The Economics of Natural Disasters

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Abstract

This review discusses the ways in which countries are affected by natural disasters, depending on their socioeconomic characteristics, their level of development, and their inherent levels of natural disaster risk. We also explore various aspects of ex ante disaster mitigation such as improvements in natural disaster risk information and natural disaster insurance markets, as well as ex post responses to natural disaster in the form of postdisaster aid and long-run growth prospects. By highlighting some of the recent findings in this literature, we synthesize what we know about the economics of natural disasters and identify research areas of interest for future work.

OECD: Organization for Economic Cooperation and Development

1. INTRODUCTION

Since 1970 there have been more than 9,800 natural disasters worldwide, killing more than 3.7 million people, affecting more than 5.8 billion people,[1] and causing more than $1.7 trillion in estimated damages, and the numbers are steadily increasing (**Figure 1**).[2] Yet despite a nearly fivefold increase in the number of annual natural disasters since the early 1970s, **Figure 2** shows a decline in the number of people killed per disaster, due primarily to a decrease in deaths per disaster in non–Organization for Economic Cooperation and Development (OECD) countries and relatively constant deaths per disaster in OECD countries. A similar story has occurred with respect to the number of people affected by natural disasters. **Figure 3** shows that the total number of people affected per natural disaster has declined overall since 1970, again as a result of the decreasing impact of natural disasters in non-OECD countries, with the most notable decrease over the past two decades.

Figure 4, however, demonstrates a rather different relationship. In non-OECD countries there is a minimal increase in the value of damages from natural disasters (normalized to 2008 US$) since 1970. However, damage per disaster in OECD countries has increased substantially over the time period.

These data, along with recent events such as the Indian Ocean tsunami in 2004, Hurricane Katrina in 2005, the Sichuan earthquake in China in 2008, the Haitian earthquake in 2009, and the Japanese earthquake and tsunami in 2011, serve as potent reminders of the magnitude of the economic consequence of disasters. Economic research on the topic has, however, remained limited. With scientists arguing that global warming is likely to generate even more frequent and violent natural disasters in the future, a need for research on their impacts has increased.

This review discusses the many factors that make nations more vulnerable to natural disasters and their far-reaching effects. We explore the ways countries are affected, depending on their socioeconomic characteristics, their progression along the development curve, and their inherent levels of risk. We also examine research that has explored various aspects of both ex ante and ex post disaster mitigation in the form of improvements in natural disaster risk information, natural disaster insurance markets, and postdisaster aid. By highlighting some of the recent findings in this literature, we hope to synthesize what we know about the economics of natural disasters and to identify areas of interest for future research. Growing populations, which are increasingly in disaster-prone geographical locations, combined with the potential for more extreme weather events due to global warming have increased the importance of our understanding of the effects of natural disasters and people's responses to public policy. Through better predictions of where disasters will strike, improved risk mitigation, and better disaster mitigation, policy makers will be better able to promote an efficient level of ex ante mitigation.

The remainder of this review is organized as follows. Section 2 discusses the geographic regions that are affected by natural disasters, Section 3 describes the theory behind the impact of natural disasters, Section 4 provides empirical evidence regarding damages caused by disasters, Section 5 explores methods of mitigating these effects, Section 6

[1]The EM-DAT database (**http://www.emdat.be/database**), an emergency events database collected by the Centre for Research on the Epidemiology of Disasters (CRED), defines the total number of people affected by a natural disaster as the sum of those people injured, homeless, or needing immediate assistance following a disaster.

[2]All data come from the EM-DAT database.

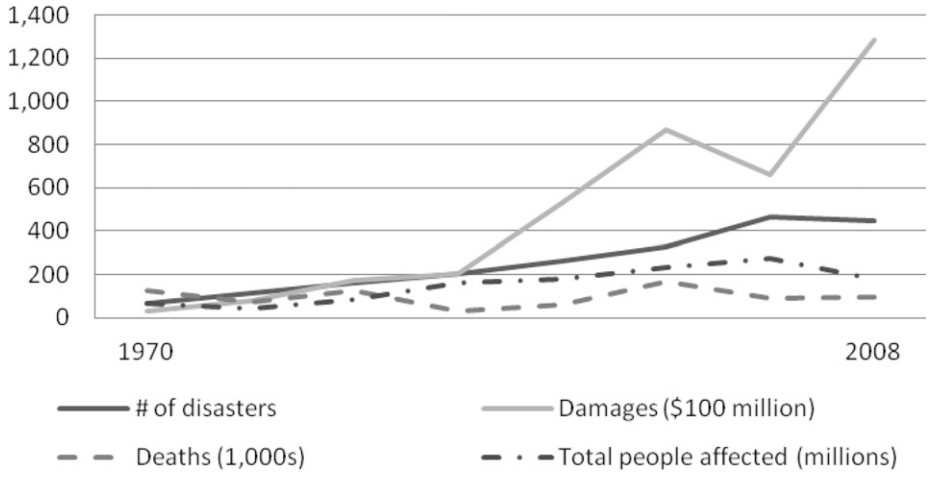

Figure 1

World disaster effects, 1970–2008.

