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Gauging the societal impacts of natural disasters using a capability approach

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There is a widely acknowledged need for a single composite index that provides a comprehensive picture of the societal impact of disasters. A composite index combines and logically organizes important information policy-makers need to allocate resources for the recovery from natural disasters; it can also inform hazard mitigation strategies. This paper develops a Disaster Impact Index (DII) to gauge the societal impact of disasters on the basis of the changes in individuals' capabilities. The DII can be interpreted as the disaster impact per capita. Capabilities are dimensions of individual well-being and refer to the genuine opportunities individuals have to achieve valuable states and activities (such as being adequately nourished or being mobile). After discussing the steps required to construct the DII, this article computes and compares the DIIs for two earthquakes of similar magnitude in two societies at different levels of development and of two disasters (earthquake and wind storm) in the same society.

Keywords: capability approach, individual well-being, natural disasters, recovery, social impact

Introduction

Natural disasters refer to **damaging or destructive** natural events such as tornados, hurricanes and earthquakes that impact the well-being of individuals. Quantifying the societal impact of natural disasters is essential for taking appropriate recovery measures and planning future mitigation strategies.[1] There have been several recent efforts to quantify the societal impact of disasters on the basis of a comprehensive index that gauges their overall impact on the quality of life of individuals.[2]

These approaches correctly focus directly on the quality of life or well-being of individuals in order to assess the impact of disasters. This paper argues, however, that there are two primary problems with their assessments. First, the adopted definition of the quality of life is too narrow, omitting from consideration important components such as being adequately nourished, being sheltered and being mobile. This narrow definition leads to an overly narrow picture of the impact of natural disasters on individuals within a society and, hence, to an underestimation of the actual impact of natural disasters. Second, current approaches lack a theoretically sound, practical framework for defining and combining the consequences on the quality of life of individuals into a comprehensive composite index of the overall societal impact of a disaster. Such an index would be able to assist policy- and decision-makers in setting well-informed and responsible policy priorities and make decisions regarding disaster recovery.

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The objective of this paper is to present a theoretically justified methodology for gauging the societal impact of disasters on individuals' quality of life. In the proposed capability approach, the impact of a disaster on the quality of life is defined in terms of the changes in the individuals' capabilities, which are measured and quantified using selected indicators. Capabilities are components of well-being and refer to the effective freedom of individuals to do and become things of value, such as being nourished or being sheltered (Sen, 1999a). This study proposes a Disaster Impact Index (DII) to assess the societal impact of a disaster in terms of changes in capabilities. The construction of the DII is discussed in detail in subsequent sections and is modeled on the methodology currently used by the United Nations to calculate the level of development of societies around the world.

The next section reviews the original application of a capability approach to development economics and policy. The paper then discusses the advantages of using a capability approach to assess the societal impact of a disaster, comparing this approach to other currently available approaches considered for recovery and mitigation planning. The following section presents the details of the proposed methodology for gauging the societal impact of a disaster in terms of changes in individuals' capabilities. Finally, as an application of the proposed methodology, the paper compares the different impacts of two earthquakes of similar magnitude that occurred in two different countries (the Unites States and Pakistan) and of two different disasters (windstorm and earthquake) in the same country (United States).

A capability approach to gauging the development of societies

The concept of *capabilities* was first developed in the context of development economics and policy in an attempt to gauge the quality of life of individuals as a way of determining the overall level of development of societies (Sen, 1989; 1993; 1999a; 1999b; 2004; Nussbaum, 2000a; 2000b; 2001). Nobel Prize-winning economist Amartya Sen and philosopher Martha Nussbaum argue that the well-being of individuals should be defined and gauged in terms of individual capabilities. Capabilities refer to the effective freedom of individuals to achieve valuable functionings, or doings and beings (Anand and Sen, 2000). Examples of functionings include being healthy, adequately nourished, adequately sheltered, mobile and educated. Capabilities thus describe the genuine opportunities open to a person.

Assessing an individual's quality of life from a capability approach is distinct from other gauges of well-being, including utilitarian and resource-based assessments. Unlike utilities, capabilities do not reflect the preferences of individuals, but rather their genuine opportunities (Sen, 1999a; 1999b). Further, capabilities refer to what individuals can actually do or become with a specific bundle of resources, which varies according to personal, social, and environmental conversion factors, and not just the amount of resources they have.

