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González, Fernando Antonio Ignacio; London, Silvia
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NATURAL DISASTERS AND THEIR IMPACT A METHODOLOGICAL REVIEW

Fernando Antonio Ignacio González
Institute of Economic and Social Research of the South, Argentina
faigonzalez@iiess-conicet.gob.ar

Silvia London
Institute of Economic and Social Research of the South, Argentina
slondon@uns.edu.ar

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Abstract:

Natural disasters generate profound socio-economic changes in the affected communities. A consistent methodology that allows quantifying its impacts is essential for the implementation of adaptation and mitigation policies. The objective of this work is to provide a systematic review of existing methodologies to quantify the economic impact derived from the occurrence of natural disasters. To do this, a keyword search is conducted in two search engines (Scopus and Science Direct).
The results suggest the existence of wide differences between methodological proposals. Consideration of physical damage (direct effect) is more frequent than the impact on productive flows (indirect effect). The destruction of the natural environment (loss of ecosystem services) is not usually included. In the context of global climate change, these findings highlight the importance of having a consistent methodology.

Keywords: Natural disasters, Economic impact.

INTRODUCTION

Natural disasters constitute a serious threat at the global level. Every year an increasing number of natural disasters take place (Center for Research on the Epidemiology of Disasters [CRED], 2020) and this is expected to deepen in the future as a consequence of climate change (Intergovernmental Panel on Climate Change [IPCC], 2018). During 2018 alone, natural disasters affected 68.5 million people worldwide -with an estimated mortality of more than 11,000 people- and generated losses of US $ 132 billion (CRED, 2019).

The occurrence of natural disasters involves profound changes in the living conditions of the affected communities (Economic Commission for Latin America and the Caribbean [ECLAC], 2014). First, the evidence suggests lower economic growth after a disaster (Klomp and Valckx, 2014; Lazzaroni and van Bergeijk, 2014). In turn, natural disasters affect the formation of human capital. On the one hand, they can destroy educational and health centers or the transport infrastructure of the affected areas. On the other hand, if they affect household income, the demand for human capital may be reduced given the lower disposable income and an increase in the marginal utility of child labor (Ferreira and Schady, 2008). The effects of disasters were also examined in dimensions such as health (Maclean et al., 2016; Hikichi et al., 2019; Ogasawara, 2019), poverty (Sánchez and Calderón, 2015; González et al., 2019; 2020) or education (Caruso, 2017).

Given the potential effects of natural disasters, it is essential to have a consistent methodology that allows quantifying their socio-economic impact and facilitates the implementation of mitigation and prevention actions. However, nowadays, the existence of multiple methodologies is observed. Thus, ECLAC (2003) has proposed a damage classification frequently used by the disaster literature: direct effects to refer to the physical damage caused by the disaster (includes damage to assets, mortality and morbidity) and indirect effects when considering the impact on productive flows. In a similar way, the World Bank (2010) distinguishes between first order effects (assimilable to direct effects) and higher order effects (effects of order n resulting from effects of order n-1)1.

Meyer et al. (2013) disaggregate the damage caused by disasters into five types: direct effects (destruction of physical assets), indirect effects (loss of salary, employment, etc.), business interruption costs (less production of goods and services), intangible costs (impact on health or the environment and in general goods not exchanged in a market) and mitigation costs (spending on reducing the future risk of disaster in affected areas). In order to avoid double counting the damage, Merz et al. (2010) consider that, since the value of an asset is equal to the discounted flow of its expected future benefits, a damage assessment methodology should not consider direct and indirect effects simultaneously. Therefore, it is evident that when considering the economic impact of a disaster, different elements and types of damage can arise. Logically, the use of different methodologies can lead to wide differences in damage estimates for the same disaster (Ladds et al., 2017; Avelino and Dall´erba, 2019).

Considering the above, this work provides a review of existing methodologies for evaluating the impact of natural disasters. In particular, it tries to identify similarities and differences in the quantification of damage and potential methodological gaps. Therefore, hereinafter section 2 describes the search methodology and information sources used. Section 3 presents the results of the review and, finally, section 4 discusses the main conclusions.

