

# A Monte Carlo Approach to Quantify and Analyze Uncertainty in a Social Vulnerability Index

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## Margin of Error in the American Community Survey data can impact the social vulnerability index.

### Background

Social vulnerability indices have been prevalent in hazards and disasters research for over twenty years. These indices are useful to understand people's and places' vulnerability, prepare for future hazards, and recover from past hazard events. The uncertainty of vulnerability to hazards model has not been systematically studied and developed. Though evaluating uncertainty in geography is not very common, recently a growing literature has put vulnerability indices under scrutiny (Tate 2012, 2013; Rufat, Tate, Emrich, and Antolini 2019).

### Research Questions

The purpose of the study is to establish a method to quantify the uncertainty of a census-based social vulnerability index. We have two research questions. First, how can we quantify uncertainty in the SVI that results from use of ACS data? Second, how does quantification of uncertainty in the SVI change interpretation of the index values?

### Data & Study Area

We collected the SVI data from the CDC/ATSDR website (CDC/ATSDR Social Vulnerability Index 2011). The CDC website provided county and tract level SVI downloadable and ready to use. We used the tracts level SVI data to generate the new SVI. The data used to generate the SVI is ACS 5-year estimation. We used the already calculated SVI instead of calculating from the raw data to save time. We conducted the analysis on FEMA Region 4 at census tract level. The states in the region 4 includes Florida, Alabama, Georgia, South Carolina, North Carolina, Tennessee, Mississippi, and Kentucky (FEMA, accessed in March 2024). The region has 17,208 census tracts. We generates a modified SVI and reproducible maps at the census tract level for the FEMA Region 4.