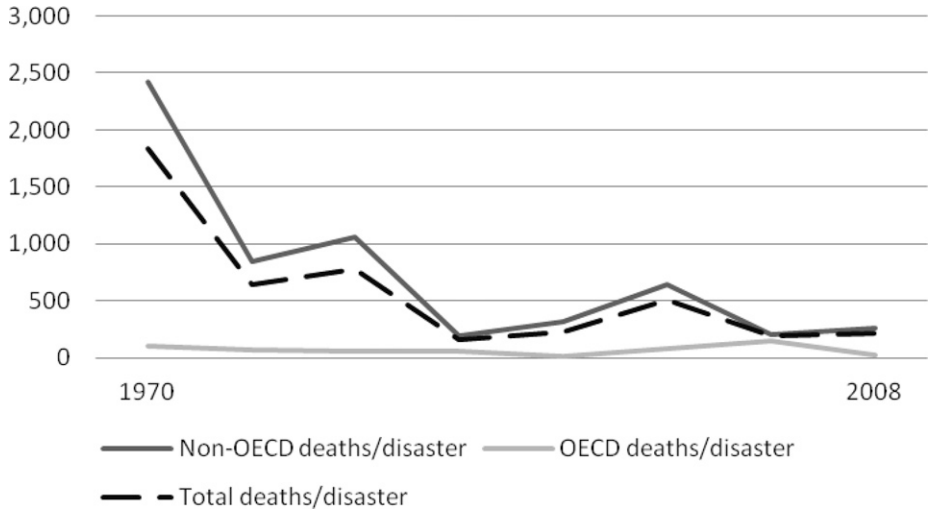

Figure 2

Deaths per disaster.

discusses policy recommendations, and Section 7 outlines areas of future research on the economics of natural disasters.

2. WHAT COUNTRIES FACE THE HIGHEST RISK OF NATURAL DISASTERS?

Geography, not surprisingly, dictates both the likelihood of facing a natural disaster as well as the potential consequences of the disaster. Substantial cross-continent differences in the probability of disasters are found; the Americas, Europe, and Asia experience more disaster

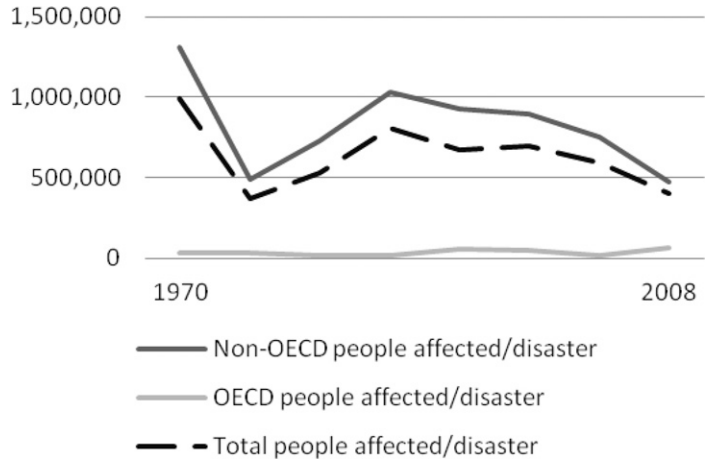

Figure 3

People affected per disaster.

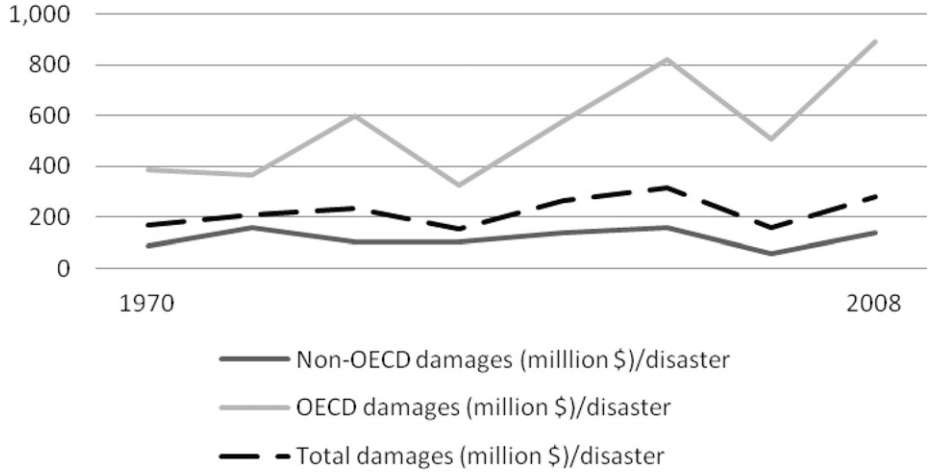

Figure 4

Damages per disaster.

shocks than does Africa. In fact, Kahn (2005) finds that, relative to Africa, Asia is 28.5 percentage points more likely to experience a disaster in any given year. Countries with coastal exposure are more likely to suffer the consequences of windstorms or tsunamis, whereas countries located on or near fault lines are more likely to suffer losses due to earthquakes.