DEVELOPMENT

Methodology and sources of information

Given the objective of the work, we proceed with a systematic review of the literature. The review is qualitative in nature. That is, we explore the heterogeneity observed between the relevant studies, identifying coincidences and dissimilarities from a descriptive perspective.

The literature review was carried out based on keyword searches in two well-known search engines (Scopus and Science Direct). In particular, the descriptors "impact assessment", "methodology" and "natural disasters" and their equivalents in Spanish were used. Neither temporal (according to publication date) nor geographic (place of publication) restrictions were considered. Additionally, the official websites of institutions with extensive experience in the study of disasters (ECLAC, the World Bank, the Federal Emergency Management Agency [FEMA] and the World Meteorological Organization) were considered.

The selection of relevant documents was made differentiating those contributions that constitute a method for measuring any effect of disasters, from those that are comprehensive methodologies. In terms of Eckhardt et al. (2019), a method is a formal prescription for achieving an objective -including a consistent set of tools and techniques- and that has a limited range of application. In this regard, various methods have been applied in estimating the effects of natural disasters -input-output matrices (Galbusera and Giannopoulos, 2018), computed general equilibrium models (Kajitani and Tatano, 2017), social accounting matrices (Okuyama, 2007), regression analysis (Klomp and Valckx, 2014; Lazzaroni and van Bergeijk, 2014) or multi-criteria analysis (Khalid and Ali, 2019). A methodology, on the other hand, constitutes a consistent and coherent set of methods to achieve an objective. Thus, the methodology proposed by FEMA suggests the use of replacement costs for the analysis of damage to physical assets and the use of input-output matrices when examining economic flows. In turn, those disaster risk assessment methodologies -as opposed to impact assessment- are beyond the scope of the analysis (Grimaz and Malisan, 2020). This work builds on the proposal of Eckhardt et al. (2019).

Considering the above, the keyword search yielded a total of 2,028 documents. After reading the title and abstract, 15 representative documents of 14 methodologies were selected (ECLAC updated in 2014 a previous methodology from 2003 and, therefore, two documents correspond). This selection was made considering the exclusion criteria presented above (works that do not constitute methodologies but methods were discarded). Table 1 summarizes the selected documents:

TABLE 1
Methodologies for evaluating the impact of natural disasters

Reference	Institution	Denomination
Calderón Patier et al. (2003)	Individual	Not specified
IASC (2009)	Inter-Agency Standing Commitee	Initial Rapid Assessment (IRA)
Petrucci et al. (2009)	Individual	Suppor tAnalysis Framework (SAF)
World Bank et al (2013)	World Bank, European Comission and United Nations Development Group	Post Disaster Needs Assessment (PDNA)
Dorra et al. (2013)	Individual	Not specified
WMO and GWP (2013)	World Meteorological Organization and Global Water Partnership	Not specified
ECLAC (2003; 2014)	Economic Commission for Latin America and the Caribbean	Damage and Losses Assessment (DaLA)
AIDR (2015)	Australian Institute for Disaster Resilience	Not specified
IASC (2015)	Inter-Agency Standing Commitee	Multi-cluster/sector Initial Rapid Assessment (MIRA)
Lombardi et al. (2016)	Individual	Not specified
Milan Polytechni cet al. (2017)	Milan Polytechnic, Consejo Superior de Investigaciones Científicas and Oxford BrooksUniversity	Improving Damage Assessments to Enhance cost-benefit Analysis (IDEA)
FEMA (2018)	Federal Emergency Management Agency	Hazards-United States (HAZUS)
Nunes et al. (2020)	Individual	Not specified
Sangha et al. (2020)	Individual	Not specified

own elaboration

It is observed that the existing methodologies come from both official institutions (8) and proposals from researchers (6). The growing interest in the study of natural disasters is evident considering that 7 of the methodologies were published in the last five years. In this sense, the number of documents identified from the keyword search also shows an increasing trend:

