In the Eye of the Storm:
Coping with Future Natural Disasters in Hawaii

Makena Coffman
Department of Urban Planning and UHERO
University of Hawai'i at Mānoa

and

Ilan Noy*
Department of Economics
University of Hawai'i at Mānoa

Working Paper No. 09-4
May 2009

Abstract

Hurricane Iniki, that hit the island of Kauai on September 11th, 1992, was the strongest hurricane that hit the Hawaiian Islands in recorded history, and the one that wrought the most damage, estimated at 7.4 billion (in 2008 US$). We provide an assessment of Hawaii's vulnerability to disasters using a framework developed for small islands. In addition, we provide an analysis of the *ex post* impact of Iniki on the economy of Kauai. Using indicators such as visitor arrivals and agricultural production, we show that Kauai's economy only returned to pre-Iniki levels 7-8 years after the storm. Today, it has yet to recover in terms of population growth. As an island state, Hawaii is particularly susceptible to the occurrence of disasters. Even more worrying, Hawaii's dependence on tourism, narrow export base, high level of imports and relatively small agricultural sector make Hawaii much more likely to struggle to recover in the aftermath. By thoroughly learning from Kauai's experience and the state's vulnerabilities, we hope we can better prepare for likely future disaster events.

Keywords: natural disasters, hurricane, Iniki, Kauai, Hawaii, climate change, global warming

JEL codes: Q54, R50

* Corresponding author, email; noy@hawaii.edu, Phone: 1-808-956-7749, Fax: 1-808-956-4347.

1. Introduction

Natural disasters often result in significant human and economic loss. Major recent catastrophic events — such as the December 2004 tsunami in the Indian Ocean, the Pakistani Kashmir earthquake of October 2005 and cyclone Nargis that hit Myanmar in May 2008 — have brought the human and material cost of these disasters to the forefront of public attention worldwide. Hurricane Iniki, that hit the island of Kauai on September 11th, 1992, was the strongest hurricane that hit the Hawaiian Islands in recorded history, and the one that wrought the most damage, estimated at $5 billion.[1]

Today, with the evident warming of the planet and the attendant changes in the patterns of climatic events that are predicted to accompany such warming (IPCC, 2007), the importance of understanding the economic impact of natural disasters cannot be overstated.[2] International bodies like United Nations are particularly concerned, reporting that: "Since 2000, some 1.6 billion have lost their homes or livelihoods or have suffered other damage [from natural disasters – MC & IN]; by some measures this constitutes a four-fold annual increase from the decade of the 1970s."[3]

Research in both the social and natural sciences has been devoted to increasing our

[1] Very few people died. See Jarrell et al. (2001), for estimates of the costliest U.S. hurricanes in the 20th century.

[2] Changing sea, land and air temperatures, rising sea levels, changing patterns of precipitation and an unstable climate are all likely catalysts of future weather-related events such as storms, floods, and draughts. For now, there is apparently no evidence that geo-physical disasters may also be affected by global warming.

[3] The United Nation's *Integrated Regional Information Network* notes, "while the number of lives lost has declined in the past 20 years - 800,000 people died from natural disasters in the 1990s, compared with 2 million in the 1970s — the number of people affected has risen. Over the past decade, the total affected by natural disasters has tripled to 2 billion." (IRIN, 2005).

ability to predict disasters and prepare for them; but curiously, few economists participate in this research agenda. We were surprised to realize at the onset of this project, for example, that no comprehensive or even cursory attempt has been made to account for the long-term impact of hurricane Iniki on the economy of the island of Kauai.

Here, we would like to focus on the Iniki's *ex post* impact on the economy of Kauai. We hope that by thoroughly describing these economic impacts, we can learn and better prepare for likely future disaster events. But, because Hawaii's experience with disasters is not in any way unique, we first describe the current state of the literature that examines the economics of disasters in small island (mostly nation-) states, and discuss a recent attempt by the United Nations to assess vulnerabilities to these disasters. We then assess the impact of Iniki on the island of Kauai, and finish by describing the current state of knowledge on the connection between climate change and storms.

2. The economics of natural disasters

2.1 GDP and disasters

Research on disasters' impact on the economy is only in its infancy with very few papers examining any facet of disaster phenomena. Several research projects have examined specific

disaster events - such as hurricane Mitch in Honduras, the Kobe earthquake in Japan, and estimated some of the specific costs and consequences of those individual events.[4]

Clearly, this research strand is directly relevant to our work here. However, the economy of the state of Hawaii, with its unique set of vulnerabilities, will most likely be impacted differently from large disaster events such as Iniki. Storms, unlike geo-physical disasters such as earthquakes and volcanic eruptions, are fairly expected events with some advance warning, even if their magnitude can sometime be unusual. This predictability, together with the resources that can be mobilized both before and after a storm hits, also differentiate Hawaii's likely experience with that of, for example, Kobe – Japan.

As far as we know, there are only very few papers that examine the economic facets of natural disasters using a multiple-events framework. These are briefly discussed below, though none of them attempts the level of detail in which we examine Kauai's Iniki experience. The first recent attempt to empirically describe macro-aspects of natural disasters is Albala-Bertrand (1993); a book that develops an analytical model of disaster occurrence and reaction and collects data on a set of 28 disaster events (1960-1979). Albala-Bertrand finds that after these disasters GDP increases, inflation does not change, capital formation increases, agricultural and construction output increase, the fiscal and trade deficits increase (the trade deficit sharply), and international reserves increase.

[4] E.g., Halliday (2006) on the 2001 earthquake in El Salvador, Horwich (2000) on the 1995 earthquake in Kobe-Japan, Selcuk and Yeldan (2001) on the Turkish earthquake of 1999, and Vigdor (2008) on hurricane Katrina.

Tol and Leek (1999) survey the literature as far back as the 1960s, and argue that the positive effect on GDP can readily be explained since disasters destroy the capital stock, while the GDP measure focuses on the flow of new production. They emphasize the incentives for saving for and investing in disaster mitigation and recovery efforts.

Noy (2009), on the other hand, finds an adverse short-run effect on GDP growth and describes some of the structural and institutional details that make this negative effect worse. In particular, he concludes that countries with a higher literacy rate, better institutions, higher per capita income, higher degree of openness to trade, higher levels of government spending, more foreign exchange reserves, and higher levels of domestic credit, but with less-open capital accounts are better able to withstand the initial disaster shock and prevent further spillovers. [5]

Several other papers investigate the institutional and structural determinants of the initial disaster costs (Anbarci et al., 2005; Kahn, 2004; Raschky, 2008; and Skidmore and Toya, 2007) or of the subsequent impact on the economy (Cavallo et al., 2009). Much of this research however, is probably less relevant for an investigation into the likely impact of a hurricane in Hawaii because of the uniqueness of Hawaii's circumstances and the structure of its economy.