The capabilities framework is currently used by the United Nations and development agencies to estimate societal development through the Human Development Index (HDI).[3] The HDI is a composite index, which assesses the level of development of a society based on an assessment of three primary functionings (living a long and healthy life, being knowledgeable and having a decent standard of living). Functionings and capabilities are dimensions of well-being that are not directly quantifiable. Thus, the HDI uses *indicators* to indirectly measure the level of individuals' functionings in practice. Each indicator is a proxy for a specific capability (Raworth and Stewart, 2003). For example, an indicator of living a long and healthy life is life expectancy at birth. The value of each indicator is then converted into a uniform scale, creating an Indicator Index. Finally, the Indicator Indices are combined to create the composite HDI. A detailed description of how the indicators are used to construct a composite index and of the process of scaling and combining Indicator Indices is provided later in this paper.

Proposed capability approach to gauging the societal impact of natural disasters

There have been a number of recent attempts to develop a comprehensive index that gauges the overall impact of disasters on the quality of life of individuals. Examples of such indexes are the Life Quality Index (LQI) (Rackwitz, 2002; 2006; Nathwani, Lind and Pandey, 1997), the Life Quality Time Allocation Index (LQTAI) (Ditlevsen and Friis-Hansen, 2007), and the Societal Willingness to Pay (SWTP) (Pandey and Nathwani, 2004). The above approaches acknowledge the need to take into consideration different aspects of the quality of life of individuals. Ultimately, however, they assess the quality of life only on the basis of (1) the length of life in good health, assessed in terms mortality (or life expectancy) and (2) the gross domestic product (GDP), based on the assumption that the actual quality of life of individuals is a direct function of the GDP.

These approaches have the virtue of focusing directly on the quality of life of individuals to assess the impact of disasters. However, there are two primary problems with their assessment of the quality of life. First, the GDP provides an incomplete picture of the quality of life of individuals. Indeed, it was the very inadequacies of GDP as a gauge of the development of societies, where development is defined in terms of the quality of life of individuals, that motivated Sen to develop a capability approach (Sen, 1989; 1999a; 1999b). For example, GDP does not tell us how well off individuals are because it does not tell us how income is distributed within a society. If wealth and income are concentrated in the hands of a small percentage of a population, then the standard of living of most individuals within a society might be very low. It may be difficult for most individuals to be adequately nourished and adequately sheltered. In a similar way, the GDP of a country does not reveal what individuals are effectively able to do or become with their available resources. The degree to which individuals are able to prevent and treat diseases, for example, depends on their income as well as the structure of the health care system (such as whether health care is provided by the government, or how many hospitals and doctors are in the vicinity where individuals live) (Sen, 1989; 1999a; 1999b).

The second, more general limitation stems from the narrow definition of the quality of life adopted by the above approaches. Instead of considering diverse, intuitively significant dimensions of the quality of life of individuals (such as being adequately nourished, being sheltered, being mobile), the above approaches implicitly define the quality of life in terms of length of life and resources enjoyed. As the first limitation illustrates, other, diverse dimensions of the quality of life cannot be inferred from these two measures. The narrow definition of the quality of life subsequently leads to an overly narrow picture of the impact of natural disasters on individuals within a society and, hence, an underestimation of the actual impact of natural disasters. Even if the dimensions of the quality of life considered by the above approaches were to be expanded, the approaches themselves lack a theoretically sound and practical framework for (1) selecting which additional dimensions are important to consider and (2) combining these dimensions into a comprehensive composite index.

A capability approach provides a stronger theoretical foundation for identifying and quantifying the *societal impact* of natural disasters on the basis of overall changes in individuals' capabilities (Murphy and Gardoni, 2006). The approach defines the impact in terms of broader constitutive dimensions of the quality of life of individuals. Indicators for each selected capability are designed to indirectly capture whether that functioning (e.g. being sheltered, being adequately nourished) is or can be achieved. So, for example, an indicator for being adequately nourished could be average daily caloric intake.

Because the proposed capability approach is more comprehensive in dimensions of well-being affected by a natural disaster it considers and, hence, in the picture of the societal impact it provides, it allows for a more complete and more accurate policy- and decision-making process for disaster recovery and mitigation. In addition, implementing a capability approach to the societal impact of a disaster will facilitate an integrated and coordinated approach to public policy decision-making for both development and disaster recovery and mitigation. The need to take into consideration natural disasters in development assessment, projects and planning is widely recognized in development economics.[4] Using capabilities to measure both development and the impact of disasters will encourage the inclusion of a component on the vulnerability of that society to disasters in the assessment of the development of a society. Further, the same data could be used for the assessment of both the vulnerability and development of a society, therefore optimizing the allocation of the resources available for the data collection. As a step towards bridging the assessment of the vulnerability and development of a society, the authors of this paper have previously proposed how to evaluate hazard mitigation policies from a capability approach (Murphy and Gardoni, 2007; 2008; Gardoni and Murphy, 2008).