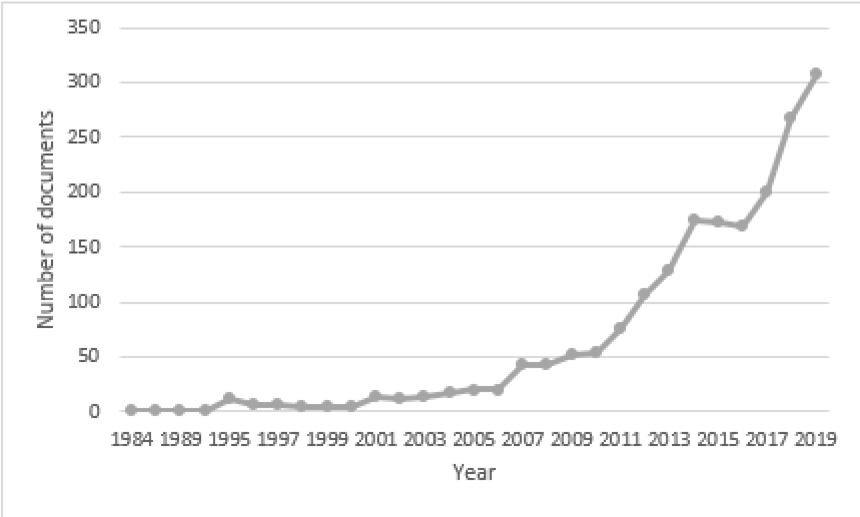

FIGURE 1
Number of documents resulting from keyword search
own elaboration based on Scopus and Science Direct

It is observed that, especially since 2006, the number of documents referring to natural disasters increases significantly. This may be linked to the occurrence of disasters with broad socio-economic consequences such as the Sumatra-Andaman earthquake (2004) and Hurricane Katrina (2005) (Okuyama, 2007).

Results

Next, Table 2 presents each of the selected methodologies and includes a brief description, damages included, valuation methods used, sources of information and types of natural disasters contemplated.