Two research projects have investigated the impact of hurricanes on economies in the Caribbean. Given similarities between island economies, these studies are likely to provide more insight into the case of Hawaii. Rasmussen (2004) conducts a tabulation of the data for

[5] In contrast to these papers, Skidmore and Toya (2002) and Noy and Nualsri (2007) examine the long-run impact of natural disasters on growth in contrast with our aim of describing the short-run dynamics of the macro-economy following a disaster for an isolated well-defined region. They also reach diametrically opposing conclusions with the former identifying expansionary and the latter contractionary disaster effects.

the island members of the Eastern Caribbean Currency Union (ECCU). He finds that: "Among these…the median number of affected persons amounted to 9 percent of the country's population and the median value of damage was equivalent to 14 percent of the country's annual GDP" (p. 7). For Oahu, that could mean more than a 100,000 people may be affected by a hurricane that hits the island while direct damages can amount to more than $7 billion.[6]

Heger et al. (2008) also focus on Caribbean islands (not limiting themselves to ECCU countries only). Their results also do not agree with the earlier largely optimistic research that concluded that disasters are typically followed by a period of higher growth. They find that as growth collapses, the fiscal and trade deficits both deteriorate and the island economies of the region find it difficult to rebound from the short-run impact of the disaster. They relate this deepening recessions to the reliance of island economies in the region on very few sectors (typically tourism and agriculture).

Many other impacts of disasters have been under-investigated. Most important, especially when the disasters are likely to generate significant inter-regional transfers, is a more precise account of their fiscal impact. On the expenditure side, the disaster reconstruction costs to the public may be very different than the original magnitude of destruction of capital that occurred (see Fengler et al., 2008 for more detail). On the other side of the fiscal ledger, the impact of disasters on tax and other revenue sources has also seldom been quantitatively

[6] Though, as Rasmussen (2004) points out, some events can be significantly worse. "For example, in 1979 Hurricane David hit Dominica…killing 42 people, damaging 95 percent [of GDP] and completely destroying 12 percent of buildings, damaging or destroying the entire banana crop and 75 percent of the country's forests, rendering virtually the entire population homeless, and leading to the temporary exodus of about a quarter of the population." (p. 7)

examined. A cross-country investigation of these effects, as in Noy and Nualsri (2008) yields some predictions, but to a large extent, the disaster impacts on revenue and spending depend on the country-specific macroeconomic dynamics occurring following the disaster shock, and the structure of revenue sources (income taxes, consumption taxes, custom dues, etc.) and large expenditures. Obtaining accurate estimates of the likely fiscal costs of a disaster is useful in enabling better cost-benefit evaluation of various mitigation programs. These should also assist foreign aid organizations and international multilateral institutions in planning and preparing their programs. Another motivation to estimate the fiscal cost is to better enable governments to directly insure against disaster losses, indirectly through the issuance of catastrophic bonds (CAT bonds), or through precautionary saving. The only attempt we know of estimating the likely fiscal insurance needs of a government has been calculated for Belize (Borensztein et al., 2008); though whether these estimates for Belize apply to Hawaii, for example, is an unexplored question.

2.2 Vulnerabilities to disasters

Regions are vulnerable to disasters for many reasons. Amongst traditionally conceived geographical characteristics such as proximity to coastal areas, volcanoes or fault lines, there is a growing understanding of economic conditions that make regions vulnerable as well. More accurately, identifying economic conditions that lead to resiliency in the aftermath or, alternatively, exacerbate the impacts of disaster. Vulnerability has been defined in many ways. The United Nationals International Strategy for Disaster Reductions describes it as “the

conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impacts of hazards" (UN, 2004). Resiliency, on the other hand, is the antonym of vulnerability. It is described as "the capacity of a system, community or society potentially exposed to hazards to adapt by resisting or changing in order to reach and maintain an acceptable level of functioning and structure" (UN, 2004). Vulnerability (or conversely, resiliency) to hazards can be categorized both ex-ante and ex-post. Ex-ante vulnerability is described by indicators such as frequency and magnitude of disaster events, susceptibility of the economy to be impacted by external shocks, and existence of disaster management plans such as adequate shelters. Ex-post vulnerability is characterized by the ability to recover from the aftermath of disaster. Factors include success of disaster management plans deployment, inflow of outside aid, and ability for the economy to recover. For the purposes of this section, we will focus on the economic characteristics of vulnerability in Hawaii.

Baritto (2008) outlines a framework for quantifying a region's economic vulnerability to disasters based on types of economic activity including a region's export base, manufacturing and service activities; local food sources; levels of wealth; and the relative role of imports. Earlier work to construct an Economic Vulnerability Index (EVI) has focused specifically on the needs of small-island developing states (SIDs). For example, SIDs are often characterized by a narrow range of exports and heavy reliance on imports. From these analyses, Baritto (2008) assesses which factors can make an economy sensitive to the impact of external shocks, i.e. disasters. Because Hawaii is a State and not a country, Baritto's set of indicators do not

necessarily translate to the case of Hawaii. Nonetheless, the general themes of vulnerability remain: 1) diversification of export products and destinations, 2) levels of wealth, 3) net food import ratio, 4) manufacturing and services value-added proportion, and 5) characteristics of imports.

2.2.1 Exports and Tourism

Regions with a large export sector will be generally less vulnerable to disasters because the markets for products will presumably be unaffected. On the other hand, an economy with a less diversified set of export products is generally more vulnerable to external shocks.

Hawaii has a very small manufacturing export base, with 2.4% of the value of Hawaii's $90.2 billion economy, roughly $2.2 billion. The largest export is refined petroleum manufacturing ($0.6 billion) comprising 27% of the total value of manufacturing exports. Transportation equipment, processed foods, raw agricultural products, and mining and other manufacturing comprises the rest. Export supported jobs linked to manufacturing account for only an estimated 0.8% of Hawaii's total private sector employment. The state's largest export markets in 2008 were Australia (0.37 billion), South Korea (0.1 billion) and Japan, China, and Singapore. Obviously, all the state's export markets are distant, and therefore will not be affected should a disaster hit the islands.

By far the largest export sector in the state is tourism. Although tourism activities take place within the State, goods and services are "exported" to out-of-State consumers. Tourism, with its heavy reliance on domestic infrastructure and public perceptions, is different than

other export sectors in terms of its vulnerability to disasters. Tourism activity typically decreases significantly following disasters, as was the case after hurricane Iniki (see next section). Over 7 million visitors come to Hawaii each year and spend $16.3 billion annually (2005), which accounts for 22% Hawaii's state gross product or seven times the value of all other exported goods. This sector is not diversified in terms of destinations. Nearly 70% of visitor expenditures are from the continental U.S. (29.6% from the U.S.-East and 37.3% from the U.S. West). Japanese visitors comprise 15.5% of spending and Canadian visitors only 5%. All other visitors comprise 11.2% of spending.[7] Hawaii's economy is thus unusually vulnerable because of its heavy reliance on tourism.

