Validating Resilience and Vulnerability Indices in the Context of Natural Disasters[i]

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Introduction

Resilience implies that a system can persist and function more successfully over the duration of an event, relative to a less-resilient counterpart. These key elements are highlighted in two definitions, including the National Academy of Science's definition of disaster resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" and the Intergovernmental Panel on Climate Change's definition of "the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions".

Despite risk management actions to lessen impacts, losses from natural disasters have increased over time and motivated discussion of a new resilience management paradigm as a policy objective in the U.S. and worldwide. While there has been a recent proliferation of resilience assessment tools and methods to help develop an understanding of existing resilient capacity, few of these approaches point to specific improvement measures or support specific investment priorities. Although resilience quantification may be in its infancy, researchers should understand that their methods are likely to be used in decision making for funding justifications or policy development, whether they are intended for use in that way or not.

Objective

Quantifying resilience and vulnerability through aggregation of metrics has become a popular approach to aid in decision making. However, empirical validation remains an important final step. While such multi-metric resilience indices may be well substantiated by theory, they may not perform as expected. The policy relevance of a resilience assessment relies on its ability to pinpoint areas in need of improvement that can confidently be expected to reduce some disaster impact, whether total losses, spatial extent of disruption, or recovery time. The objective of this work is to

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[i] This paper is part of the IRGC Resource Guide on Resilience, available at: https://www.irgc.org/risk-governance/resilience/. Please cite like a book chapter including the following information: IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. *v29-07-2016*

present a first effort at partial validation of five popular U.S. resilience indices. Multi-variate regression is used to empirically validate each index to test their power to explain historical property losses, fatalities, and disaster declarations at the county-event level across states in the Southeast. The results are compared with the stated index objectives, to examine the relevance of each index and to identify best practices for index development to support further validation. Lastly, policy recommendations are made based on the findings in order to enable disaster indices to be better utilized to inform policy and action.

The authors acknowledge that this is an initial and incomplete attempt at validation. One, most of the indices' authors do not specifically state that their indices will explain the three outcomes tested here. Also, resilience goes beyond simply withstanding disruptive events and speaks to the ability of a system to recover from disturbances and adapt to changing conditions, the latter of which this validation does not assess. The recovery component of resilience could perhaps be validated using explanatory power for number of days that schools are closed, or length of time for local business revenues to rebound. However, as much of that data is currently lacking, this intent of this paper is bring to reader's attention the need for external validation of these methods and to demonstrate one approach using regression analysis.

Instruments for resilience management

In response to the clear need for disaster research, academics and practitioners alike have conducted many studies in an effort to better understand resilience and vulnerability. One major focus has been the development of indices to quantify resilience and vulnerability using metrics. In that vein, a main effort in quantification is through an index, or "composite indicator", that aggregates metrics across a variety of numerical factors in order to gauge the level of disaster resilience or vulnerability across space. Cutter (2015) reviews the assortment of tools, indicators, and scorecards that currently populate the resilience literature in the United States. Some of these are "resilience" indices and some are "social vulnerability" indices but this turns out to be only a nominal difference. Although social vulnerability and resilience may be different theoretical constructs, popular indices of vulnerability have stated goals of identifying "uneven capacity for preparedness and response and… determining differential recovery from disasters" and informing management across "all phases of the disaster cycle," which closely match the definition of, and goals of, resilience indices. As a result, most indices include very similar set of metrics related to demographic and municipal data, for example: number of owner-occupied homes, hospital beds per capita, educational attainment rates, existence of hazard mitigation plans, and the Gini coefficient of inequality. The output of these indices is relative—comparing one county to another, or one county at to the same county at some later point in time. The decision making that this sort of result could inform would be statewide allocation of funding, or identification of target areas for improvement. However, though many indices draw on similar sets of metrics, the results may vary from index to index—one index may show county A as more resilient than county B, while another index may show the reverse, confusing the selection of an appropriate index to base decision making on. To enhance the utility and policy external validation of these indices with actual disaster outcomes should be performed. Community resilience to disasters is still an emerging field and index developers often describe their products as frameworks or baseline assessments but there is little utility unless they can be confidently used to inform decision makers. This work takes as inputs the results of five prominent disaster indices in the United States: Cutter, Burton, and Emrich's Baseline Resilience Index for Communities (BRIC);