Practical implementation of a capability approach

This section considers the question of how to construct a composite Disaster Impact Index (DII) to gauge the societal impact of natural disasters. The proposed methodology is parallel to the methodology used by the United Nations to construct the HDI (Raworth and Stewart, 2003; BCPR, 2004).

Selection of capabilities

This section begins by outlining the criteria to be used to select the specific capabilities to consider in assessing the societal impact of disasters. These criteria are derived from (1) general discussions by Sen (1993; 2004) as well as Wolff and de-Shalit (2007) about principles to guide the selection of capabilities, (2) critical reflection by the authors of this study upon the relevance of such discussions to the question of the selection of capabilities in the context of assessing the societal impact of natural disasters, and (3) general requirements for scientific and engineering theory construction. This section then proposes specific capabilities and shows how they meet the developed criteria. Future work might demonstrate that other capabilities could also fulfil the criteria below.

Selection criteria

The capabilities taken into consideration to determine the actual societal impact of disasters should fulfil the following four general criteria:

1. **Relevance.** The choice of capabilities needs to be directly connected to the overall purpose of determining and evaluating the impact of natural disasters.
2. **Importance.** The proposed capabilities need to be important enough to justify taking mitigation actions to protect and maintain them.
3. **Influenceability:** Influenceability requires that it be possible to reduce the impact of a disaster on selected capabilities through public policy decisions or disaster mitigation.
4. **Practical implementability:** The proposed DII should be usable practically, while at the same time not omitting relevant information. The DII should fulfil two conditions for this to occur. First, the minimum possible number of capabilities should be chosen (*capabilities parsimony*). The fewer the capabilities selected, the less data needs to be gathered, which enhances the methodology's practicability. Parsimony is critical for a model to be actually implemented in practice and to have a concrete impact on decision- and policy-making. Inevitably, a trade-off between model accuracy and parsimony is essential for a model to be implemented practically. Second, each of the capabilities selected should provide information that cannot be ascertained from the other capabilities (*capabilities orthogonality*). Integrating additional capabilities that are not orthogonal (that is, that will echo aspects already included) would create double counting of a specific capability because two (or more) capabilities would relate to the same thing. This would be problematic later, when combining the corresponding indicators into a comprehensive index.

Proposed capabilities

To satisfy Criterion 1 and ensure their relevance, the selected capabilities should be characteristically negatively affected by a disaster. This research has identified four broad dimensions of individual well-being (here called capability groups) typically impacted by disasters: (1) longevity; (2) physical and mental health; (3) affiliation and mobility; and (4) continued command over resources (see column 1 of Table 1). The immediate consequences of natural disasters normally include casualties, physical injuries, mental trauma, the destruction of homes and livelihoods as well as the isolation of some communities, all of which are captured by the above capability groups. Table 1 also lists specific capabilities associated with the four capability groups mentioned above.

The proposed capabilities are significant, as required by Criterion 2. The importance of these four capability groups (and their corresponding more specific capabilities) stems from their particular connections to individual well-being. Longevity and physical and mental health are both constitutive aspects of well-being and conditions for the possibility of attaining other important capabilities. Affiliation and mobility capture the social dimensions of human well-being. Command over resources has a strictly instrumental connection with individual well-being; material resources provide essential conditions that make it possible for individuals to achieve other capabilities.

A discussion of how the chosen capabilities meet Criterion 3 (influenceability) and Criterion 4 (practical implementability) will follow the next section, which focuses on the selection of indicators.

Selection of indicators

Selection criteria

Capabilities are not quantifiable and, therefore, it is impossible to directly gauge them or their changes. Consequently, indicators of the selected capabilities have to be

Table 1 Proposed capability groups, capabilities and corresponding indicators

Capability group	Capability (being able to. . .)	Indicator
Longevity	. . . live to the normal end of life	No. of individuals killed
Physical and mental health	. . . avoid injuries	No. of individuals injured
	. . . have adequate and permanent shelter	No. of individuals left homeless
	. . . have adequate nourishment	Correlated
	. . . live in a healthy environment	No. of individuals without access to water supply
Affiliation and mobility	. . . engage in forms of interaction with others	No. of individuals unemployed due to the disaster
	. . . move freely from place to place	Correlated
Command over resources	. . . hold property	Direct economic losses [$]

identified. Such indicators are intended to monitor specific capabilities indirectly. Adequate indicators should fulfil the following criteria:

1. **Be representative of the corresponding capability:** an indicator should track in practice the particular capability of interest and with which it is associated.
2. **Be intuitively plausible:** an indicator should be transparent and easily communicable and understandable to the public and policy-makers.