2.2.2 Military Sector

The literature suggests that regions with more dependence on primary activities are also more vulnerable to the impact of external shocks. Hawaii's second economic pillar is the U.S. federal military. Military expenditures account for $8.9 billion of spending, accounting for 12% of Hawaii's gross state product. Military operations have historically been located in Hawaii because of its ports and geographic proximity to Asia. Continuing military presence will likely not change due to external shocks and will provide assistance in the aftermath of any disaster. For example, when the 6.7 magnitude earthquake hit Hawaii in October, 2006, the military was on stand-by (Kim, 2007).

[7] 2007 Annual Visitor Research Report, http://hawaii.gov/dbedt/info/visitor-stats/visitor-research/2007-annual-research.pdf)

2.2.3 Resident Wealth

As a U.S. State, the living standards in Hawaii are relatively high. Total per capita income in Hawaii was $39,239 in 2007. Nonetheless, nearly 11% of the population is considered to be living under the poverty line.[8] This is thought to be a low estimate of actual poverty, however, because the cost of living in Hawaii is substantially higher than the U.S. mainland and thus a different threshold should be applied.[9] The city and county of Honolulu has 9.9% of individuals living the poverty level, Kauai County and Maui County with 10.5%, and Hawaii County with 15.7%. The poor are generally much more vulnerable during disasters, as the events following hurricane Katrina amply and painfully demonstrated.

2.2.4 Food Security

Baritto (2008) suggests that regions with high levels of food imports are more vulnerable to disasters, particularly depending on the infrastructure required to bring in food. Hawaii is then extremely vulnerable; over 85% of the food consumed in Hawaii is imported through one primary port (Honolulu).[10] In 2006 the total value of crop and livestock production was $0.56 billion, but much of that was exported. Any destruction to port facilities will have dire consequences for food consumption. The 15% of consumed food that is produced locally is

[8] From 2000 census.

[9] State of Hawaii Data Book 2007, Table 13.23.

[10] Leung and Loke (2008).

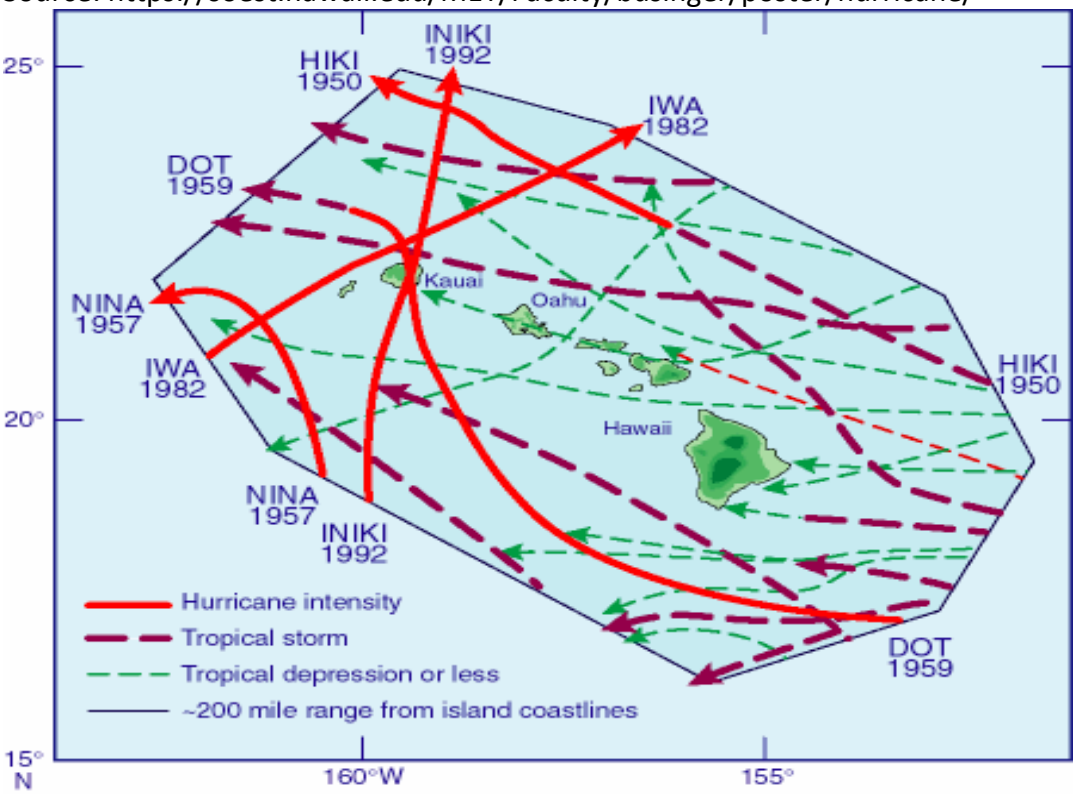
primarily crops (vegetables, fruits and taro) and some livestock. As the case of Iniki shows, these crops are very susceptible to a hurricane.

3. Kauai's Iniki (1992)

3.1 Iniki's Initial Effects

Hurricane Iniki hit land on the south shore of Kauai on the afternoon hours of September 11, 1992 (for a more detailed description of Iniki's trajectory, see the appendix). CRED-EMDAT, the most comprehensive and credible international data source on natural disasters, estimates that 4 people were killed, 25,000 were affected, and there was 7.4 billion (2008 US$) destruction of infrastructure and property. According to NOAA, 14,350 homes were damaged or destroyed on Kauai, and electric power and telephone service were lost throughout the island and only 20 percent of power had been restored four weeks later. Crop damage was likewise extensive as sugar cane was stripped or severely set back, while tender tropical plants, such as banana and papaya, were destroyed and fruit and nut trees were broken or uprooted (see appendix for more details).

Figure 1: History of Hawaiian Hurricanes (1950-1992)
Source: https://soest.hawaii.edu/MET/Faculty/businger/poster/hurricane/