In his research, Kahn (2005) focuses on four geographical indicators: continent, elevation, distance from the equator, and population density. He finds that nations at higher elevation levels are prone to landslides but are less likely to suffer from windstorms. With the exception of landslides, countries farther from the equator show an increased number of disasters. Similarly, Schumacher & Strobl (2008) note that only certain coastal areas

Table 1 Number of deaths (in thousands) by natural disaster categories (1960–2007)[a]

	Climatological	Geophysical	Hydrological	Meteorological
Europe	83	40	5	3
Africa	878	23	19	4
Asia	1,532	827	213	692
Oceania	1	1	3	2
North America	3	1	2	12
Latin America and the Caribbean	2	162	55	50
Total	**2,499**	**1,054**	**297**	**763**

[a]From Cropper & Sahin (2009).

Table 2 Number of deaths (in thousands) by natural disaster categories (1988–2007)[a]

	Climatological	Geophysical	Hydrological	Meteorological
Europe	81	29	2	1
Africa	2	5	15	2
Asia	19	460	105	209
Oceania	0	1	2	1
North America	2	0	1	5
Latin America and the Caribbean	2	7	43	28
Total	**106**	**502**	**168**	**246**

[a]From Cropper & Sahin (2009).

suffer from tropical cyclones (e.g., the U.S. North Atlantic and Gulf of Mexico coastline, Caribbean Sea, South Pacific). Only areas where tectonic plates collide experience earthquakes (e.g., United States, Turkey, Chile, Japan).

Geographic location is indicative not only of the likelihood of a natural disaster but also of the effect the disaster will have. In **Table 1** and **Table 2** below, we see that the distribution of deaths from natural disasters across regions of the world is anything but uniform, with Asia suffering the largest losses, particularly for geophysical, hydrological, and meteorological disasters.[3] Cropper & Sahin (2009) point out that the number of deaths due to climatological disasters, such as drought, has decreased substantially over more recent time periods relative to other types of natural disasters, due primarily to increased foreign aid to affected countries. However, the number of deaths due to other disaster types (i.e., geophysical, hydrological, and meteorological) is still largely biased

[3]Climatological disasters are defined as droughts, extreme temperatures, and wildfires; geophysical disasters are volcanoes, earthquakes, or tsunamis; hydrological disasters are floods or landslides; and meteorological disasters are storms such as cyclones or hurricanes (Cropper & Sahin 2009).

GDP: gross domestic product

toward particular regions; Asia, Latin America, and the Caribbean are the most affected by hydrological and meteorological disasters. One explanation for the geographical differences in death tolls can be found in Kahn (2005), who finds that, although a nation's elevation or distance from the equator does not predict the severity of a shock, it can dictate the death toll. His findings show that a one-standard-deviation increase in elevation lowers the death count from windstorms by approximately 25%. An elevation of 1,000 feet or more has the same effect on the death toll as an increase in per-capita gross domestic product (GDP) of $4,740.

3. WHAT IS THE IMPACT OF NATURAL DISASTERS ON A COUNTRY?

There are several ways in which a country is impacted by a natural disaster; research is divided on whether a natural disaster is beneficial for a country on the whole. In the short run, according to Raddatz (2007), certain disaster shocks, including climatic disasters such as droughts, extreme temperature events, windstorms, and floods, can have a significant impact on per-capita GDP. Such climatic disasters result in an average real per-capita income loss of 2%, whereas humanitarian disasters such as famines or epidemics result in an average real per-capita income loss of 4% in the short run. Skidmore & Toya (2002), in contrast, argue that GDP does not account for damage to capital and durable goods in the short run; indeed, the addition of new capital in the immediate term may increase GDP.

Skidmore & Toya (2002) also find a positive correlation between natural disasters and growth in the long run. Using a panel data set on 89 countries, they first look at the effects of disaster events on GDP/per-capita growth rates and find that climatic disasters have a positive and significant effect on growth rates. They hypothesize that this growth is due to capital stock accumulation, human capital accumulation, or improvements in technological capacity. The hypothesis comes from a simple growth framework in which they specify a Cobb-Douglas production function:

$$y_t = A_t k_t^a h_t^{1-a}, \tag{1}$$

where y is total output per capita at time t, A represents the level of technology, k is the capital stock per capita, and h is the human capital stock per capita. A growth equation based on the production function above yields

$$\dot{y}_t/y_t = \dot{A}_t/A_t + a(\dot{k}_t/k_t) + (1-a)(\dot{h}_t/h_t). \tag{2}$$

Long-run growth rates may be affected as newer and more productive technologies replace outdated ones. Despite the destruction of capital, disasters increase the return to human capital relative to investment capital and increase total factor productivity through the adoption of newer and more productive technologies (Skidmore & Toya 2002). The research findings therefore highlight important macroeconomic channels through which countries may grow following catastrophic natural disasters.