TABLE 2
Description of impact assessment methodologies for natural disasters

Reference	Type of damages	Description	Valuation method	Sources of information	Types of disasters
CalderónPatier et al. (2003)	Distinguishes between direct effects (on physical assets) and indirect effects (less production of goods and services). Considers secondary effects (lower macroeconomic flows)	Based on the use of input-output matrices, Tries to estimate the socio-economic impact of disasters and prepare recovery plans	Replacement cost and observed changes in economic flows	Input-output matrices, national accounts, macroeconomic indicators, etc.	Natural of all kinds. Also applicable to anthropogenic disasters
IASC (2009)	Distinguishes the impact by categories (population, shelter, health services, nutrition and health). Proposespotentialindicators to use	It is a tool that provides an overview of an emergency situation, based on multi-sectoral information, identifies impacts and needs and determines priority humanitarian actions in the first weeks after the disaster	Qualitative scale of severity by category (severe, worrying or normal)	Household surveys, strategic informants, group discussions, secondary data on previous demographic and climatic conditions	Natural of all kinds
Petrucci et al. (2009)	Considers direct damage (destruction of buildings, roads and physical damage to people), indirect damage (reduction in productivity and displacement of people) and intangible damage (psychological or emotional consequences on people)	Through questionnaires by category, normalized numerical damage indices are generated for the case of mass movements in Calabria-Italy	Quali-quantitative by generating index numbers	Historical records of disasters, technical reports, municipal reports, local newspapers, etc.	Mass movements
World Bank et al. (2013)	Distinguishes between effects (damage to infrastructure, less access to services, greater vulnerability of people) and impacts of disasters (macroeconomic and human development consequences)	The methodology consists of a guide to help governments assess the damage generated by natural disasters and formulate recovery strategies and their implementation	Replacement cost for damage to physical assets and analysis of time evolution in macroeconomic aggregates and development indicators (HDI, MPI, etc.)	Censuses, economic reports, household surveys, remote sensor images, strategic informants, national accounts, etc.	Natural of all kinds
Dorra et al. (2013)	Distinguishes between direct (on physical assets) and indirect (lower economic flows) damages	Presents a probabilistic model for estimating losses (especially considering losses in buildings and gas and electricity networks). A macroeconomic model is also developed from input-output matrices	Replacement cost, observed changes in economic flows and fragility curves	Censuses, surveys, building inventories, input-output matrices, etc.	Earthquakes
WMO and GWP (2013)	Distinguishes between damages (on physical assets) and losses (lower economic flows). It also incorporates intangible losses (human lives, injuries, etc.)	It is a tool to assess flood losses and generate recovery plans. Proposes pre and post disaster evaluations	Replacement cost, observed changes in economic flows and damages curves	Geographic information systems, land use and building reports, surveys, strategic informants, etc.	Floods
ECLAC (2003; 2014)	Considers direct (on the assets and infrastructure of the affected area) and indirect (lower economic flows from the disaster) damages. Also includes "macroeconomic effects" as a result of direct and indirect damages.	Analyzes conceptual and methodological aspects for the measurement of damage caused by disasters. Take a micro-macro perspective. Damage can be estimated from information from multiple affected sectors but also from macroeconomic aggregates that condense information from all sectors	Replacement costs for direct damages and counterfactual analysis for indirect damages	Written press, cartography, surveys, remote sensor images, strategic informants, national accounts, etc.	Natural of all kinds. Also applicable to anthropogenic disasters
AIDR (2015)	Distinguishes between direct damage (physical destruction of assets) and indirect (lower economic flows). In each case, disaggregates between tangible losses (goods that can be sold in a market) and intangible losses (human lives)	Constitutes a guide to estimate the economic costs of natural disasters in Australia. Proposes pre and post disaster evaluations	Replacement costs for direct damages and loss of added value for indirect damages. Also for indirect damage, higher cost of provision or operation	Interviews, focus groups, meteorological office, government reports, etc.	Natural of all kinds
IASC (2015)	Considers primary effects (damage to infrastructure), secondary effects (less economic flows and the impact of disasters generated as a consequence of a previous disaster) and humanitarian needs (mortality, morbidity, etc.)	It is a needs assessment tool in cases of the occurrence of a sudden disaster. Proposes a comprehensive framework considering underlying conditions, damage caused and humanitarian responses	Replacement cost and observed changes in economic flows	Household surveys, strategic informants, discussion in community groups, secondary data, etc.	Natural of sudden ocurrence
Lombardi et al. (2016)	Distinguishes between damages (on physical assets) and losses (lower productive flows) for each agricultural subsector. Suggest indicators to be used in each case	Proposes a methodology to estimate the impact of natural disasters in the agricultural sector (emphasis on crops, livestock, fishing, aquaculture and forestry)	Replacement cost and observed changes in economic flows	Agricultural surveys, satellite images, climate indicators, etc.	Natural of all kinds
MilanPolytechnic et al. (2017)	Distinguishes between direct (on physical assets) and indirect (lower economic flows) damages	Provides a methodology for collecting, analyzing, and using disaster loss data for multiple purposes (including damage assessment, mitigation, and development of tools for state agencies). Emphasis on cost-benefit analysis of post-disaster investments	Replacement cost and observed changes in economic flows	Highlights the importance of information from insurers and state agencies	Natural of all kinds
FEMA (2018)	Distinguishes between direct physical damage (damage to buildings, public services, transportation and essential facilities -health, education or emergency centers-), induced damage (damage generated by rubble, trees and fires) and direct losses (furniture for buildings, inventories, income and people injured or displaced)	Based on geographic information systems, it estimates the potential impact, economic losses and social impact of disasters. Includes software with databases and disaster type models for the United States	Consider replacement cost for direct physical damage. It also uses probabilistic models such as loss curves and input-output matrices.	The software includes databases that are used as a source. They contain information on the stock of buildings, transport systems, services and demographic data. In addition, the user can incorporate external sources	Earthquakes, floods, tsunamis and hurricanes
Nunes et al. (2020)	Considers the damage to infrastructure (transport routes, energy supply) and human damage (deaths, injuries, displaced people, requests for help)	Presents a methodology to estimate the cost of meteorological disasters in the city of Rio de Janeiro. It proposes a division of tasks between 15 local state agencies	Quali-quantitative by generating a multi-criteria impact scale	Reports from the agencies involved in the evaluation	Meteorological
Sangha et al. (2020)	Distinguishes between direct (stocks) and indirect (flows) damages. In each case it breaks down between tangible and intangible losses	Presents a methodology to estimate the cost of natural disasters with special emphasis on the environmental costs (loss of ecosystem services) that arise from the disaster	Consider monetary and non-monetary indicators. Defines valuations that arise from revealed and declared preferences (willingness to accept or to pay, cost avoided, etc.)	Interviews and surveys of affected people with a strong emphasis on the local and subjective evaluations	Natural of all kinds