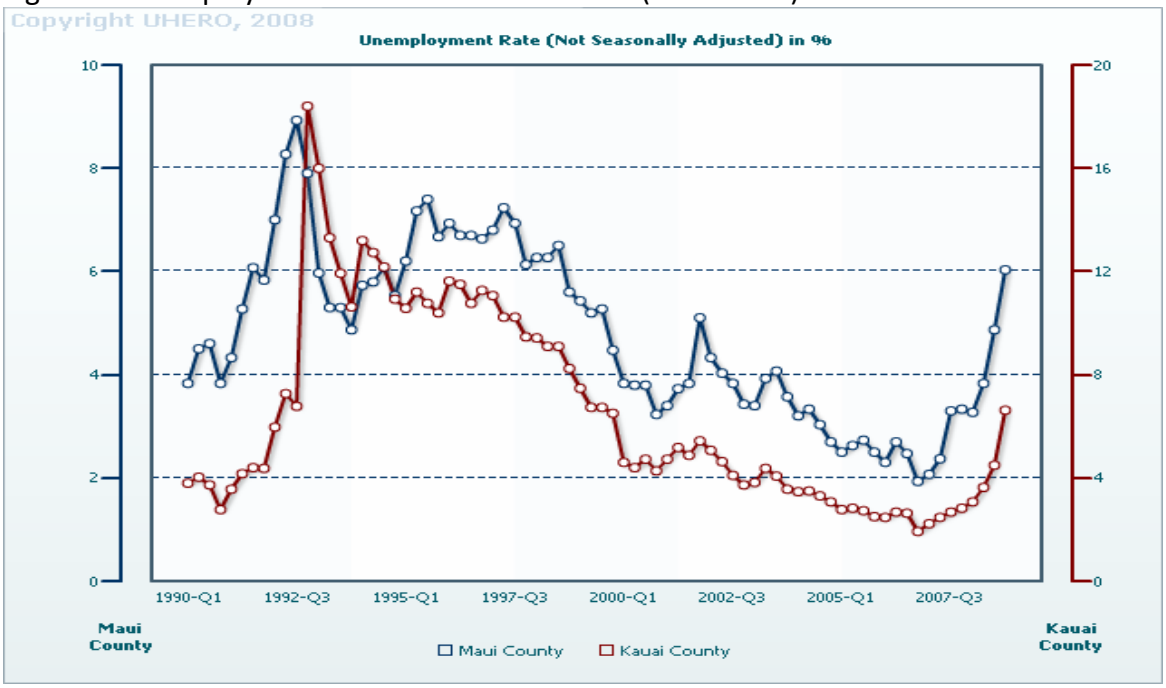


As can be seen in figure 1, Iniki was not the only hurricane to hit Kauai in the past 50 years; but the direct destruction that Iniki wrought was unprecedented. These direct impacts, however, do not necessarily represent the longer run indirect economic effects of the hurricane. The following section traces out these economic affects. Kauai, however, like the other Hawaiian Islands, was hit at about the same time by a prolonged and painful recession in Japan. For this, the county of Maui is also discussed as a control group.

3.2 The economic effects of Iniki

The massive destruction of property and infrastructure resulted in a dramatic rise in unemployment as is shown in figure 2.[11] Unemployment was already inching up from a low of around 3% in 1990 to 7% just before the hurricane as the Japanese economy was suffering from the aftermath of its real estate and stock market bubbles. However, immediately after the hurricane, unemployment on Kauai shot up to 17%. Maui, our control group, also experiences a rise in unemployment as a result of the Japanese bubble, but on Maui unemployment peaked at only 9%. Clearly, the drastic rise in unemployment was primarily due to Iniki.

Figure 2: Unemployment Rate in Kauai and Maui (1990-2007)

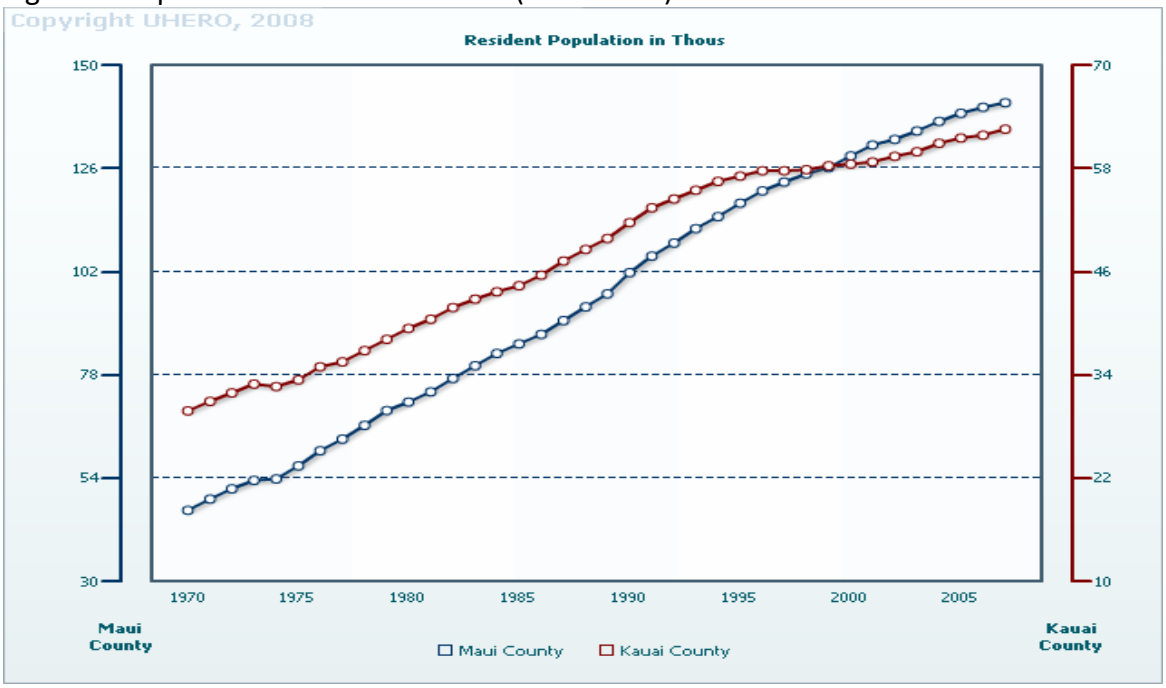


Maybe more striking is that it took Kauai 7 years for its labor market to recover to its previous pre-Iniki unemployment rate of 7% (by that time, Maui's unemployment was less than 5%). This pattern of a recovery that takes 7-8 years, while evident in several other statistics, is

[11] Unless otherwise cited, all the data in the following figures was taken from a database maintained by the University of Hawaii Economic Research Organization (UHERO).

also misleading because there was a striking out-migration of residents. Figure 3 presents population figures for Kauai and Maui.