Some would argue that the benefits of investing in more technologically advanced capital are offset by the short-run productivity losses of a disaster: Extra time is required to train workers and to fully incorporate new technology. As a result, capital is often immediately replaced with older, out-of-date technology. Hallegatte & Dumas (2009) argue that this tendency leaves long-run productivity unchanged compared with predisaster levels. This trend demonstrates how low-income countries that suffer from

frequent disasters are at risk of becoming stuck in a poverty trap. They continually replace damaged capital with capital similar to what existed before the disaster in order to resume prior levels of productivity as quickly as possible. This, however, limits the possibility of future increases in productivity.

Natural disasters also affect labor markets. Using a panel data set on floods across the United States, Sarmiento (2007) shows that on average, aggregate local employment falls by 3.4% following a flood event as workers flee the area. Income levels, however, increase following a disaster, according to Belasen & Polachek (2009). In their study of the impact of a hurricane in Florida on income in affected relative to indirectly affected counties, income grew by 4.35% in directly affected areas as a result of the decrease in the labor supply and the simultaneous increase in posthurricane labor demand, particularly in construction and building. Another explanation for this growth in income levels is the loss in public capital in affected counties where the quality of life has decreased and workers are therefore monetarily compensated for working in an area lacking its prehurricane amenities. Neighboring counties, however, suffered from the influx of workers and experienced a decrease in earnings of 4.51% compared with directly affected counties. According to Banerjee (2007), flooding can also have a positive effect on long-term wages if it increases crop yield in the dry season.

There is also a literature on the psychological impacts of natural disasters. Luechinger & Raschky (2009) use data from a life satisfaction survey to value flood disasters. Specifically, they use the approach to monetize utility loses for 16 European countries between 1973 and 1998 and compare the results with data on floods in the United States. Not surprisingly, the authors find that flood disasters have a statistically significant negative effect on life satisfaction, although this effect diminishes as income increases. They find that the average willingness to pay to prevent one disaster event in the region of residence is $6,505, the equivalent of 23.7% of average income. The most interesting result is the effects of floods on life satisfaction in regions without risk transfer mechanisms (catastrophe insurance, emergency relief, or ad hoc help). These effects are larger than the effects in all regions, suggesting that risk transfer mechanisms have large offsetting effects of flood disasters on life satisfaction. One explanation for this is that uninsurable costs such as suffering, grief, or trauma are small relative to the economic damages associated with disasters.

Carroll et al. (2009) also use life satisfaction survey data to quantify the economic losses associated with disasters. Specifically, they look at the effects of droughts on life satisfaction in Australia between 2001 and 2004. They find that in rural areas, if a drought occurs in the springtime (as opposed to any other time in the year), it has a negative and statistically significant effect on life satisfaction—equivalent to losing $14,500 of income for rural households. They use this estimate to predict that the expected doubling of dry springs after 2020 will lead to a 1% drop in Australia's GDP.

4. EFFECTS OF DISASTERS AT DIFFERENT LEVELS OF DEVELOPMENT

Not surprisingly, there are several effects of disasters on an economy. The most significant impacts are felt on short- and long-run GDP, physical capital, human capital, and the labor and real estate markets. As disasters have an undeniable effect on the trajectory of development, a country's state of development similarly dictates the impact of a natural disaster. This pattern is explained by behavioral changes that accompany economic

development. Only when levels of development have reached a certain point can nations successfully address weak institutions, create better insurance markets, require more stringent building standards, reduce corruption, and institute more advanced warning and emergency response systems. As a result of all these improvements, more developed countries are less affected by a natural disaster than are less developed countries.

Kellenberg & Mobarak (2007) find evidence of an inverted-U relationship between levels of development and the effects of natural disasters. They find that, to a certain point, per-capita damages increase with per-capita GDP—the peak of the inverted U—after which a country is less affected by disasters as it continues to develop. Using a panel data set, they find that natural disaster damages associated with flooding and windstorms increase up to per-capita GDP of $5,000 and $6,200 per annum (in 1995 purchasing power parity dollars), respectively. After that level is reached, damages from natural disasters decrease with income. However, for other types of disasters such as earthquakes and extreme temperatures, damages from disasters decrease with per-capita income.

Kellenberg & Mobarak (2007) also report descriptive statistics on deaths from natural disasters that appear to follow the inverted-U pattern. The first portion is upward sloping between income levels of $0 to $4,000, the second is near the peak of the curve between $4,001 and $7,000, and third is the downward-sloping portion of the curve with income levels above $7,000.

