# The Economic Costs of Natural Disasters, Terrorist Attacks, and Other Calamities: An Analysis of Economic Models that Quantify the Losses Caused by Disruptions

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***Abstract* - Over the past decade, numerous studies have estimated the economic impacts of a variety of disruptions. Most of these studies are based on macroeconomic models that quantify the direct and indirect economic losses from a disruption. Direct economic losses occur due to damaged facilities or when consumers change their purchasing behavior because of the disruption. Indirect economic losses occur when directly impacted businesses consequently reduce their orders to their suppliers. Indirect economic losses are often larger than direct economic losses. This paper compiles the results from these economic models in order to compare the costs of different disruptions and help decision makers prioritize among disruptions. We compare the direct and indirect economic losses from a variety of disruptions, including earthquakes, hurricanes, terrorist attacks, pandemic diseases, and port closures. Some studies model hypothetical scenarios, but other studies quantify the economic losses from historical events such as the September 11 attacks and the 2011 Japanese tsunami. This paper provides a useful benchmark to understand the consequences from disruptions and highlight areas that public officials could address in planning for future disruptions.**

*Index Terms* – economic models, natural disasters, risk analysis, terrorist attacks

## INTRODUCTION

Disruptions such as natural and man-made disasters are becoming more frequent and more costly. The cost of natural disasters has risen from an average of $50 billion per year in the 1980s to an average of $200 billion in the past 10 years. According to Kristalina Georgieva, European Commissioner for Humanitarian Aid and Crisis Response, every dollar spent on preparing for natural disasters prevents in $4 worth of damages. However, only 4% of the amount of money spent on natural disasters is allocated towards preparing for them, whereas 96% of it goes to the recovery process [1]. The United States has experienced catastrophic disruptions, such as Hurricane Katrina, with inadequate preparedness measures.

A study by the United Nations Food and Agriculture Organization [2] reiterates that natural disasters are becoming more frequent and costly. About $1.5 trillion in economic losses from natural disasters occurred from 2003 to 2013. These disasters have taken the lives of 1.1 million people and affected another 2 million people. In general, the direct costs associated with natural and man-made disasters come in the form of lost lives, damaged infrastructure, and business closures. Indirect costs associated with disasters occur when businesses and consumers that are directly impacted reduce their purchases of goods and services from other businesses. For example, Hurricane Katrina may have cost up to $149 billion [3] and the September 11 terrorist attacks may have cost the United States $108 billion [4].

Governments and other organizations have acknowledged the need to mitigate disasters and the risks associated with them. The United Nations International Strategy for Disaster Reduction (UNISDR) coordinates efforts in disaster reduction and humanitarian aid (UN General Assembly Resolution 56/195). The organization's work focuses on implementing strategies to reduce the damage caused by natural disasters [5]. In the United States, the Department of Homeland Security was established after the September 11 attacks in order to focus on all threats to the nation and protect the United States from another terrorist attack.

With disasters becoming extremely costly and occurring more frequently, preparing and planning for them is necessary. However, authorities face difficulties in assessing which regions take priority and on which disruptions to focus. Authorities need to decide where to allocate funds and how to prepare for disasters. Understanding the potential risks associated with disasters and their consequences can help authorities decide how best to plan for these disruptions.

This paper can help authorities understand the consequences of these disasters by examining disruptions from other studies and summarizing their key components with a focus on the economic consequences—both direct and indirect costs—of disruptions.

## ECONOMIC MODELS

We reviewed 55 papers that model the economic consequences of natural and man-made disasters. These papers comprise both peer-reviewed journal articles and book chapters. We created a database to group papers that studied similar types of disruptions and examined the key components and assumptions of the models. Of these 55 papers, 16 model the economic consequences of earthquakes, 15 focus on hurricanes, 13 involve terrorist attacks, 5 model pandemic diseases, 3 concentrate on cyber-attacks, 5 model the closures of ports, and 11 examine other disruptions. (Some of the papers model multiple disruptions.) Some of these studies analyze disruptions that occurred, such as the September 11 terrorist attacks and the 2011 Japanese earthquake and tsunami, and some studies explore the impacts of hypothetical but plausible disruptions.