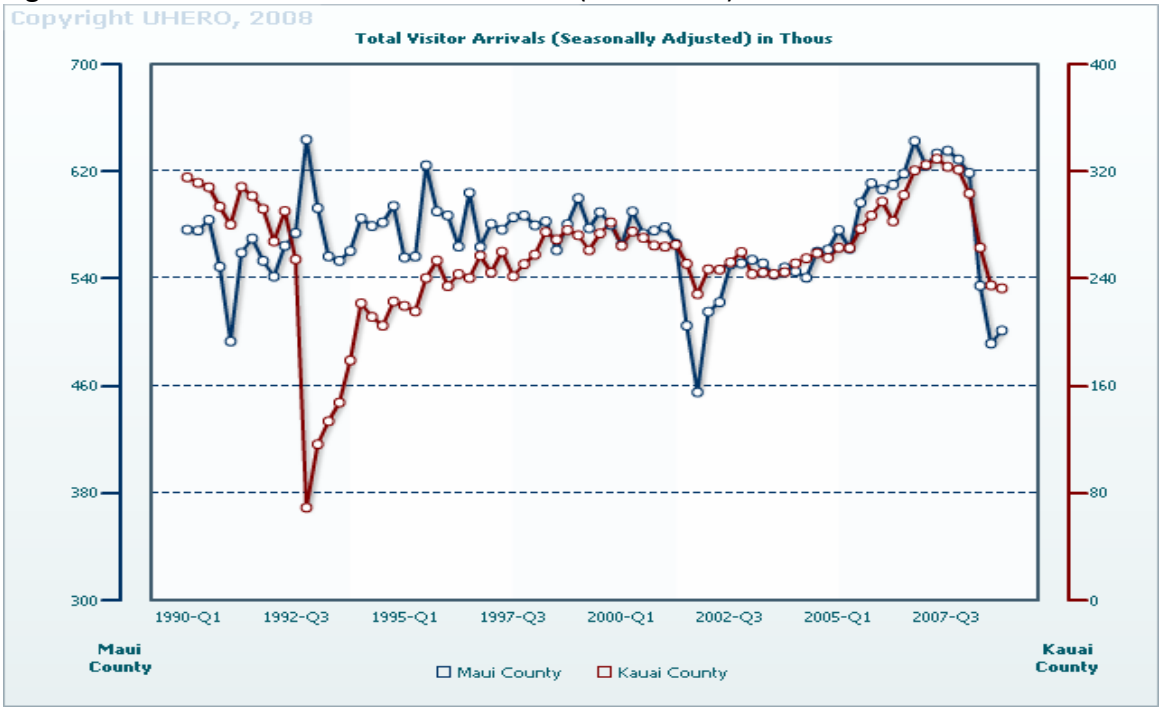
Figure 3: Population of Kauai and Maui (1970-2007)



Both islands seem to follow a similar population trajectory starting in 1970, with both experiencing a very constant rate of population increase. However, Kauai's population trajectory shifts in 1992. For several years after that (about 7-8) the population is constant, but the rate of population increase after that is slower than before. Not only does Kauai not recover the population it 'lost' as a result of the hurricane, it has yet to return to its previous growth rate. In that sense, Kauai seems to have permanently 'lost' about 10% of its population. By comparing Kauai and Maui's population trajectories, it again becomes apparent that the changes in Kauai were the result of Iniki since both were exposed to the same external economic conditions beffeting the islands during the 1990s.

Figure 4 examines the tourism sector in both islands by looking at tourist arrival data for the years surrounding the hurricane.

Figure 4: Tourist arrivals for Kauai and Maui (1990-2007)

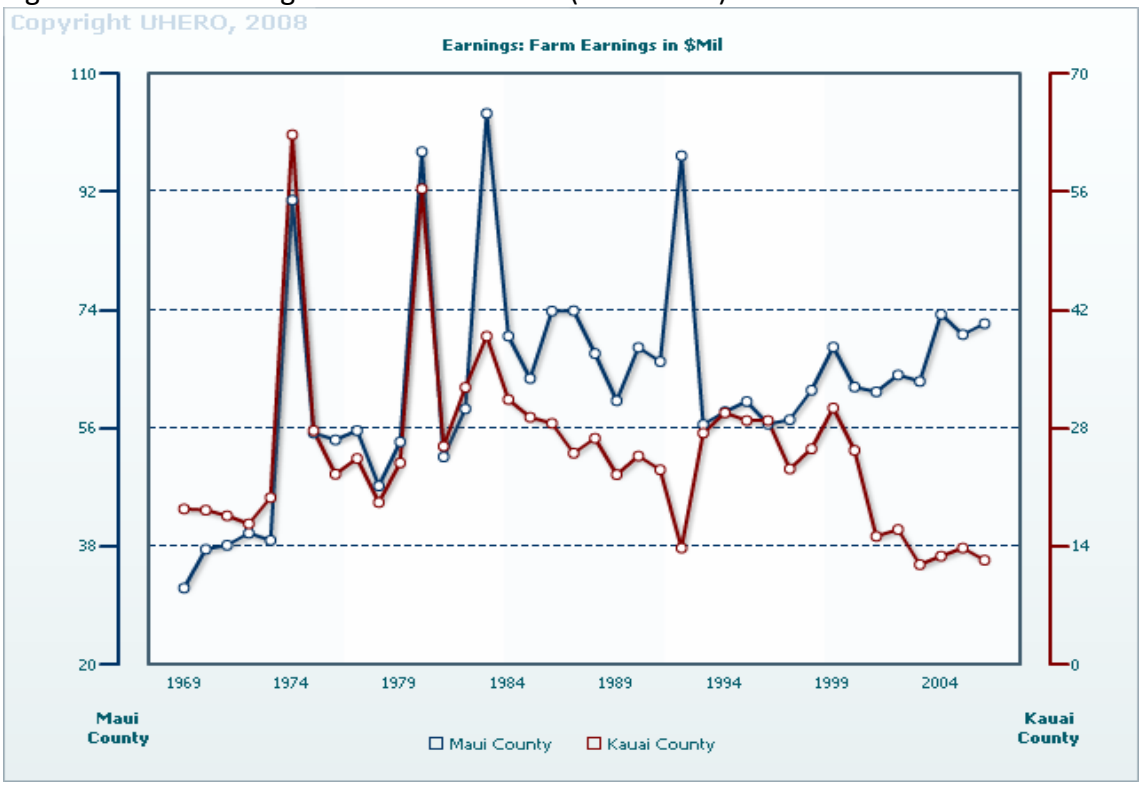


The tourism cycle seems to be highly correlated between the two islands, except for the 7-8 years following Iniki. Immediately after the hurricane, tourist arrivals drop by 70%, with a temporary spike up in tourist arrivals in Maui when previously booked trips were re-directed to Maui facilities since Poipu, the main tourist area on Kauai was heavily damaged both by winds and by the wave surges. Kauai's tourism based economy only recovered almost a decade later when tourist arrivals climbed back up to pre-Iniki numbers in 2000. This number remained fairly constant even in spite of the events of September 11, 2001, and visitor arrival numbers only reached the pre-Japanese bubble numbers of 1990 in 2006.

A distinct picture can be seen with the second biggest private income-generating sector

on both islands, agriculture (figure 5). The agricultural economy is much more volatile than tourism as a result of fluctuating world prices for the farm products produced on the islands (mostly pineapple and sugar, but also macadamia nuts, coffee, and other fruits and vegetables consumed locally).