In many cases, citizens, as well as the government, seem responsible for the increase in vulnerability to natural disasters. Kellenberg & Mobarak (2007) argue that a risk-return trade-off between the benefits of greater development and higher income and the risks associated with natural disasters can explain the nonlinear relationship between development and disaster damages. At low levels of income, individuals may be more willing to engage in income-generating activities that carry environmental risks, such as cutting down mangrove forests for shrimp farming developments, and such behavior could actually increase individuals' risk of exposure to a natural disaster. At higher levels of development, the dominant effect of increasing income may be the extra protection and mitigation that the extra income allows.

Schumacher & Strobl (2008) also derive nonlinear relationships between development and disaster risk using a formal model of development, risk exposure, and losses. However, this paper argues that the development-disaster relationship is mediated through long-term risk exposure (i.e., whether the country is located in a risky or a nonrisky area) and that the shape of the GDP per-capita–disaster losses graph should be U shaped in high-risk countries and should follow an inverted-U shape in low-risk countries.

Schumacher & Strobl (2008) find that an increase in the risk of earthquakes, hurricanes, or floods increases adaptation expenditure only if risk aversion is significantly large, if there is the necessary amount of wealth, or if costs are low. This phenomenon can be seen in the skyscrapers on hydraulic balances in Japan and the flood dams in the Netherlands that provide significant marginal benefits. Poorer countries at high risk will have a greater percent of their wealth destroyed by a natural disaster and are therefore likely to spend a higher percentage of their GDP on adaptation than they would if they were rich. Because higher risk aversion increases the marginal value of wealth, incentives to invest in adaptation are reduced.

Lower-risk countries, especially those that are less wealthy, have only a small marginal benefit for adaptation expenditure and therefore allocate less funding toward natural

hazard adaptation. As a result, countries with a low probability of being affected by a disaster suffer greater damages than countries with a high risk of being affected. As these low-risk exposure countries become increasingly wealthy, they are likely to experience higher economic losses until the peak of the curve, when wealth is spent on adaptation expenditure and leads to diminishing losses.

Thus, by separating two underlying components of the disaster-development relationship, namely, (*a*) increases in income increase the demand for safety and (*b*) higher incomes enable countries to employ costly precautionary measures, Schumacher & Strobl (2008) argue that two equally wealthy countries may suffer very different losses from natural disasters due to their differing risk and expenditure profiles.

Individuals also increase their risk of loss in the event of a natural disaster by migrating to urban centers and overwhelming a city's capacity and ability to provide essential public services. This leads to inadequate housing and congestion and increases the number of people exposed to a natural disaster. In addition, development can degrade the natural environment and make cities more prone to being adversely affected by natural disasters such as landslides.

5. WHAT ARE THE MITIGATING FACTORS THAT ALLOW A COUNTRY TO BETTER HANDLE A NATURAL DISASTER?

The effects of natural disasters span reductions in GDP, disruptions in labor markets, and reduced levels of life satisfaction. Yet the degree to which a country is affected depends on a number of proxies for institutional quality, including measures of democracy, educational attainment of the population, level of corruption, macroeconomic conditions, income inequality, and ethnic fragmentation. Toya & Skidmore (2007) use a cross-country panel data set covering a 44-year period to assess several of these critical indicators. They find that greater educational attainment, greater openness, and a strong financial sector have a negative effect on the number of people killed by natural disasters. The results (especially for schooling) tend to be particularly important when the model is run on a subset of developing countries. Additional findings from Noy (2009) include the fact that GDP growth is less affected by natural disasters in more literate countries, in countries with higher per-capita incomes, in countries with higher degrees of openness, and in countries with better institutions. Democratic governments are expected to have a positive effect on addressing the impact of disasters because they will be held accountable for their disaster preparations and response to postdisaster assistance. The results suggest that policy makers may be able to decrease risk of loss in the event of a natural disaster by holding themselves to the highest institutional standards. The results on the openness and size (depth) of financial markets are not inconsistent with the findings of Yang (2008).

The degree of corruption, particularly among government officials and regulators, similarly contributes to disaster mitigation. Escaleras et al. (2007) examine the effects of corruption on disaster deaths for 344 earthquakes between 1975 and 2003 in 42 countries. They do not blame earthquakes for killing people but instead blame poorly constructed buildings. To prove this, they develop a model of corruption in which contractors compete in a competitive building market and government regulators take bribes that allow contractors to lower their construction costs and increase safety risks. Bribes taken at an early structural stage in the building process often lead regulators at later stages to approve of construction that does not meet required standards. As a result, the impact of

bribes in the regulation process is known only after an earthquake occurs and a structure fails. The model predicts that, all else equal, the level of public sector corruption in a country will have a significant positive effect on the number of fatalities from earthquake disasters.

In addition to the state of institutions and corruption in a country, the economic state of the country dictates its ability to mitigate the effects of a natural disaster. According to a cross-country panel study conducted by Noy (2009), the magnitude of the effect of a natural disaster depends on the level of development and the size of an economy. Smaller or less developed economies are not as diversified in their productive capacity and financial markets and are thus less able to successfully insure against the external shocks of a natural disaster, thereby increasing the adverse effects on GDP.