These studies use input-output (I-O) models to calculate the economic consequences from disruptions. I-O models describe the interdependent relationship among industries in terms of how much one industry requires from another industry in order to produce its goods and services [6]. A disruption can kill or injure people, destroy infrastructure, and disable production facilities. Immediate or direct economic losses result from a reduction in final demand due to lost wages or fatalities and from inoperable facilities. I-O models measure the system-wide effects of these direct losses because directly impacted industries reduce their demand for goods and services from other industries, which are labeled as indirect losses. Total economic losses are the sum of direct and indirect losses. I-O models are supported by an extensive data collection worldwide. In the United States, the Bureau of Economic Analysis collects and publishes national I-O data, which can be supplemented by local and state data published by private corporations.

Different I-O models are used to calculate the economic consequences of disruptions. The Inoperability I-O model (IIM) transforms the traditional I-O model to calculate how an industry's inoperability leads to less production in other industries [7]. Since this model is usually populated with economic I-O data, the IIM and the traditional I-O model return the same economic loss [8]. The computable general equilibrium (CGE) model is derived from the industry relationships described in the I-O model, but CGE incorporates the simultaneous optimizing behavior of firms [9, 10]. Since firms can use substitution and prices can fluctuate, CGE models often calculate less severe economic losses when compared to the IIM [11]. The social accounting matrix (SAM) examines the effects across different socio-economic entities to explore equity considerations following a disruption, but the core of the SAM model remains the I-O interdependent relationships [12].

## ECONOMIC ANALYSIS

This section analyzes the results of the economic studies for each type of disruption. Similar disruptions have been grouped together, to include earthquakes, hurricanes, terrorist attacks, pandemics, cyber-attacks, and port closures. Miscellaneous disruptions are discussed separately.

### *I. Earthquakes*

Earthquakes can inflict severe damage on infrastructure leading to fatalities, with some earthquakes causing more damage than others. The economic impacts of earthquakes range between $100 million and $100 billion. This large range depends on the magnitude of the earthquake and the assumptions within the economic model. Japan has suffered some of the most costly earthquakes. Direct losses from the 1995 Great Hanshin Earthquake (i.e., losses in infrastructure, facilities, transportation, and utilities) were estimated at $100-144 billion, or 2.1% of Japan's gross domestic product (GDP) [13]. Accounting for indirect losses, the losses in gross output from this earthquake may have been $144 billion [14]. The 2011 earthquake and tsunami in Japan induced production losses in Japan of $32 billion in March and $52 billion in April. Production losses outside of Japan due to this earthquake were $17 billion over those two months [15]. Most of the other earthquakes in the 21st century had economic impacts on the order of $1 or $2 billion [14].

In addition to the loss of life and damage to buildings, earthquakes can damage transportation networks, leading to severe economic impacts. The 2004 Niigata-Chuetsu earthquake in Japan led to $247 million in losses due to disabled transportation [16]. A hypothetical 8.7-magnitude earthquake in Tennessee based on an earthquake in 1812 would lead to a $254 billion economic cost across the entire United States due to disabled highways and railways [17].

Other studies on earthquakes include hypothetical scenarios that simulate real-life possibilities. For example, a 7.1-magnitude earthquake in the Los Angeles metropolitan area could lead to almost $100 billion in total losses with business interruption losses outweighing damage to infrastructure [18]. An earthquake that disables the Portland Metropolitan Water System in Oregon could lead to regional output losses between $418 and $516 million according to a CGE model [19]. Brookshire and McKee [20] estimate the effect of a hypothetical earthquake in the United States of a 10% loss scenario to inflict around $29 billion in direct losses nationwide and $16 billion in indirect losses.