Figure 5: Farm Earnings for Kauai and Maui (1969-2006)

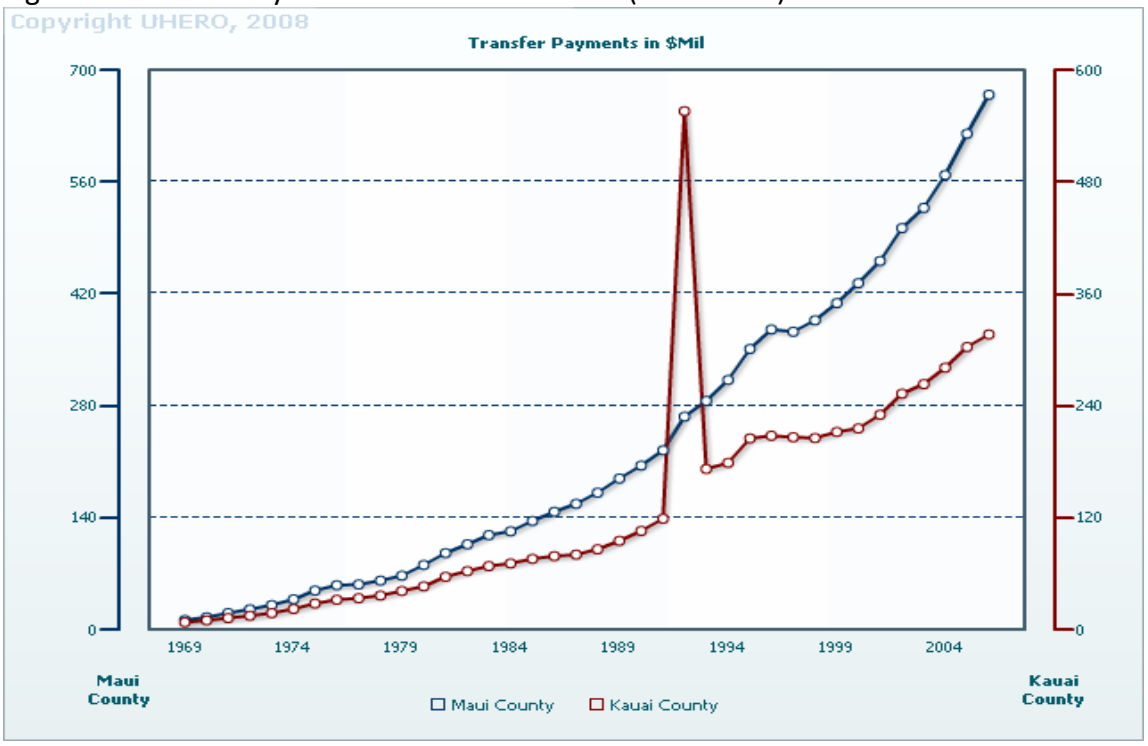


In 1992 we observe a large drop in Kauai's farm earnings' coupled with an increase in Maui's earnings. Both, however, bounce back rapidly to their pre-Iniki levels. Kauai later loses much of its farming sector because of several large plantation closings; these are probably unrelated to Kauai's experience with Iniki, although Iniki did create an increased awareness of

the future possibility of more hurricanes hitting Kauai.[12]

A reason why Kauai's experience with Iniki could have been much worse is evident once one examines the amount of funds the county received from state and federal sources (figure 6).

Figure 6: Transfer Payments for Kauai and Maui (1969-2007)



Clearly, the spike in funds associated with Iniki enabled a quicker recovery than otherwise would have been the case. However, even with this massive increase in transfers to the state government (about $450 million), the economy of Kauai only recovered after nearly a decade, and by some measures it had never recovered.

[12] Maui seems significantly less likely to experience hurricanes given the past hurricane record (see figure 1).

4. Climate Change

4.1 Climate Change and Natural Disasters

There is growing scientific consensus that human activity, particularly the burning of fossil fuels, is drastically altering the globe's climate. Global greenhouse gas emissions have increased by 70% between 1990 and 2004 (IPCC, 2007). The Intergovernmental Panel on Climate Change, a scientific body established by the World Meteorological Organization to assess the risks and impacts of human-induced climate change, states that: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007). Average global surface warming is projected to increase from between 1.8 degrees Celsius to 4 degrees Celsius depending on the success of emissions mitigation strategies by 2100 (IPCC, 2007). Some level of warming is expected regardless, even if all emissions were stopped today. The 2007 IPCC report predicts sea levels to rise between 0.18 and 0.59 meters by 2100. Current predictions of global sea level rise are considerably more drastic, however, as increased information on glacial melting has become available since 2005. In addition, the absorption of carbon in the ocean has lead to increased acidity and has resulted in calcification of coral reefs. Coral bleaching leads to destruction of surrounding ecosystems, both harming fisheries and deteriorating reef systems that protect coastal areas from storm surges.

There is limited understanding on how global warming will affect hurricanes (or cyclones). There are five necessary conditions for hurricane formation: 1) ocean water

temperature greater than 26 degrees Celsius (80 degrees Fahrenheit) to a depth of about fifty meters, 2) an unstable atmosphere (i.e. thunderstorm activity), 3) high relative humidity in the middle troposphere, 4) a pre-existing disturbance with cyclonic circulation, and 5) little to no change in the wind speed or direction so that warm air is concentrated over one area (Businger, 2009). Several studies posit that, as global sea surface temperatures rise, there will either be more or more intense hurricanes (see for example Webster et al., 2005).

The science, however, is not entirely conclusive. IPCC 2007 states that: "There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones. It is difficult to ascertain longer-term trends in cyclone activity, particularly prior to 1970" (IPCC, 2007). A 2008 study published in *Nature* suggested that warming temperatures allowed for already strong storms to get even stronger. This suggests that, while there may not necessarily be an increased occurrence of storms, there will be an increased occurrence of strong storms (Elsner et al., 2008). In general, however, the debate over how global warming will affect storms in both magnitude and incidence continues. In particular, there has been questioning over the quality of global databases on storm activity (Landsea et al. 2006). There is nonetheless concern that the combination of sea level rise and deteriorated coral reef ecosystems will make coastal areas considerably more vulnerable to storms, regardless of whether there are more frequent or more intense ones.

4.2. Climate Change and Hawaii

Islands are extremely vulnerable to the expected (and often already occurring) effects of climate change (IPCC Working Group II, 2007). Sea level rise will "exacerbate inundation, storm surge, erosion and other coastal hazards" (IPCC Working Group II, 2007). Although Hawaii is not a particularly low-lying island relative to other Pacific nations, it shares similar characteristics in that key infrastructure is located on or near the coast. For example, Hawaii's main international airport on the island of Oahu operates with a coral reef runway. The two petroleum refineries located on Oahu area also at sea level, nested in with the entire industrial sector of Oahu at Campbell Industrial Park. Moreover, the tourist hub Waikiki sits beachfront. Many of the most famous hotels in Waikiki, like The Royal Hawaiian and the Moana Surfrider, have largely lost their sandy beachfronts and are constantly battling further erosion. A recent study projected it would cost $30 million to restore the length of Waikiki Beach, based on a $475,000 demonstration project where 9,500 cubic yards of sand from offshore was brought onto one section of Waikiki, Kuhio Beach (Vorsino, 2008). Fletcher (2009), however, has argued that the coastal erosion Hawaii has and is experiencing is primarily due to beach mismanagement. Sea level rise in Hawaii can be attributed, at this point, solely to thermal expansion from warming temperatures and it will take several decades for glacial melt water to travel to the Pacific. It is projected for Hawaii to experience a one-meter rise in sea level by the turn of the century. Thus all erosion and flooding problems that Hawaii currently faces will be substantially exacerbated (Fletcher, 2009).