Proposed indicators

Column 3 of Table 1 lists the proposed indicators corresponding to each selected capability. The number of individuals killed due to a disaster is an indicator for the change in the capability of individuals to live to the normal end of their natural lives. The indicator for the change in the capability to avoid injuries (part of the capability group of mental and physical health) is the number of individuals injured, where the injured refers to 'people suffering from physical injuries, trauma or an illness requiring medical treatment as a direct result of a disaster' (EM-DAT, 2006). The indicator for the change in the capability for adequate and permanent shelter is the number of individuals who are homeless or 'needing immediate assistance for shelter' (EM-DAT, 2006). The indicator for the change in the ability to live in a healthy environment is the number of individuals without access to sanitary water. The indicator for the change in the capability for affiliation is the number of individuals made unemployed due to the disaster. The proposed indicator for the change in the capability to have command over resources is direct economic losses divided by the GDP. The GDP has to be defined over the population that will carry the burden (in terms of the economic costs) of the disaster.

The following section argues that each indicator meets the four criteria for indicators and discusses how the raw data used to determine the value for each indicator fulfil the four criteria for raw data outlined below.

Indicators criteria

1. **Be representative of the corresponding capability:** There is a direct correlation between the number of fatalities and the change in the capability to live to the normal end of life because dying as a result of a disaster means losing this capability. Similarly, being injured due to a disaster directly diminishes the overall level of health an individual would otherwise be capable of achieving. The loss of one's home reduces, temporarily, the capability of individuals to be adequately sheltered.

   Access to sanitary water is an essential condition for enabling individuals to have a healthy living environment. Often sewage systems and water supplies are disrupted by disasters.

   > *Drinking water supply and sewage systems are particularly vulnerable to natural disasters, and the disruptions that occur in them pose a serious health risk. [. . .]*

> *Natural disasters can cause serious damage to health facilities and water supply and sewage systems, having a direct impact on the health [and therefore well-being] of the population dependent on these services* (PAHO, 2000).

Thus, an indicator for the change in the capability to live in a healthy environment is the number of individuals without access to sanitary water following a disaster.

The indicator for the change in the capability for affiliation, or the capability to engage in forms of interaction with others, is the number of individuals made unemployed due to the disaster. Being an active participant in the economy is one of the ways in which individuals engage in interaction with others. This general line of reasoning is similar to the rationale for using the long-term unemployment rate to indicate social exclusion in the HDI (Fukuda-Parr and Kumar, 2003).

Finally, the proposed indicator for the change in the capability to have command over resources is direct economic losses divided by the GDP of the population that will carry the burden (in terms of the economic costs) of the disaster. This indicator captures losses which are a direct result of a disaster and that immediately negatively diminish an individual's wealth and ability to use material commodities.

2. **Be intuitively plausible:** It is standard to use three of the proposed indicators when determining the societal impact of a disaster: the number of individuals killed, the number injured and the number left homeless. This reflects their intuitive plausibility. This capability approach provides a theoretical framework for explaining *why* these intuitively important figures are in fact significant. Furthermore, the argument given in the previous section attests to the intuitive plausibility of the other indicators.

Finally, there is one temporal consideration that might be factored in to better gauge the impact of a disaster in the medium and long term. The proposed indicators represent candidates to assess the immediate impact of a disaster. Societies in the process of recovery may restore the most basic indicators to the same level as before a disaster and so using those indicators may convey the false impression that a disaster no longer impacts a society in the medium and long term. Further, supplemental indicators may be required to more accurately capture the medium- and long-term impact of a disaster over time.

Selection criteria for raw data

The raw data used to quantify the values of the indicators needs to fulfil four criteria. This will ensure that the quality of the data used to compute the societal impact of disasters is accurate. This discussion of raw data draws in part on Raworth and Stewart (2003). The data has to be:

1. **available for a large segment of the world's population.** In theory, the DII should make it possible to compare the societal impacts of hazards that occur in disparate regions around the world.