### *II. Hurricanes*

Hurricanes or cyclones can cause destruction through high-intensity winds, storm surges, and flooding. Over the last decade, the United States has experienced tremendous hurricane disasters as Hurricane Katrina and Hurricane Sandy. Hurricane Katrina in 2005 is regarded as one of the worst disasters to ever strike the United States. Hallegate [3] uses the regional I-O model in Louisiana to estimate a total economic loss of $149 billion. Direct costs are $107 billion with the housing sector losses at $19 billion. Inventory can reduce the economic costs because firms can rely on inventory if supply shortages occur. If the I-O model includes inventory, the total losses from Katrina are estimated at $74 billion with direct losses accounting for $63 billion [21].

Katrina hit the oil and gas and petroleum sectors particularly hard. The inoperability of this sector alone led to $870 million in losses in Louisiana and $5 billion in the Gulf region during the first month following Hurricane Katrina [22].

Several other U.S. disasters have occurred since Hurricane Katrina. Hurricane Sandy had major economic disruptions nationwide, especially in New York, New Jersey, and North Carolina, although the economic costs are only a tenth of those from Katrina [23]. Total lost wages in the United States was $10 billion with $3 billion in indirect losses. Richardson *et. al* [24] estimate the economic consequences of the Joplin Tornado in 2011. The disruption was estimated to lead to a total loss of $6 billion the first year. The highest losses occurred in the business sector at a loss of $4 billion.

The losses of hypothetical hurricanes reveal the losses that occur in other states. A hypothetical hurricane in the Houston-Galveston area could lead to $30 billion in output loss. [25]. A hurricane leading to a midtown tunnel closure in Virginia would disrupt transportation and could cost the state $5 million [26].

Okuyama uses the SAM model to estimate the costs of several hurricanes occurring outside of the United States. In 1998, Hurricane Mitch reduced output in Central America by $3.5 billion and $1 billion lost wages in Honduras. The 2005 Hurricane Stan in El Salvador had a total output losses of $363 million with lost wages at $287 million. The 2005 Mozambique floods and cyclones are estimated to have a total impact on outputs of $372 and lost wages of $106 million. The 2007 Cyclone Sidr in India had a total impacts on outputs of $2.3 billion and lost wages of $1 billion [12].

*III. Terrorist Attacks*

Although less frequent than natural disasters, large-scale terrorist attacks can have significant economic consequences too. The attacks of September 11 had one of the highest economic losses in recent times with estimated at $108 billion of which $40 billion was recorded in the air transportation sector [4].

Thankfully, terrorist attacks in the United States are rare events, and most of the studies on the economic impacts of terrorism focus on hypothetical events that have not occurred. If a shoulder-borne missile launcher brings down a plane near an airport, air transportation could be closed for 7 days, and people would be reluctant to fly. The economic costs of these business losses could range from $13.5 to $21 billion for the first week, $137 to $218 billion in the first year, and $98 billion to $155 billion in the second year [27].

As seen from the September 11 attacks and later attacks in Europe, terrorists seem to desire to target large metropolitan cities. Attacks on American cities can be especially consequential due to the economic activity in those cities. If a radiological dispersal device (a "dirty bomb") were detonated on the twin Ports of Los Angeles – Long Beach, economic losses in the Los Angeles area could be $34 billion [28]. A different attack involving a 50-pound radiological bomb in downtown Los Angeles with a radiation plume of 4 km by 200 m could cost almost $6 billion [29]. A conventional bomb in a Los Angeles shopping mall could induce losses of $19.3 billion [30].

Bioterrorism is another concern for homeland security officials. Lee *et al.* [31] model the scenario of a bio-agent being released in a stadium with approximately 75,000 spectators and neighboring area of 5.5 $km^2$. The three major categories for losses included the loss of life, remediation costs, and business interruption costs due to people not attending sporting events. Such an attack could cost between $62 billion and $73 billion. A bioterrorist attack using a foot-and-mouth disease (a highly contagious viral disease) in California could lead to nationwide losses of $23 to $34 billion [32].