5. Conclusion

5.1. Lessons Learned

Islands have been deemed vulnerable to effects of climate change "with very high confidence" (IPCC Working Group II, 2007). This assessment is based on the physical implications of climate change on island ecosystems (proportionately larger coastal areas, dependence on ocean ecosystems, and limited fresh water availability) as well as the economic conditions of islands (tourism dependence, narrow export markets, large import base, and limited agricultural production). By these standards, including the vulnerability index established by Barrito (2008), Hawaii is highly vulnerable to future disasters, both ex-ante and ex-post. Changes to Hawaii's climate and ocean ecosystems, as well as the uncertainty involved in predicting and adapting to those changes, increase the region's ex-ante vulnerability. As the case of Iniki shows, high dependence on tourism makes Hawaii particularly vulnerable in the aftermath of the storm. It was difficult for Kauai's economy to rebound quickly as it immediately lost its primary export and income generator: visitors. Kauai did not regain its previous levels of visitor arrivals until 2000, eight years after Iniki hit. In addition, there was an out-migration of Kauai residents from which the island has never fully recovered.

The largest damages caused by Iniki occurred near the coast. This effect will only be exacerbated in the future as coastal areas are further inundated with rising sea levels. Posit, for example, the scenario where a category four or five storm goes through the island of Oahu and, in particular, Waikiki. Hotels and buildings that are already faced with issues of flooding will be entirely inundated on their lower floors, making escape routes more difficult and more

dangerous. The case of Kauai shows that, not only are there immediate economic consequences, but that those impacts last years afterwards.

5.2 Supporting Policies and Recommendations

After Hurricane Iniki there was a "property insurance crisis" in Hawaii (Hamnett et al., 1996). One insurance company became insolvent and two others left the State. During the following year, the legislature called for the creation of the Hawaii Hurricane Relief Fund (HHRF) to provide windstorm coverage for hurricane force winds and reinsurance. The Fund is primarily financed through special mortgage recording fees and participating insurance companies. Currently, May 2009, the HHRF has about $185 million. Considering the $7.4 billion that Iniki destroyed (in 2008 US$), the HHRF is clearly far from adequate should a major storm hit any of the main four inhabited Hawaiian Islands (Kauai, Oahu, Maui and the Big Island). To compound this problem, this sum is hardly growing since all interest income is re-distributed to the general budget.

A typical concern with these kinds of insurance policies is the generation of moral hazard; i.e., the willingness to incur more risk since this risk is insured. This tendency is especially acute if the insurance premiums are not paid by the risk-taker or if their size does not reflect the actuarial reality. Clearly, both of these conditions hold in this case. However, it is difficult to see how the HHRF can generate much moral hazard given the obvious puny size of the fund relative to the potential need should a major hurricane hit any of the larger islands.

Perrow (2007), in a recent book on reducing catastrophic vulnerabilities in the U.S., concludes that public policy should focus on the need to 'shrink' the targets: Less population concentrated in vulnerable (especially coastal) areas, less concentration of electric utilities and other infrastructure, or reduced exposure of population centers to industrial accidents. This advice clearly applies to Hawaii.

Appendix: Hurricane Iniki Natural Disaster Survey Report

Hurricane INIKI (Hawaiian for sharp and piercing wind) formed over the warm waters near 12N 135W on September 5 about 1600 statute miles southwest of Baja California. This is somewhat farther west and south than the initial position of most mid season storms. The system formed from an area of disturbed weather…[which] may have originated as a tropical wave that moved off the coast of west Africa on August 18…INIKI was upgraded from a tropical storm to a hurricane…470 miles SSE of Hilo and was moving steadily west northwest.

INIKI was approaching the western edge of the subtropical high pressure ridge, a semipermanent feature found north of Hawaii that normally keeps hurricanes south of the islands. This ridge was now weakening as a large low system or trough aloft began to dig south along and just east of the International Dateline. This caused INIKI to take a slight north of west track. INIKI continued west northwest between 12 and 15 knots on September 9 and was…425 miles south of Honolulu at 5 am HST on the 10th….Reconnaissance aircraft reported top winds of 100 knots and a central pressure of 951 millibars. INIKI slowed even more and started to turn northwest. Its center was near 15N 160W or about 400 miles south of Lihue, Kauai at 110300Z. The system had strengthened and maximum winds were now estimated at 110 knots with gusts as high as 135 knots. A hurricane watch was issued for the western Hawaiian chain from Kauai and Niihau west to French Frigate Shoals.

Southwesterly flow ahead of the upper cold trough and the low pressure system to the northwest continued to turn INIKI more northward with time. An intermediate advisory was issued at 110630Z. Hurricane warnings were issued for Kauai and Niihau and tropical storm warnings were issued for Oahu. A tropical storm watch was issued for the Islands of Maui, Lanai and Molokai. High Surf Advisories were continued for all of the Hawaiian chain.

….Hurricane warnings were extended eastward to include the island of Oahu. INIKI continued to strengthen during the early morning hours of September 11 as it moved north along 160W. Maximum sustained winds had increased and were estimated at 125 knots with gusts as high as 150 knots….at 3:30 pm HST, the eye crossed the south coast of Kauai just east of Waimea and departed Haena on the north coast about 40 minutes later. Estimated maximum sustained winds over land were 140 miles per hour with gusts as high as 175 miles per hour, making INIKI the most powerful hurricane to strike the Hawaiian Islands in recent history. The path INIKI took was the worst possible placing most of the island in the dangerous semicircle. INIKI moved on a bearing of about 15 degrees on the compass across Kauai while accelerating to 25 knots….

Damage was extensive throughout Kauai. Damage from the ocean was heaviest along the south shore of Kauai and affected shoreline hotels and condominiums, especially around Poipu. Wind damage was extremely heavy throughout Kauai as many homes and buildings were flattened or lost their roofs. According to Red Cross figures, INIKI left 14,350 damaged or destroyed homes on Kauai. The number of homes that were completely destroyed was 1,421. A total of 63 homes were destroyed by wave action or storm surge on the south coast of Kauai. The number suffering major damage was 5,152 while 7,178 received minor damage.