The effects of a natural disaster can be mitigated not only by having a larger economy but also by being in a certain stage in the economy's business cycle, according to Hallegatte & Ghil (2008). Findings show that during periods of expansion, economies are more likely to suffer negative consequences to growth. The theory is that countries experiencing high rates of growth and full employment of resources are more vulnerable to natural disasters that destroy productive capital. During a recessionary period, however, countries are able to use their excess capacity to better respond to a disaster.

At the micro level, Carter et al. (2007) finds that households are also affected by natural disasters to different degrees. Using household-level survey data and information on two natural disaster events, Hurricane Mitch in Honduras in 1998 and the 1998–2000 drought in Ethiopia, the authors estimate (*a*) the effects of disaster events on household assets and consumption and (*b*) the ability of a household to recover. The analysis is predicated on the idea that households with assets above a certain threshold will be more likely to borrow against their assets or future earnings and to recover more quickly, whereas those below the threshold will find it difficult to borrow through capital markets and will be less capable of recovering quickly as a result. Carter et al. (2007) find that the effects of Hurricane Mitch on Honduran households were indeed felt more severely, and for a longer time span, for households in the lowest-income groups, whereas households in the higher-income groups recovered their lost assets at a much faster rate.

Kahn (2005) also finds that richer nations suffer fewer deaths from natural disasters. Such nations are expected to be more capable of protecting against the devastating effects of natural disasters by designing and enforcing building codes, developing early warning systems, and providing effective and timely postdisaster emergency care and assistance. These predictions are confirmed by Kahn's empirical results, as GDP per capita has a negative and significant effect on the number of people killed by natural disasters for most of the specifications reported. Escaleras & Register (2008), in a study of 146 earthquake-generated tsunamis between 1966 and 2004, similarly find that wealthier countries also suffer less from natural disasters because of the advanced technologies they employ to predict disaster events and to better disseminate warnings to the general public.

Kellenberg & Mobarak (2007) extend the analysis regarding the role of income on natural disaster risk by examining the marginal effect of income at different levels of development. Prior work found a negative effect of income on deaths from disaster, suggesting that efforts to eliminate poverty and to increase development may be a successful policy prescription for effective disaster risk mitigation. However, income growth as a policy for reducing natural disaster risk is predicated on the idea that demand for natural disaster risk reduction is monotonically increasing in income.

Although income tends to decrease the risk of death from natural disasters for earthquakes and extreme temperature events, other disaster events such as floods, landslides, and windstorms display strong, nonmonotonic, inverted-U-shaped relationships between income and disaster deaths. Therefore, for some categories of natural disasters, a blanket policy prescription of growing away from risk may be ill conceived. Indeed, countries with per-capita income of less than $3,360, $4,688, and $5,044 could potentially increase their risk of deaths from disaster from landslides, windstorms, and floods, respectively. In these low-income countries, more proactive policies aimed at affecting location decisions and other behavioral or environmental choices that affect disaster risk may be necessary in conjunction with policies aimed strictly at economic development.

GINI coefficient: a statistical measure of income inequality

ODA: official development assistance

Anbarci et al. (2005) also explore the effects of income, but by looking at income disparity. The authors develop a theoretical political economy model to demonstrate the importance of income and the degree of income inequality on the distribution of resources for social collective action decisions. They find that decisions regarding building codes, zoning regulations, licensing requirements for engineers or contractors, and the enforcement of these rules can have substantial mitigating effects when an earthquake strikes. The study looks at the effects of income per capita and income disparity (measured using various types of GINI coefficients) on fatalities in 269 earthquakes worldwide that occurred between 1960 and 2002 and that measured greater than six on the Richter scale. Findings are consistent with the hypothesis that lower income and greater inequality make it more difficult for societies to achieve collective action decisions that can better mitigate disasters, and therefore lead to greater mortality from disasters. Ethnic fragmentation is similarly positively correlated with higher deaths, as under such circumstances it is more difficult for government institutions to provide public goods (e.g., infrastructure or disaster prevention resources) and to enforce regulations (e.g., building codes). One explanation for this finding is that in unequal societies, in which a large percentage of the population is poor or there are a large number of fragmented ethnic groups, it is more difficult to build trust in governments and institutions.

In addition to domestic characteristics that mitigate the effects of a natural disaster, external factors affect how successful a country will be in handling the effects of a natural disaster. One such factor is international financial flows into a country following a natural disaster. Yang (2008) examines the response of various types of financial flows, including official development assistance (ODA), lending from multinational institutions, bank and trade-related lending, foreign direct investment, portfolio investment, and migrants' remittances following hurricanes. He finds that ODA is the only type of international financial flow that responds in a significant manner to hurricanes and that the response of ODA to hurricanes tends to be greater for poorer countries relative to richer countries in the sample. Whereas richer countries are better able to engage in self-insurance prior to the occurrence of hurricanes, poorer countries are more reliant on external funding sources. In many cases such development assistance is substantial, replacing nearly 80% of the economic damage following a hurricane. During such times, migrants' remittances also increase.