2. **internationally comparable.** In order to be able to gauge the differential impacts of disasters globally, the data must be comparable.
3. **of reasonable quality.** The quality of the comparison of impacts of different disasters will be as good as the quality of the data on which the judgements are based.
4. **easily collectable.** If data for an indicator is not easily collectable, this increases the likelihood of error or inaccuracy in the final measurement of the impact of the disaster. Furthermore, the required data has to be easily and quickly measurable from reconnaissance inspections for the proposed approach to be easily implementable to determine the societal impact of a disaster and guide recovery. Information that requires lengthy or costly inspections would undermine the usefulness of the proposed approach to public policy.

If data is of poor quality and is not available, comparable or collectable, efforts should be made to gather better data in the future.

Proposed raw data

1. **Available for a large segment of the world's population** and
2. **internationally comparable.**

   Extensive data on the numbers of individuals injured and left homeless has already been collected and recorded for past disasters. Thus, the required data for these two indicators has already proven to be internationally available and comparable. Data on direct economic losses has also been collected and information on the GDP for areas affected is available from reports such as the *Human Development Report*. Thus, the relevant information for the indicator of direct economic losses divided by the GDP is available internationally and is comparable internationally.

3. **Of reasonable quality** and
4. **easily assessable.**

   A common and widely used source of data for most research on disasters is the Emergency Events Database (EM-DAT, 2006). Support for this database was initially provided by the World Health Organization and the Belgian government. EM-DAT contains data on the occurrence and effects of more than 12,800 mass disasters in the world from 1900 to the present. The database is compiled from various sources, including United Nations agencies, non-governmental organizations, insurance companies, research institutes and press agencies, and is used and referred to by national and international media and academic publications. This database has demonstrated the possibility of acquiring data from disasters that is of reasonable quality.

Some of the required data might not currently be available. For example, there is limited data on the number of individuals without access to sanitary water. This paper has thus highlighted the importance of and need for collecting this data in the future. While this might depart from the quantities that are typically recorded, considering this dimension would provide a richer overall picture of the societal impact of a hazard. It should also be noted that it is possible to gather data of reasonable quality for these indicators by using the same techniques employed to gather the currently recorded data. Incorporating this data into the overall DII would provide a more complete picture of the societal impact of a disaster.

Capabilities criteria (continued)

So far, this paper has demonstrated that the selected capabilities fulfil the first two criteria for capabilities: relevance and importance. This section discusses how the selected capabilities satisfy the remaining two criteria, influenceability and practical implementability, drawing on the information provided about their corresponding indicators.

3. **Influenceability.** The capability to live to the normal end of life is influenceable because, for example, the safety of the buildings in which individuals live, work or find themselves when a disaster occurs affects the number of fatalities. The safety of civil engineering structures also influences the number of individuals injured or displaced. Increasing the structural reliability of buildings is likely to diminish the number of injured or displaced due to a disaster, to decrease the direct economic costs of a disaster, to decrease the costs stemming from structural failure and to decrease the number of businesses closed. It also is possible to increase the reliability of water supply and sewage systems (or their ability to withstand natural disasters), which in turn will lead to an increase in the number of individuals with access to sanitary water. Thus, the capabilities for physical and mental health, affiliation and mobility, and command over resources are all influenceable.
4. **Practical implementability (parsimony and orthogonality).** Information from EM-DAT (2006) was used to investigate the potential correlation among different indicators, such as the direct economic losses and the numbers of people killed, homeless, affected and injured. A correlation indicates the degree to which the indicators are related and change together. An analysis of various natural disasters across different countries available in EM-DAT indicated no statistically significant correlation between pairs of different variables. Therefore, the assumption made in the rest of this paper is that the correlation is negligible and, therefore, the capabilities listed above are orthogonal. The proposed capabilities are as parsimonious as possible, given that each of the capabilities captures a distinct valuable aspect of well-being that is not reducible to any other (Nussbaum, 2000b).

Scaling indicators: indicator indices

After determining the value for each indicator, the next step in the process of constructing the DII is normalizing (or scaling) the indicators into a common scale to make various different types of information comparable. Scaling is necessary, given that the goal is to achieve a composite picture of the societal impact of a disaster, as determined by the impact on multiple capabilities. Scaling makes it possible to combine different indices and thus create a composite index.