Electric power and telephone service were lost throughout the island and only 20 percent of power had been restored four weeks after the storm. Crop damage was likewise extensive as sugar cane was stripped or severely set back, while tender tropical plants, such as banana and papaya, were destroyed and fruit and nut trees were broken or uprooted. The monetary value of the damage caused by INIKI was still mounting, having reached an estimated value of close to 3 billion dollars. The areas most affected on Oahu were the leeward coast from Barbers Point through Makaha and Kaena Point with lesser damage along the south shore from Ewa Beach to Hawaii Kai. Some damage also occurred on the islands of Maui County and the Big Island of Hawaii, where swell and heavy surf from southwesterly directions pounded exposed shorelines and anchorages.

There were six deaths connected to the storm. One woman on Kauai died of a heart attack when a portion of her house fell on her, a man was killed by flying debris when he was out during the storm, two Japanese nationals drowned when their boat was capsized in waters off Kauai, one person died on Oahu when his residence was set on fire by a candle used for light, and a National Guardsman was killed when his truck overturned while trying to avoid live wires during the storm cleanup. More than one hundred people were injured, some after the storm when the cleanup began.

http://www.prh.noaa.gov/cphc/summaries/1992.php#Iniki

A more thorough scientific analysis of Iniki is available from the Department of Commerce at: http://www.nws.noaa.gov/om/assessments/iniki/iniki1.pdf

References

Albala-Bertrand J M. Political economy of large natural disasters. Oxford: Clarendon Press; 1993.

Anbarci, N., Escaleras, M., and Register, C. A, 2005. Earthquake Fatalities: The Interaction of Nature and Political Economy. *Journal of Public Economics*, 89, 1907–1933.

Benson C, Edward J C. Understanding the economic and financial impacts of natural disasters. Disaster Risk Management Series No. 4. Washington DC: World Bank; 2004.

Borensztein, Eduardo, Eduardo Cavallo, and Patricio Valenzuela, 2008. Debt Sustainability under Catastrophic Risk: The Case for Government Budget Insurance. IMF Working Paper WP/08/44.

Businger, Steven (2009). Hurricanes in Hawaii. Poster developed for the Hurricanes and Extreme Weather Phenomena Symposium. Available at: http://www.soest.hawaii.edu/MET/Faculty/businger/poster/hurricane/

Cavallo, Eduardo, Sebatian Galiani, Ilan Noy, and Juan Pantano (2009). Disasters and Institutions. Manuscript.

Cuaresma, J.C., Hlouskova, J., and M.Obersteiner. Natural disasters as creative destruction? Evidence from developing countries. *Economic Inquiry* 2008; 46(2); 214-226.

Dacy, D.C., and H.C. Kunreuther. The Economics of Natural Disasters. New York: Free Press; 1969.

Elsner, J., Kossin, J., Jagger, T. (2008). The Increasing Intensity of the Strongest Tropical Cyclones. Nature 455, 92-95.

Fletcher, Charles (2009). Hawaii Coastal Geology Group, Sea Level Rise. Downloaded May 17, 2009. Available at: http://www.soest.hawaii.edu/coasts/

Halliday T. Migration, risk and liquidity constraints in El Salvador. *Economic Development and Cultural Change* 2006;54(4); 893 -925.

Heger, Martin, Alex Julca, and Oliver Paddison, 2008. Analysing the Impact of Natural Hazards in Small Economies: The Caribbean Case. UNU/WIDER Research paper 2008/25

Horwich G. Economic Lessons of the Kobe Earthquake. *Economic Development and Cultural Change* 2000; 521-542.

IPCC. Climate Change: The Physical Science Basis. Geneva: Intergovernmental Panel on Climate Change; 2007.

IPCC, 2007. Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

IRIN. Disaster Reduction and the Human Cost of Disaster. Accessed at: http://www.irinnews.org; 2005.

Jarrell, J. D., et al. (2001). The Deadliest, Costliest, and Most Intense United States Hurricanes From 1900 To 2000. NOAA. Available at: http://www.aoml.noaa.gov/hrd/Landsea/deadly/index.html

Kahn M E. The death toll from natural disasters: The role of income, geography, and institutions. *Review of Economics and Statistics* 2004;87(2); 271–284.

Kim, Leland (2007). Military Trains For Natural Disaster Relief. KHNL News, February 27. Downloaded May 16, 2009. Available at: http://www.khnl.com/global/story.asp?S=6152804

Landsea, C.W., Harper, B.A., Hoarau, K., and Knaff, J.A. (2006). Can We Detect Trends in Extreme Tropical Cyclones? Science Vol. 313 No. 5785, 452-454.

Leung, PingSun, and Loke, Mathew (2008). Economic Impacts of Increasing Hawaii's Food Self-Sufficiency. Manuscript.

Narayan P K. Macroeconomic impact of natural disasters on a small island economy: evidence from a CGE model. *Applied Economics Letters* 2001;10; 721-723.

Neumayer E, Plümper T. 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* 2007;97(3); 551–566.

Noy, Ilan, 2009. The Macroeconomic Consequences of Disasters. *Journal of Development Economics*, 88(2), 221-231.

Noy, Ilan, and Nualsri, Aekkanush, 2007. What do exogenous shocks tell us about growth theories? University of Hawaii Working paper 07-28.

Noy, Ilan, and Nualsri, Aekkanush, 2008. Fiscal Storms: Public Spending and Revenues in the Aftermath of Natural Disasters. University of Hawaii Working paper 08-09.

Perrow, Charles 2007. *The Next Catastrophe: Reducing Our Vulnerabilities to Natural, Industrial, and Terrorist Disasters*. Princeton University Press.

Raschky, P. A., 2008. Institutions and the losses from natural disasters. *Natural Hazards Earth Systems Science* 8, 627–634.

Rasmussen T N. Macroeconomic implications of natural disasters in the Caribbean. IMF working paper WP/04/224; 2004.

Selcuk F, Yeldan E. On the macroeconomic impact of the August 1999 earthquake in Turkey: a first assessment. *Applied Economics Letters* 2001;8; 483-488.

Skidmore M, Toya H., 2002. Do natural disasters promote long-run growth? *Economic Inquiry* 40(4); 664-687.

Tol R, Leek F. Economic analysis of natural disasters. In Downing T, Olsthoorn A, Tol R, eds.. Climate change and risk. London: Routledge; 1999; 308-327.

UN, 2004.

Vigdor, Jacob, 2008. The Economic Aftermath of Hurricane Katrina. *Journal of Economic Perspectives* 22, 4, pp. 135–154.

Vorsino, Mary (2008). Erosion of Waikiki Beach would cut Hawaii Tourism by $2 billion. The Honolulu Advertiser, December 8. Downloaded May 17, 2009. Available at: http://www.soest.hawaii.edu/SEAGRANT/sgnews/pdf/news_2008/Erosion%20of%20Waikiki%20Beach%20would%20cut%20tourism%2012.8.08.pdf

Webster, P.J., Holland, G.J., Curry, J.A., and Chang, H.R. (2005). Changes in Tropical Cyclone Number, Duration, and Intensity. Science 309 no. 5742, 1844-1846.