (No. w31361). National Bureau of Economic Research.
161. Skidmore, M. and Toya, H., 2002. Do natural disasters promote long-run growth?. Economic inquiry, 40(4), pp.664-687.
162. Somanathan, E., Somanathan, R., Sudarshan, A. and Tewari, M., 2021. The impact of temperature on productivity and labor supply: Evidence from Indian manufacturing. Journal of Political Economy, 129(6), pp.1797-1827.
163. Sotomayor, O., 2013. Fetal and infant origins of diabetes and ill health: evidence from Puerto Rico's 1928 and 1932 hurricanes. Economics & Human Biology, 11(3), pp.281-293.
164. Strobl, E., 2011. The economic growth impact of hurricanes: Evidence from US coastal counties. Review of Economics and Statistics, 93(2), pp.575-589.
165. Strobl, E., 2012. The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions. Journal of Development economics, 97(1), pp.130-141.
166. Sun, F. and Carson, R.T., 2020. Coastal wetlands reduce property damage during tropical cyclones. Proceedings of the National Academy of Sciences, 117(11), pp.5719-5725.
167. Surminski (2022) The role of insurance in integrated disaster risk management with a focus on how insurance can support climate adaptation and disaster resilience – in Handbook on the Economics of Disasters, edited by Mark Skidmore, pp. 294-318.
168. Taylor, C.A. and Druckenmiller, H., 2022. Wetlands, flooding, and the clean water act. American Economic Review, 112(4), pp.1334-1363.
169. Tol, R.S., 2018. The economic impacts of climate change. Review of environmental economics and policy, 12(1), pp.4-25.
170. Tol, R. and Leek, F., 1999. Economic Analysis of Natural Disasters, In Climate Change and Risk, edited by Thomas E. Downing, Alexander A. Olsthoorn, and Richard S.J. Tol. Routledge, London, pp. 308–327.
171. UNDRR (United Nations Office for Disaster Risk Reduction) 2015, Sendai Framework for Disaster Risk Reduction 2015-2030. Accessible at https://www.undrr.org/quick/11409
172. UNEP (United Nations Environment Programme) 2022. Adaptation Gap Report 2022: Too Little, Too Slow – Climate adaptation failure puts world at risk. Nairobi. https://www.unep.org/adaptation-gap-report-2022
173. van Valkengoed, A.M. and Steg, L., 2019. Meta-analyses of factors motivating climate change adaptation behaviour. Nature climate change, 9(2), pp.158-163.

174. Wagner, G. and Weitzman, M.L., 2015. Climate shock: the economic consequences of a hotter planet. Princeton University Press.
175. Weitzman, M.L., 2009. On modeling and interpreting the economics of catastrophic climate change. The review of economics and statistics, 91(1), pp.1-19.
176. World Economic Forum, 2023. Global Risks Report https://www.weforum.org/reports/global-risks-report-2023/digest
177. Yang, D., 2008. Coping with disaster: The impact of hurricanes on international financial flows, 1970-2002. The BE Journal of Economic Analysis & Policy, 8(1).
178. Yeh, C., Perez, A., Driscoll, A., Azzari, G., Tang, Z., Lobell, D., Ermon, S. and Burke, M., 2020. Using publicly available satellite imagery and deep learning to understand economic well-being in Africa. Nature communications, 11(1), p.2583.
179. Zachariah, M., Philip, S., Pinto, I., Vahlberg, M., Singh, R., Arrighi, J., Barnes, C., Otto, F.E.L, 2023. Extreme heat in North America, Europe and China in July 2023 made much more likely by climate change. Report: Grantham Institute for Climate Change, DOI: https://doi.org/10.25561/105549