Recognizing the benefit of such international aid, Eiseensee & Strömberg (2007) conducted a study on the effect of news coverage of natural disasters on the probability that the United States provides disaster relief. The authors looked at current newsworthy events as instruments to measure whether a disaster event is covered in prime-time media. On the basis of an analysis of 5,000 natural disasters between 1968

and 2002, the authors find that the probability that the United States provides disaster relief increases with news coverage but that competing news stories, or highly televised activities such as the Olympics, tend to crowd out disaster coverage and decrease the probability that a particular disaster will receive foreign aid.

6. WHAT KINDS OF POLICIES CAN BE IMPLEMENTED TO REDUCE THE EFFECTS OF NATURAL DISASTERS?

Economic research is critical in guiding policy, and the research reviewed in this article is no exception. The research highlights several areas in which policy makers might focus to mitigate the impacts of natural disasters. According to Hallegatte & Dumas (2009), government investment in upgraded technology would create additional short-term costs but would lead to long-term productivity gains. Banerjee (2007) similarly highlights the importance of policies aimed at investment to improve specifically agricultural productivity as a possible ex ante mitigation effort against short-term income losses to agricultural communities in developing countries. Other significant policies to mitigate disaster losses include reforestation efforts, the use of available insurance policies, and policies to encourage relocation.

As noted in Kellenberg & Mobarak (2007), deforestation often occurs in the process of development and has a direct, adverse effect on the environment. It may also affect the impacts of natural disasters, including floods, landslides, and droughts. As a result, policies should be aimed at encouraging reforestation. Research done by Barbier (2008) demonstrates that such policies have the potential to be quite effective if adequate incentives are provided. His work looks at the household decision to provide public goods to prevent the damaging effects of tsunamis and hurricanes. In a survey of 199 households in Thailand, he assesses willingness to contribute labor hours to mangrove reforestation projects. He hypothesizes that households make their decision to participate in mangrove reforestation projects on the basis of a utility function in which potential earnings from mangrove forests outweigh the destructive environmental consequences of deforestation. However, his research rejects his hypothesis; men, in particular, are more likely to participate in such activities when they understand the destructive environmental impacts of deforestation.

The second critical area for policy lies in insurance markets. From a theoretical perspective, natural disaster insurance is one of the most efficient ex ante mitigation strategies for protecting against catastrophic material loss. Yet in practice, Kunreuther (1996) points out that the use of natural hazard insurance is far more limited than disaster risk warrants, and he details a number of the issues regarding the lack of insurance policies to protect against natural disaster events. First, individuals underestimate the true probability of a disaster event occurring and/or have fairly high discount rates for the benefits of uncertain future reimbursements due to losses. Second, Kunreuther & Pauly (2004) provide evidence that, even when insurance for low-probability, high-loss events is offered at favorable premiums, the search costs associated with obtaining the information on premiums and disaster probabilities may be enough to deter individuals from purchasing insurance. Trends on the other side of the market can further explain the lack of insurance. Private insurers are often reluctant to offer insurance against natural disasters such as hurricanes, floods, or earthquakes due to the uncertain nature of low-probability, high-loss risks and the potential for large-scale disasters to result in financial insolvency. The combination of search costs and the underestimation of disaster probabilities by consumers, in addition to private

insurers' unwillingness to insure many types of natural disaster loss, means that the government is often left to provide ex post disaster relief.

Kunreuther & Pauly (2006) suggest that mandatory comprehensive disaster insurance in disaster-prone areas may be the solution to government disaster relief that is often poorly targeted and inefficient. Such mandatory insurance premiums could be based on models of risk potential, something that is not always easily identifiable by consumers of natural hazard insurance, even when the knowledge is available. Subsidizing the purchase of insurance by low-income households would be a more efficient use of government funds than would public disaster relief following a natural disaster.

In addition to the direct benefits that improved natural disaster markets may have for ex ante mitigation efficiency, there may be additional benefits to related markets. Garmaise & Moskowitz (2009) show that the lack of earthquake or hurricane insurance can distort bank credit markets when disaster insurance is underutilized, as a result of either owners underestimating their true risk or insurance companies being unwilling to take on the risk of a catastrophic event. As a result, at-risk properties receive less than optimal financing from banks, creating inefficient bank financing in these markets. This occurs because banks do not monitor whether property owners invest in disaster mitigation measures on their properties. In the absence of disaster insurance, property owners with a bank loan have an incentive to shift the risk of a disaster to the bank. In response, banks offer fewer loans in risk-prone areas when there is an underprovision of insurance in markets. The mandatory insurance, suggested by Kunreuther & Pauly (2006), could help to alleviate this distortion in bank credit markets.