The particular kind of scaling implemented in the case of the DII involves ranking the values for each indicator due to a disaster over a scale from 0 to 1, where 0 means no consequences for indicator I_k, and 1 means reasonable maximum consequences. To acquire some sense of how significant the impact on a given indicator is, the indicator value can be compared to a reasonable worst-case scenario that has occurred. This comparison allows for relative judgements about the impact of disasters on capabilities. For example, if the value of the indicator for a given capability is equal to the maximum possible value, then that disaster has the worst or most extreme impact on a given capability. Each indicator I_k has a unique associated reasonable maximum value, max I_k.

This process is analogous to the process used in the HDI to assess the level of development of societies around the world. The data from each indicator is compared along a range of minimum and maximum values. For example, the life expectancy at birth of individuals in a country is compared along the range of minimum and maximum values (goalposts) of 25 and 85 years (UNDP, 2000). Where a country falls along this range provides a picture of how far along that country is in achieving a specific functioning, which in this case is living a long and healthy life (Jahan, 2003). The goalposts are not selected based on the actual minimum and maximum values for life expectancy among all countries in any specific year. Rather, reasonable maximum and minimum values are selected based on historical data for life expectancy and are kept constant over time. To base estimates on the actual maximum and minimum values of countries in a particular year obscures the real progress made by countries along a dimension. Consequently, a country could 'improve its performance and yet see its HDI fall because the countries at the top or at the bottom had done even better' (ul Haq, 2003). It would also be impossible to gauge the progress of a country over time in terms of the change in its value for the HDI, since that change might not represent progress or regression *for that country* along the dimensions the HDI considers.

The first step in the process of scaling indicators for the DII, then, is to select minimum and maximum values for each variable. The minimum value is zero, indicating no changes in capabilities. So a disaster that has no impact on existing levels of individual capabilities, gauged in terms of individual indicators, would be judged to have had no societal impact. The selection of the maximum value for the k-th indicator could be informed by considering the worst consequences among all disasters recorded. To avoid using an outlier (exceptionally rare and non-representative figure of the reasonably anticipated worst consequences) as the maximum value, the β-percentile of the ranked recorded values of an indicator is used as the maximum value. That is, if all the recorded values of the k-th index for all disasters (e.g. number of fatalities) are ranked based on the magnitude of their values, the value that is greater than β% of all the values is selected. While there is a degree of arbitrariness in selecting this goalpost, it avoids the problem of over-scaling the actual value of the index (dividing the actual value of an index by a mistakenly non-representative larger number), which would lead to weighting down (or arbitrarily diminishing the importance of) the contribution of an indicator when compared to the contribution of the other indicators to the DII, since the number of the consequences is divided by the maximum value.

This scaling is performed using the following equation:

$$\text{Indicator Index } (II_k) = \frac{\text{actual value of the indicator } (I_k)}{\text{reasonable maximum value for that indicator } (\max I_k)} \quad (1)$$

Where k = 1,…,n identifies a specific indicator and n is the total number of indicators considered (in the example shown later in the paper, n = 6). As for the HDI, it is important to keep the goalposts constant for the DII to track the progress in the recovery of a society over time.

Weighting indicator indices: Disaster Index

The Disaster Index (DI) is a summary gauge of the societal impact of a disaster that describes the average impact on each indicator captured using IIs. It is important to consider how to weigh the various indicator indices. This paper proposes that the IIs should have equal weight. The main reason for assigning equal weight is the fact that the loss of specific capabilities cannot be compensated for or substituted for by a gain in other capabilities. So, for example, no amount of command over resources can compensate for the lack of physical and mental health. This view is consistent with the position adopted in the case of human development.[5] In addition, decisions about weighting are based on the relative impact on a society of the change in the level of each indicator and not on the impact from the perspective of each individual whose indicators have been affected. For these reasons, it is sound to assign each II_k equal weight.

A DI is thus computed as:

$$\text{Disasters Index (DI)} = \left[\frac{1}{n}\sum_{k=1}^{n} II_k^{\alpha_k}\right]^{1/\alpha_k} \quad (2)$$

Where k ranges over the IIs and n is the total number of IIs.

The power α_k (where $0 < \alpha_k \leq 1$) may be used to taper the impact of the IIs on the DI, as the IIs grow. That is, a unit increment of II_k may be made less important when II_k is already high than when II_k is lower. This is to capture mathematically the fact that the significance of a unit increase in the consequences for the overall societal impact of a disaster may be smaller as the level of the consequences increases. The smaller the value of α_k, the greater the tapering is. A value of $\alpha_k = 1$ implies no discounting. Furthermore, though for the reasons discussed above it seems appropriate to assign equal weight to each II_k, the proposed approach is flexible and can account for different weights being assigned to the IIs by modifying equation (2) so that each term in the summation would be multiplied by its corresponding weight, making the DI a weighted average of the IIs.