Terrorist attacks can also disable critical infrastructure, which would cause economic hardship for businesses and consumers that depend on that infrastructure. An attack that destroys bridges over the Mississippi River or leading into Denver could lead to losses in the U.S. economic of $17.8 billion [33]. The results in this section demonstrate that major terrorist attacks could cost as much as a severe earthquake or hurricane (on the order of $100 billion). Terrorist attacks of a smaller magnitude (e.g., a bombing in a shopping mall, the destruction of major bridges) have cost estimates on par with less severe hurricanes.

*IV. Pandemic Diseases*

Pandemic diseases refer to infectious diseases that spread throughout human populations in a large region, and they can occur naturally or could be initiated by terrorists. Since a pandemic would force people to stay home from work, the economic losses consist primarily of less business productivity and lost wages. However, the current studies suggest that a pandemic would be serious economically than a major terrorist attack, earthquake, or hurricane. The economic losses from a pandemic could be further reduced if people are able to work from home. One pandemic scenario could infect 15 to 35% of the workforce and last between 4 weeks and 18 months. Ten to twenty-five percent of the available workforce would likely not go into work. If such a scenario were to occur in Virginia, the pandemic could result in $4 to $12 billion in total losses with the largest impacts occurring in the professional, scientific, and technical services [34].

A different study involving a 15% and a 25% attack on the workforce during a 4-week pandemic in Virginia was also studied. The 15% attacks were estimated to cost $4 to $5.5 billion. A similar attack of a 25% work loss is estimated between $7 billion-$9 billion [35]. Pandemics could also be global. Verikios *et. al* [36] model the impacts of a global influenza pandemic under two different scenarios. The first scenario has a high mortality rate but a low infection rate. The second scenario has a low mortality rate but a high infection rate. The second scenario has higher initial worldwide losses; however, the first scenario's losses surpass the second scenario after the first year.

## V. Cyber-Related Disruptions

With the modern advancement of technology, cyber-attacks have become a threat to individuals, organizations, and governments. This issue is a huge concern due to the growing dependency on the Internet and computers for work or leisure. Several studies quantify the effects of cyber-attacks and Internet outages. A hypothetical 10-day Internet outage in the United States models the effects on several industry manufacturers under the assumption that the directly impacted firms represent 5% of the total sector capacity nationwide. The effect of the outage on electrical manufacturers could total $22.6 million. The outage of automobile parts manufacturers could lead to $65.16 million, and an outage in the oil and gas sector could total $405 million [37]. Such a study demonstrates the importance of the U.S. automobile sector to the rest of the economy.

A 2005 study [38] on the losses due to piracy in the motion picture, sound recording, and publishing sectors could total $8.8 billion in the motion picture and sound recording sector and $21.4 billion in the publishing sector. The paper also discusses a cyber-attack of 1% loss in each sector of the U.S. economy. Total equity losses across the all sectors are estimated at $38 billion with the highest losing sector being the computer and electronic product manufacturing sector at $14.1 billion.

## VI. Port Closures

Ports serve as an important means to transport goods from one place to another. Several cities, states, and countries rely on ports for their import and export operations. If a disruption occurred in any of these ports, heavy economic consequences due to delayed operation would likely follow. Jung *et al.* [39] model a 10-day shutdown of the Ports of Los Angeles-Long Beach using an international trade I-O model. The 10-day shutdown could cost between $770 million and $1.3 billion in output losses per day. A shutdown of the twin Ports of Beaumont and Port Arthur, Texas for 90 days could reduce regional gross output by $12.9 billion [40]. These losses are substantially less than the Los Angeles-Long Beach port closure in part because the Beaumont-Port Arthur study models the resilience of the shipping and manufacturing industries. Resilience in the face of a port closure means rerouting ships to other ports, using inventory, conservation, substituting other goods, and rescheduling production.