A third policy prescription would be to encourage individuals to relocate to less risky areas. Smith et al. (2006) research individual relocation trends following a natural disaster in Dade County, Hurricane Andrew in 1992. By examining the changes in the distribution of households across neighborhoods, they find that people adjust to risk from natural disasters in different ways. Higher-income households are relatively unaffected and are therefore less likely to move following a natural disaster. This observation is consistent with the theory that higher-income households are better able to self-protect with more expensive hurricane-resistant construction and insurance—especially in coastal towns with high amenity values and high levels of perceived hurricane risk. Middle-income households move away from such locations due to the increase in perceived risk. Lower-income households, however, tend to move into damaged areas to take advantage of the increase in perceived risk and the subsequent drop in property prices.

Several studies conducted on the effects of natural disasters on the housing market in affected and neighboring areas come to the same conclusion. Beron et al. (1997) find that the quality-adjusted price of residential housing fell in the San Francisco Bay Area after the 1989 Loma Prieta earthquake; Loomis (2004) shows that the price of houses in the town of Pine, Colorado, fell after a devastating forest fire destroyed ten homes in the nearby town of Buffalo Creek; and Hallstrom & Smith (2005) show that property values in neighboring counties that suffered near misses from Hurricane Andrew in Florida in 1992 fell by at least 19%. These studies highlight the fact that homeowners often may not know, or correctly perceive, the true risk of disaster.

Chivers & Flores (2002) find that buyers purchasing homes in special flood zones underestimate the true degree of flood risk. When disaster events occur in close proximity to particular markets, home buyers adjust their perceived risk, which is subsequently

reflected in housing prices. Mueller et al. (2009) find that repeated forest fires have a negative impact on housing prices near fires and that the price impact of a second fire is greater than the impact for the first fire. This finding suggests that better ex ante risk information will improve the accuracy of risk perceptions that are capitalized into home prices.

More accurate risk information would make homes in higher-risk areas more expensive and less desirable and would therefore reduce overall damages from future natural disasters. Donovan et al. (2007) examine the effect of disseminating public information about the risk of wildfire. They look at home prices in Colorado Springs, Colorado, to evaluate the effects of Web-based wildfire risk ratings of 35,000 local homes provided by the Colorado Springs Fire Department. They find that prior to available Web-based risk measures, home prices and measures of parcel-level wildfire risk were positively correlated. This phenomenon can be explained by the fact that wildfire risk is positively correlated with amenity values (e.g., living on a mountain or near public forest) so that prior to risk information being available, buyers undervalued the risk component relative to the amenity value. After the Web site was made available, there was no longer a statistically significant positive effect of wildfire risk ratings on housing prices, suggesting that increased awareness of wildfire risk became more important relative to amenity values in buyers' decisions. This research provides evidence that increased public information can have a significant effect on home buyers' decisions, thereby demonstrating the need for policy to provide as much information as possible concerning likely current and future risk exposures of the different areas where people are currently residing or are thinking about purchasing a home.

These ex ante and ex post mitigation policy recommendations, however, cannot be introduced without careful country-specific analysis. Cropper & Sahin (2009) stress the importance of conducting cost-benefit or cost-effectiveness analyses of both ex ante and ex post mitigation policies. These methods are important tools to evaluate the efficiency of disaster risk reduction policies as well as of policies in other sectors, including road safety or environmental protection. One method is to measure the costs of losses stemming from damages and losses to financial assets in the event of a disaster, and another method is to estimate the value of mortality reductions and the value of avoided injuries as a result of disasters by using quality-adjusted life years. Although such measures are more common in developed countries, they must be carried to the developing world, and to each country specifically, so that accurate measures and efficiency levels can be determined (Cropper & Sahin 2009).

7. FUTURE RESEARCH ON THE ECONOMICS OF NATURAL DISASTERS

This review explores the current literature on the economics of natural disasters and identifies gaps for further research. Although a growing literature has begun to emerge on the economics of natural disasters, our understanding of many of the socioeconomic and political economy factors, particularly at more micro levels, such as cost-benefit analysis of policies, needs to improve. In particular, research, especially for developing countries, that addresses predisaster mitigation efforts and decision making by both governments and households, such as the research in United Nations & World Bank (2010), will prove insightful. Certainly, research into the development of more

sophisticated disaster insurance markets is an important area to explore, particularly given the rising costs of natural disaster damages. However, in the short run, developing countries are less likely to be financially and institutionally equipped to operate with the same sophistication in insurance markets as can more developed countries. For developing countries, research that identifies complementarities between disaster mitigation and antipoverty measures would help policy makers to take preemptive measures to avoid damages from natural disaster events. In particular, research that addresses how households make risk-return trade-offs with respect to employment and location decisions, especially when there is imperfect information on disaster risks, is an understudied but promising area. Micro-based studies of this nature should be specific to different types of disasters, as different regions and societies will face very different disaster risks on the basis of their geography and level of development. Policy regarding natural disaster risk in the future will be improved by a better understanding of disaster-specific analysis for countries that have different geographical risks and levels of development.

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