Putting the Disaster Index in context: Disaster Impact Index

The DI is a composite index that gauges the overall impact of a disaster on the capabilities. However, the actual impact of a disaster on a society varies based on the size of the society. For example, a disaster with identical direct economic losses has a different impact on China than on Honduras, given the different sizes of the two populations. Consequently, to determine the overall impact, the DI has to be divided by the number of individuals, n_s, in the society that shares the burden of the DI. This creates the Disaster Impact Index (DII). The DII can be computed as:

$$\text{Disaster Impact Index (DII)} = \frac{\text{Disaster Index (DI)}}{n_s} \tag{3}$$

The larger a society is, the smaller the actual impact of a disaster is for a given DI. The DII makes the composite picture of the DI more meaningful by looking at the impact of the overall consequences of the disaster, on average, for the capabilities reduction of individuals.

The selected n_s could be the entire population of a country, the population of a region, or the population of a city. Similarly, n_s could also be representative of a sub-group of the population based on, for example, age, gender, ethnicity or socio-economic status. When calculating the DII, the values of the indicators will depend on the selected n_s and should be computed for the selected group or sub-group of the population. The selection of n_s can be guided by the population group or sub-group of interest to decision- and policy-makers given their purpose in determining the impact of a disaster. For example, considering sub-groups within a population can provide important information on and insight into the potential differences in the impact of a disaster on such groups or sub-groups. Decision- and policy-makers can also do a sensitivity analysis, choosing different values of n_s and assessing the corresponding DII.

Illustration of the proposed approach

This section computes and compares the Is, the DI and the DII of four past disasters. It compares the impacts of two earthquakes of similar magnitude, one that occurred in a developing country (Pakistan) and another that occurred in a developed country (Japan). In addition, two different disasters (windstorm and earthquake) are compared in a developed country (United States).

To develop the examples, this section uses data from EM-DAT (2006) for the emergency phase of specific disasters (just after the events). Some of the data that

Table 2 Maximum post for calculating the indicator indices

Indicator	Maximum post
No. of individuals killed	20,000
No. of individuals injured	60,000
No. of individuals left homeless	2,000,000
No. of individuals without access to water supply	n/a
No. of businesses closed due to disaster	n/a
Direct economic losses / GDP	0.1

would be needed to calculate the impact on the indicators of certain capabilities is not currently available. Thus, the examples of the calculated DII reflect only a partial picture of the immediate societal impact. Should data not currently available for certain indicators be collected in the future, a more complete picture of the impact of disasters will be possible. In the calculations, $\alpha_k = 0.5$ for all IIs. According to equation (2), the assumed value of α_k is equivalent to taking the square root of II_k. While other values of α_k could also be used, the square root provides the desired tapering of the impact of the IIs on the DI, as the IIs grow. After plotting the percentiles of the data from 150 disasters recorded around the world and available from EM-DAT (2006), the maximum posts were selected as the rounded values corresponding to $\beta = 92.5$. Table 2 lists the maximum posts for each indicator based on this selection of β.

Table 3 lists the values of the Is, DI and DII for an earthquake that affected Pakistan in 2005 and an earthquake that affected Japan in 1995. The two countries' populations at the time of the earthquakes were comparable: 167 million for Pakistan and 125 million for Japan. The earthquake intensities were also comparable: 7.6 magnitude for Pakistan and 7.2 magnitude for Japan. The societal impact of the two earthquakes was significantly different, however. Table 3 shows that Pakistan had approximately 14 times more fatalities than Japan, 2 times more individuals injured and 11 times more individuals left homeless. Yet while Pakistan was more affected than Japan in these three dimensions, there is no clear trend or correlation among those dimensions. This supports the claim of this research that the dimensions are orthogonal, which is required for a parsimonious model. In terms of costs, Japan had direct economic losses that amounted to 20 times more than the direct economic losses in Pakistan. However, when factoring in the relative wealth of the two countries, it becomes clear that the economic impact (cost/GDP) on Pakistan was more than twice the economic impact on Japan. The DIs for the two earthquakes demonstrate that, in an aggregate form, the overall impact of the earthquake on Pakistan was approximately twice as big as the impact on Japan. Finally, the DIIs for the two earthquakes account for the population of each country, providing a way to assess the average impact that each earthquake had on average on the well-being of the individuals in each society. The DIIs show that the impact on each individual in