own elaboration

First, Table 2 shows some points in common and also differences in the analyzed methodologies. In relation to the types of damage considered, studies tend to discriminate between the physical damage resulting from the disaster (direct effect, damage or first order effect) and the impact on productive flows (indirect effect, loss or second order effect). However, only some of the methodologies explicitly disaggregate the impact on the physical integrity of exposed people -mortality, injuries, etc.- (IASC, 2009; Petrucciet al., 2009; World Bank et al., 2013; WMO and GWP, 2013; AIDR, 2015; IASC, 2015; FEMA, 2018; Nunes et al., 2020).

In the particular case of the so-called direct effects, some methodologies delimit the sectors or types of assets on which information is collected. Thus, housing or sanitary and health facilities (IASC, 2009), transportation networks (Petrucci et al., 2009; Nunes et al., 2020), access to services (World Bank et al., 2013; Nunes et al., 2020) and essential facilities -health centers, education or emergency assistance- (FEMA, 2018). This realizes the importance of these sectors in terms of the capacity of a community to face a natural disaster and its potential effects.

Thus, damage to a factory is a first-order effect, while lower production due to damage is a second-order effect. If, in turn, as a result of the lower production of this factory, some other company sees its activity reduced or interrupted (eg. lack of inputs), a third-order effect occurs, and so on.

Observing the valuation criteria used, it appears that the replacement cost of the destroyed assets is the most frequently used to quantify the direct effects. In terms of indirect effects, the changes observed in the main macroeconomic aggregates is the most widely used criterion. In this regard, ECLAC (2003) remarks that the use of the book value of assets -when evaluating direct effects- lacks representativeness in countries with a history of moderate or high inflation.Also, when considering indirect effects it is necessary to estimate what the evolution of the variables of interest (counterfactual analysis) in case the disaster had not taken place -in order to individualize the effect of the disaster itself-. Partially departing, Merz et al. (2010) argue that using replacement cost can overestimate the damage caused by the disaster by ignoring the depreciation of the damaged asset -recommending the use of the acquisition cost net of depreciations.

On the other hand, discrepancies are also observed in the methods to be used. Thus, some methodologies propose to use probabilistic models -such as damage or fragility curves- (Dorra et al., 2013; WMO and GWP, 2013; FEMA, 2018), while others resort to qualitative-quantitative indices (IASC, 2009; Petrucci et al., 2009; Nunes et al., 2020). This, logically, can lead to wide differences between estimates of different methodologies -as shown by Ladds et al. (2017) and Avelino and Dall´erba (2019)-.

In terms of the sources of information, there is a wide use of on-site surveys, interviews with key informants, government reports and newspaper articles. When estimating indirect effects, input-output matrices are used (CalderónPatier et al., 2003; Dorra et al., 2013; FEMA, 2018) and information from the national accounts (ECLAC, 2003; 2014; CalderónPatier et al., 2003; World Bank et al., 2013). In terms of the types of disaster analyzed, the methodologies tend to consider all natural disasters with exceptions such as Petrucci et al. (2009), Dorra et al. (2013), WMO and GWP (2013), FEMA (2018) and Nunes et al. (2020).

In terms of the existence of gaps in the methodological proposals analyzed, the following can be highlighted. First, there is a clear bias towards the analysis of direct effects. The level of detail and disaggregation in this case is usually higher compared to the analysis of indirect effects, in addition to that, although direct effects are included in all the reviewed antecedents, not all consider indirect effects (IASC, 2009; Nunes et al., 2020). In the same sense, conceiving of indirect effects as the observed changes in the variables of interest -before and after the occurrence of the disaster- can be an oversimplification and confuse the effect of a disaster with other simultaneous events.

Second, the environmental cost (loss of ecosystem services) does not seem to be explicitly considered in the methodologies examined, with the exception of ECLAC (2003; 2014), World Bank et al. (2013) and

Sangha et al. (2020). This is especially important given that subjective well-being seems to be directly linked to the availability of environmental assets and the benefits they provide (Sangha et al., 2020).