Hypothetical disruptions of an inland waterway port in Oklahoma were studied in order to understand the regional impacts of river closures. A 2-week shutdown of the port using a multi-state I-O model could lead to $37.9 million in output losses across all industries with the metal industry suffering the highest losses ($14.2 million) [41]. MacKenzie *et al.* [42] estimate the economic consequences if the same port is closed for 1 to 2 months. The shutdown could cost between $465 million and $5 billion in lost production across the central U.S. region. Losses would be in the billions of dollars if shippers were not able to transport their product by other means (e.g., rail) but would be reduced significantly if product can bypass the closed port.

## VII. Other Disruptions

Several other disruptions could and have led to serious economic losses, including electrical outages, oil spills, disruptions in the oil supply, and a potential closure of a border most likely due to immigration concerns.

The 2003 Northeast Blackout lasted for only 3 days but may have cost the United States $6.5 billion, of which $2 billion was due to the electric power perturbation and $4.41 billion due to employees not coming to work [43]. Oklahoma experienced a much smaller electrical outage in 2007 due to a winter storm. The losses from this outage are estimated at $104 million with $27.5 million of these coming within the first hour [44].

Crude oil disruptions can be very costly due to the modern economy's reliance on fossil fuels. These disruptions can be oil shortages, oil spills, or disruptions in oil terminals. The *Deepwater Horizon* oil spill in the Gulf of Mexico in 2010 may have led to production losses in the Gulf region between $11 billion and $12 billion [45]. A 2.5% reduction in oil production for a year could cost $3 billion in the United States, and a 40% reduction in rare earth metals could cost over $50 million [46].

The U.S. economy is very dependent on trade with both Canada, Mexico, and other countries. If the United States closed its borders and severely curtailed trade due to immigration concerns or because terrorists came into the United States via these borders, the economic losses could surpass the losses from any other disruption. Gordon *et al.* [47] estimate that closing the U.S. border for one year (in 2001) could cost the $2 trillion or 14% of the U.S. GDP. The authors assume a one- year shutdown in international air travel, international commodity trade (except gas and oil), legal and illegal immigration, and all cross-border shopping. Thankfully, this scenario is very extreme and unlikely to occur, but the study provides a plausible upper bound on the economic consequences from such a reaction to security and immigration concerns.

# CONCLUSION

This paper has reviewed dozens of papers modeling the economic costs of different disruptions. The studies rely on I-O models to quantify the business losses due to the interconnectedness of the modern economy. Except for the very extreme scenario of closing the U.S. border for one year, the most severe disruptions (e.g., Hurricane Katrina, the September 11 attacks, the 1995 Japanese earthquake) lead to economic losses on the order of a $100 billion. Some hypothetical but plausible disruptions such as a bioterror attack or a port shutdown could cost the U.S. economy approximately $75 billion. Smaller disruptions such as Hurricane Sandy and the *Deepwater Horizon* oil spill may cost between $10 billion and $50 billion.

This paper has emphasized the economic consequences of disruptions, which include direct costs and indirect costs. Other consequences should also be considered including the loss of life (beyond the lost business that occurs due to fatalities), environmental damage, and psychological distress.

The economic consequences of these disruptions certainly indicate that preparing for disruptions could be very cost effective. However, risk-based decision making demands consideration of the likelihood of each disruption. For example, although a bioterror attack in a stadium might cost $75 billion and a shopping mall bombing might cost $20 billion. However, if a shopping mall bombing is much more likely than bioterror attack, homeland security officials may want to focus on preparing for the shopping mall bombing. Preparedness decision making should also factor in the effectiveness of allocating resources to prevent and prepare for a disruption. It might be more effective to prepare for a less costly disruption because the resources can do more to reduce the likelihood and consequences if that disruption.

Thus, this paper represents one piece in the overall puzzle of how best to prioritize among different disruptions. However, just as the picture in a jigsaw puzzle is incomplete if pieces are missing, the homeland security picture would be incomplete without a careful understanding of the different costs and economic consequences of disruptions. This paper provides a foundation to compare and contrast the variety of calamities that strike a nation or a region. Officials responsible for preparing for these disruptions require such information to prioritize and allocate resources effectively.

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