Table 3 Comparison between earthquakes in Pakistan and Japan

Country		Pakistan	Japan
Event	Phenomenon	Earthquake	Earthquake
	Magnitude	7.6	7.2
	Date	2005	1995
Characteristics of the country	GDP (x 10^6)	91,080	4,428,530
	Population	167,121,000	125,568,000
Consequences of the event	Killed	73,338	5,297
	Injured	69,142	34,492
	Homeless	2,800,000	251,301
	Cost (x 10^6)	5,000	100,000
	Cost/GDP	0.05490	0.02258
Indicators	I_1	3.667	0.265
	I_2	1.152	0.575
	I_3	1.400	0.126
	I_4	0.549	0.226
DI		1.108	0.725
DII		0.663	0.577

the Pakistani population was about 1.1 times the impact on each individual in the population of Japan.

As this case demonstrates, only counting fatalities or economic loss does not provide an accurate representation of the actual impact of a disaster on the individuals in a society. Looking at fatalities would imply that the impact was 14 times greater in Pakistan than in Japan, while looking at direct economic costs would reveal that the earthquake in Japan was 20 times worse than that in Pakistan. These examples also highlight that one cannot gauge the societal impact strictly based on the knowledge of the magnitude of an earthquake or isolated consequences, which describe only the partial impact.

Table 4 illustrates a second example, showing a comparison between two different events that afflicted the United States. The first event is the 1994 Northridge earthquake and the second event is Hurricane Katrina of 2005. Since the two events are eleven years apart, the US GDP is marginally different for each year. The proposed approach provides a composite index to capture the significantly more devastating impact of Hurricane Katrina. Table 4 shows that the hurricane caused 22 times more fatalities and approximately the same number of injuries, and that 25 times more individuals were left homeless. These numbers also indicate the orthogonality among the indicators. The economic impact of Hurricane Katrina was approximately

Table 4 Comparison between Northridge earthquake and Hurricane Katrina in the United States

Country		United States	United States
Event	Phenomenon	Earthquake	Wind storm
	Intensity	Magnitude 6.7	Category† 5
	Date	1994	2005
Characteristics of the country	GDP (x 10^6)	7,802,980	11,153,660
	Population	260,529,000	286,981,000
Characteristics of the event	Killed	60	1,322
	Injured	7,000	6,610
	Homeless	20,000	500,000
	Cost (x 10^6)	16,500	125,000
	Cost/GDP	0.00211	0.01121
Indicators	I_1	0.003	0.066
	I_2	0.117	0.110
	I_3	0.010	0.250
	I_4	0.021	0.112
DI		0.401	0.597
DII		0.154	0.208

† According to the Saffir–Simpson Hurricane Scale.

five times greater than that of the Northridge earthquake. The overall societal impact of the hurricane was about 1.5 times the impact of the earthquake.

These examples suggest that the proposed approach provides important information for decision-makers to consider when allocating resources to mitigate natural disasters. The examples show how looking only at the number of fatalities or the direct economic losses, for example, would provide a partial representation of the actual societal impact of disasters. The proposed DII provides an aggregate gauge that is easy to use, easily communicable and representative of the actual societal impact of disasters.

Conclusion

This paper develops a Disaster Impact Index (DII) that can be used to gauge the societal impact of a disaster on the basis of the changes in individuals' capabilities. The DII is a composite index that gauges the disaster impact per capita. The detailed steps to construct the DII are described. As an illustration, DIIs are computed for two earthquakes of similar magnitude in two societies at different levels of development and of two disasters (earthquake and wind storm) in the same society to assess and compare their societal impacts. The DII provides important information for decision-makers to consider when allocating resources for the recovery from natural disasters; it can be used as a guide for designing hazard mitigation strategies. The DII may also provide a measure of the potential for recovery of a society, which is expected to be a function of the remaining capabilities of a society in the aftermath of a disaster. However, further work is needed to assess the relationship between the potential for recovery of a society and capabilities in the aftermath of a disaster.

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Endnotes

1 See, for example, Lindell and Prater (2003); Cutter et al. (2003); Murphy and Gardoni (2007; 2008).
2 See, for example, Nathwani, Lind and Pandey (1997); Rackwitz (2002; 2006); Cutter et al. (2003); Pandey and Nathwani (2004); Ditlevsen and Friis-Hansen (2007).
3 See UNDP (2000).
4 See, for example, BCPR (2004).
5 See, for example, Jahan (2003).

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