Peacock et al.'s Community Disaster Resilience Index (CDRI); Foster's Resilience Capacity Index (RCI) as applied to metropolitan areas by the Network on Building Resilient Regions; Cutter, Boruff, and Shirley's Social Vulnerability Index (SoVI); and Flanagan et al.'s Social Vulnerability Index (SVI). Figure one shows the score from each index for counties in the southeastern United States. The CDRI was only available for coastal counties, the RCI for metropolitan areas, and the BRIC for the on the eastern States.
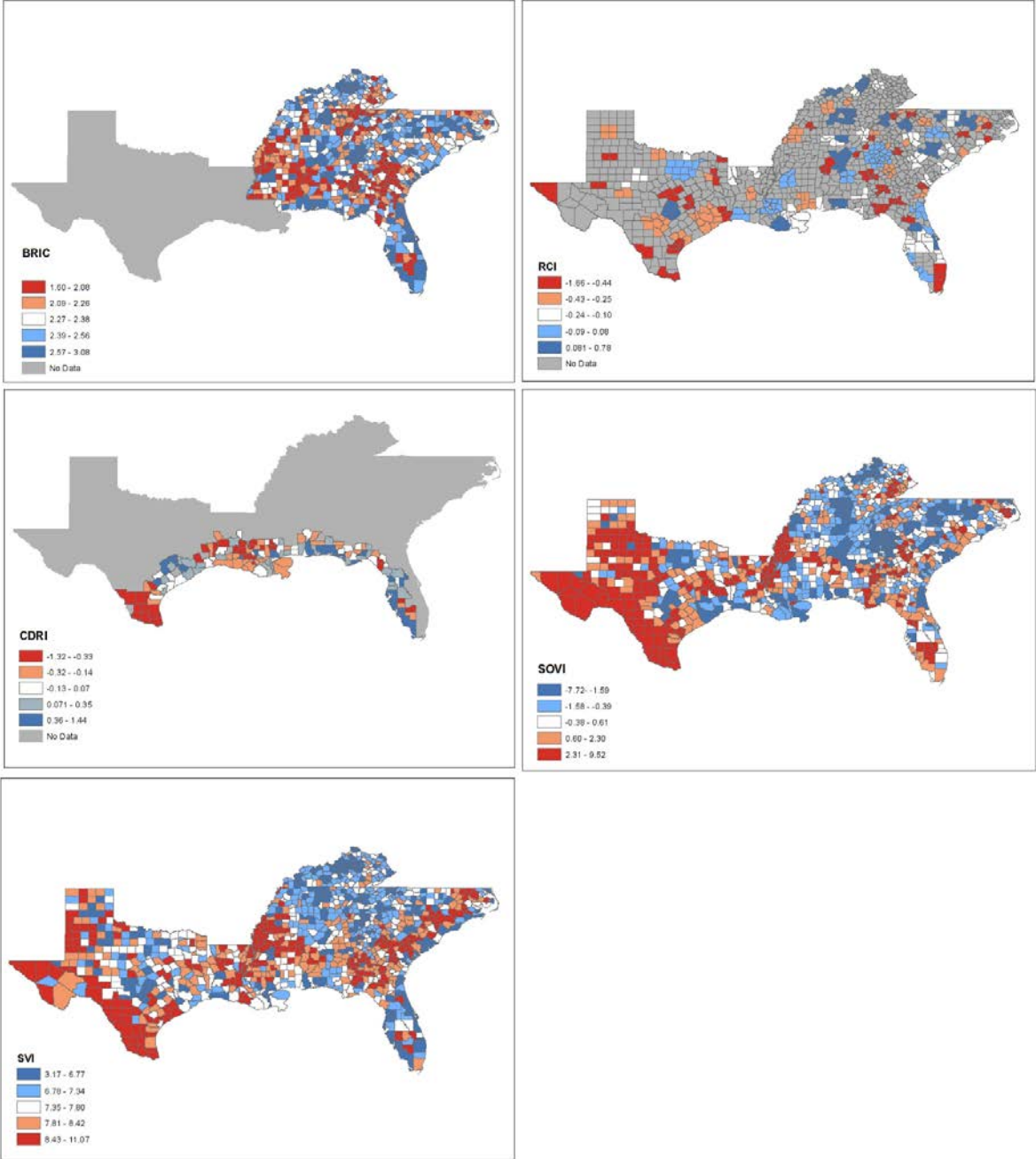

Figure 1: Scores by index for counties in the southeastern US

Figure 2 graphs the scores of each index in three selected regions. The counties listed for each region are adjacent to each other, yet across the different index, their calculated relative performances