Third, the methodologies reviewed tend to construct their estimates of indirect effects from the availability of periodic and disaggregated information on relevant macroeconomic variables -such as GDP, employment series, income, etc.-. While this is a reasonable assumption for countries with robust statistical systems, it may not be so in developing countries where disaggregated statistics are scarce. In any case, methodological proposals should explicitly consider this possibility to guide the analyst in estimating damages.

Fourth, in addition to estimating the total cost or damage produced after the occurrence of a natural disaster, it is also relevant to know how the cost is distributed within a community. In this sense, the methodologies reviewed do not contemplate an explicit treatment of people in poverty or greater vulnerability to the occurrence of disasters -even if they consider the impact of disasters on poverty or well-being. The exception to the above is given by the cases of WMO and GWP (2013) and IASC (2015).

Fifth, there is a certain gap in terms of the sources of information used by the methodologies examined and a growing body of empirical literature on disasters. Indeed, recent works estimate the impact of disasters or contribute to their detection -in real time- from data from social networks or collaborative platforms (Liu, 2014; Resch et al., 2017; Arthur et al., 2018; Kankanamge et al., 2020). It is striking that the most recent methodological proposals do not explicitly incorporate these sources of information.

Finally, an aspect pointed out by Merz et al. (2010) and Meyer et al. (2013) is the lack of validation of the estimates generated from each individually considered methodology. That is, each methodological proposal provides estimates of a certain type of damage using a certain method (example: input-output matrices or computed general equilibrium models) but without inquiring about the robustness of what was reported. In terms of policy makers, the reliability of the estimates is relevant, especially when considering the regulatory decisions behind the estimates (spatial and temporal delimitation for the evaluation, chosen valuation method, including sectors, among others). In this regard, recent evidence tries to account for the discrepancies between methods when evaluating the same disaster (Tan et al., 2019).

CONCLUSIONS

Throughout this work, we have provided a review of the literature regarding methodologies for evaluating the impact of natural disasters. From the search by keywords in two renowned search engines -Scopus, Science Direct- 14 methodological proposals were selected.

From the group of selected studies, it was observed that the majority (8) respond to institutional proposals (Economic Commission for Latin America and the Caribbean, World Bank, World Meteorological Organization, Federal Emergency Management Agency, among others) and not to works in scientific journals. Seven of the revised methodological proposals were published in the last five years. The foregoing denotes a growing interest in the study of the impacts of natural disasters.

When examining the selected methodologies in detail, points of coincidence and differences between them were observed. In all cases, the destruction of physical assets (direct effects) and, in general, also the changes in economic flows after the disaster (indirect effects) are considered. The use of replacement cost of damaged assets as a valuation criterion enjoys wide consensus even when some methodologies resort to the use of qualitative and quantitative damage indices. In terms of information sources, a large number of variants were observed: satellite images, interviews, government reports, econometric models, surveys, etc. In any case, interviews, reports and surveys are the most frequently used.

In terms of methodological gaps, it is possible to highlight the following. Damage estimation tends to focus on direct effects, to the detriment of other types of damage (indirect, intangible, etc.). Furthermore, methodological proposals usually assume the existence and availability of disaggregated and periodic macroeconomic information for the estimation of damages -which may not be realistic in developing countries. The non-use of certain sources of information -such as social networks or collaborative platforms- and the reduced consideration of the distribution of damages within the affected community are relevant aspects to include.

Finally, considering that an increase in the frequency and severityin the occurrence of natural disasters is expected, and that these generate a severe interruption in the operation of the affected community, it is essential to have a consistent methodology for evaluating their impact. For this, it is essential to have regular socio-economic information and an adequate historical record of natural disasters.

REFERENCES

REFERENCES: Please refer to articles in Spanish Bibliography.

BIBLIOGRAPHICAL ABSTRACT: Please refer to articles in Spanish Bibliographical abstract.

NOTES

1. Thus, damage to a factory is a first-order effect, while lower production due to damage is a second-order effect. If, in turn, as a result of the lower production of this factory, some other company sees its activity reduced or interrupted (eg. lack of inputs), a third-order effect occurs, and so on.