(higher or lower than a neighbor) vary. Depending on the disaster index selected, a state official would come to different conclusions about how to allocation funding for improvement in the region. This observation initiated the present effort to at a first order validation of these approaches with historical disaster data.
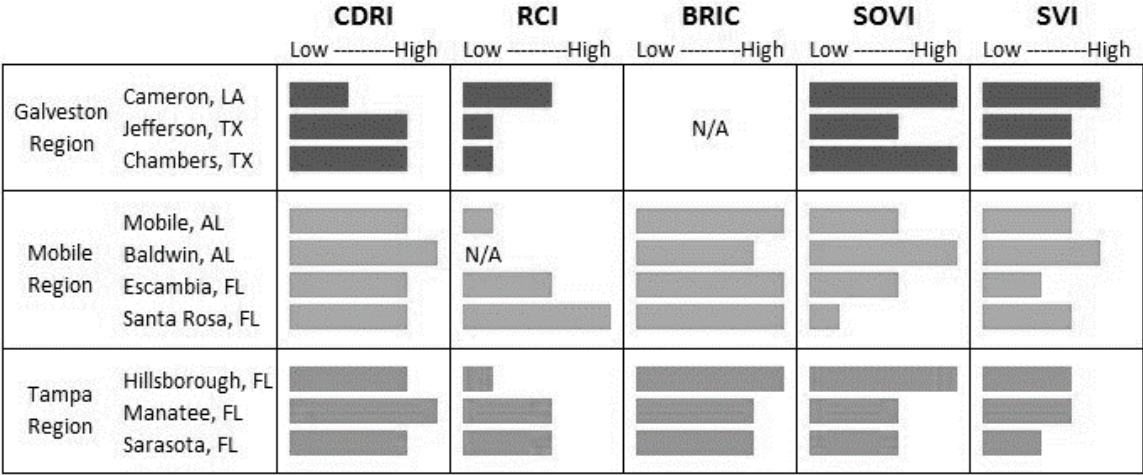

Figure 2: Score of each index in three selected regions

Metrics

For the disaster index validation, data was collected from the National Climatic Data Center and Federal Emergency Management Agency for the 10 US states shown in Figure 1. Three common outcomes for disaster planning are reduction of damage and loss of life and reduction of emergency support needed. Therefore it is expected that the resilience indices will positively correlated with property losses ($), fatalities (#), and disaster declarations (#) while the social vulnerability indices will be negative correlated with these outcomes. Multivariate regression analysis is employed to empirically validate the explanatory power of the five disaster indices, relative to their theoretical performance, while controlling for other potential confounding variables, including population density or capital stock in harm's way, magnitude of the disaster, and year. The magnitudes of each relationship are not directly compared, as these are determined, in part, by individual index assumptions and normalizations used in the index creation. Instead, the method tests the ability of each index in explaining outcomes consistent with the theoretical sign ($\beta_1<0$ for resilience indices and $\beta\_1>0$ for vulnerability indices) and statistical significance of the relationship. We do not believe, nor intend for, our validation exercise to be comprehensive in testing for all types of outcomes. Instead, we present the results as an important first attempt at formal empirical validation and comparison across indices.

The five indices analyzed were all theoretically sound and individual metrics were analyzed using statistical techniques by the creators of each index. However, empirical validation reveals that not all indices perform as expected. A pairwise comparison between the five indices was performed. While there is qualitative consistency within the index types (resilience or vulnerability), the overall correlations are not high. The highest correlations observed were between BRIC and CDRI at 0.805. Half of the ten pairwise correlations have values between -0.5 and 0.5, with some values close to

zero. Thus, it remains unclear, with only this information, whether disaster indices are picking up different facets of resilience and vulnerability or some indices are performing better. In the regression analysis, CDRI and SoVI perform the best, with all results of the correct sign, but the estimated coefficient on disaster declarations and fatalities, respectively, are not statistically significant. This may be partly driven by the fact that they were already empirically verified to some extent in the original analysis. In addition, RCI performs as expected for property losses and fatalities, but has an insignificant but incorrect sign for declarations. CDRI, RCI, and SVI perform best for both damages and fatalities, while SoVI performs best for both damages and disaster declarations (Table 1). While most indices explain historical damages, only some explain fatalities and few explain disaster declarations with significance. However, very few indices specifically explain the outcomes that they try to speak to, so the user is left to interpret the results independently. One recommendation of this paper is that indices should be much clearer in what they aim to explain—disaster reduction or recovery, infrastructure or community health, etc.—and should follow up with explicit testing to see if they indices perform well. This way, decision makers can know clearly which index to choose to inform certain types of decisions.

Index	Property Damages	Fatalities	Disaster Declarations
BRIC	○		○
CDRI	●	●	
RCI	●	●	
SoVI	●		●
SVI	●	●	○
● Filled circles indicate correlation is of the expected sign and statistically significant.			
○ Open circles indicate correlation is of the opposite sign and statistically significant.			
No circle indicates regression results were not statistically different than zero.			

Table 1: Indices compared

Understanding community resilience and vulnerability to natural disasters remains a policy priority around the world. Corporations, governments, and non-profit organizations are investing time and resources into measuring and improving resilience across many disciplines, so much so that the term has evolved into a new identity validated index functionality is fundamentally important in order to better understand the value of index results and properly apply these lessons for their intended purposes. By validating index performance using outcomes related to the stated objectives of the indices, policy makers can have confidence that investments in resilience or reduction in vulnerability, as recorded by changes in a disaster index, will translate to specific desired improvements.

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