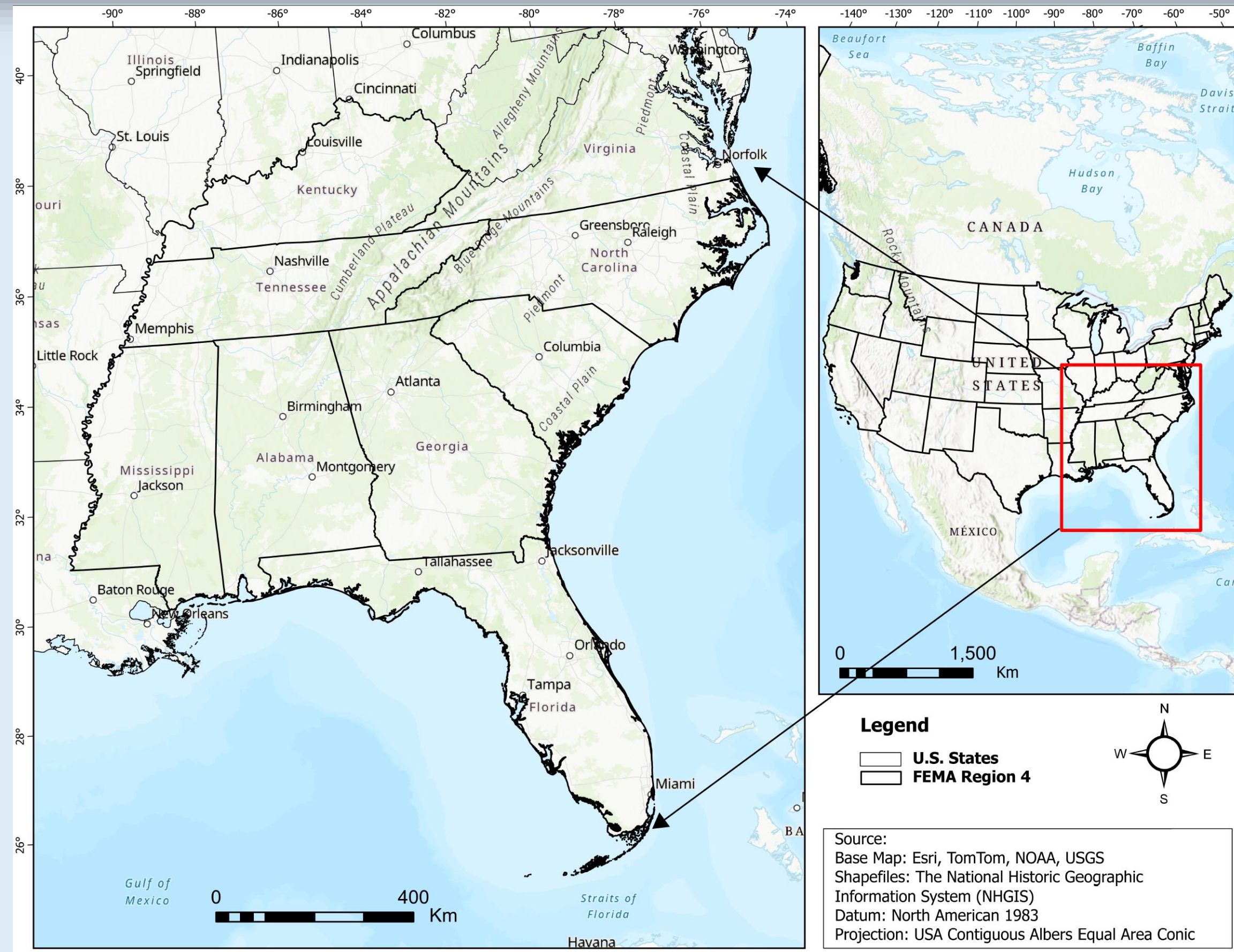


Figure 1: Study Area: FEMA region 4

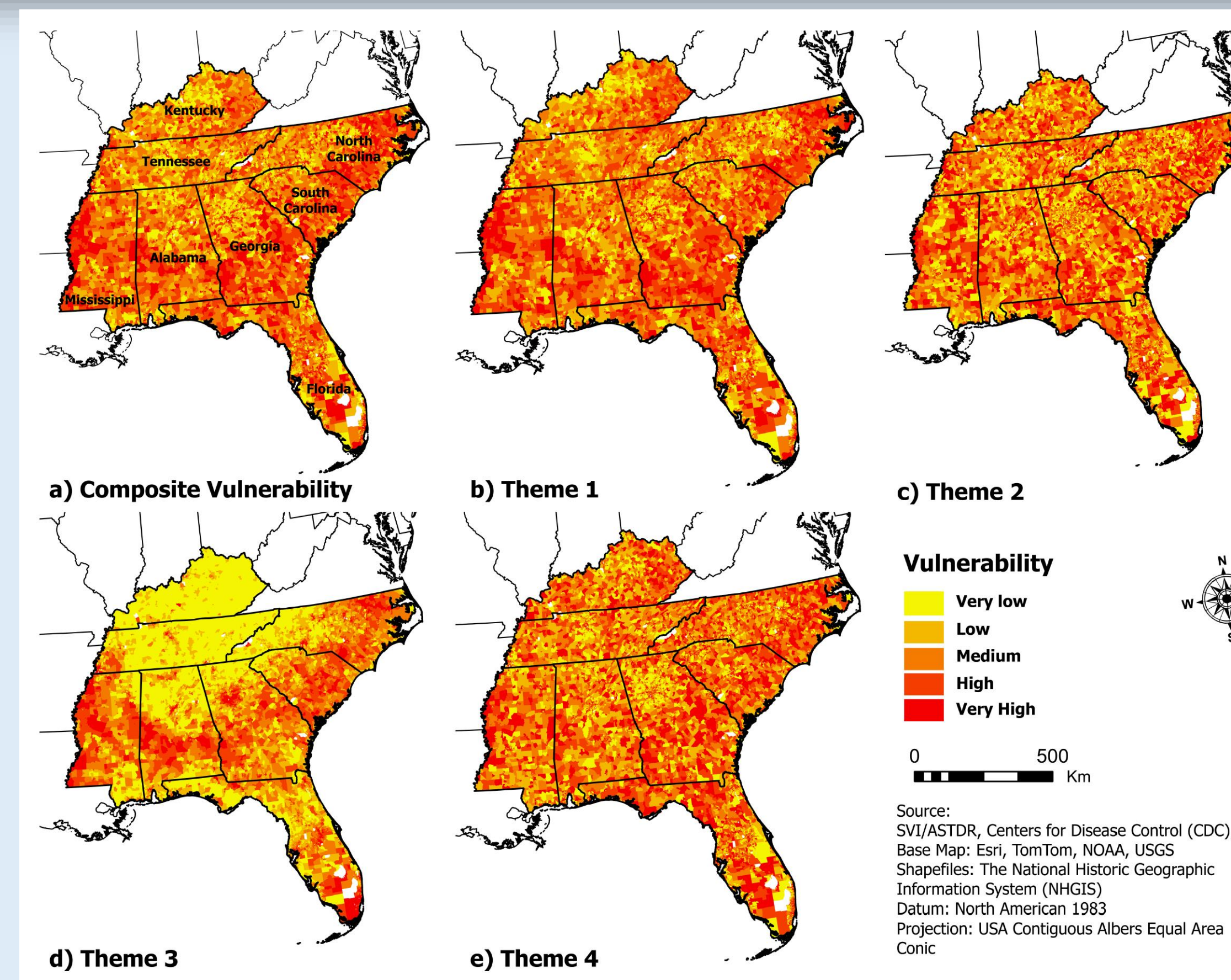


Figure 2: Original SVI including all themes

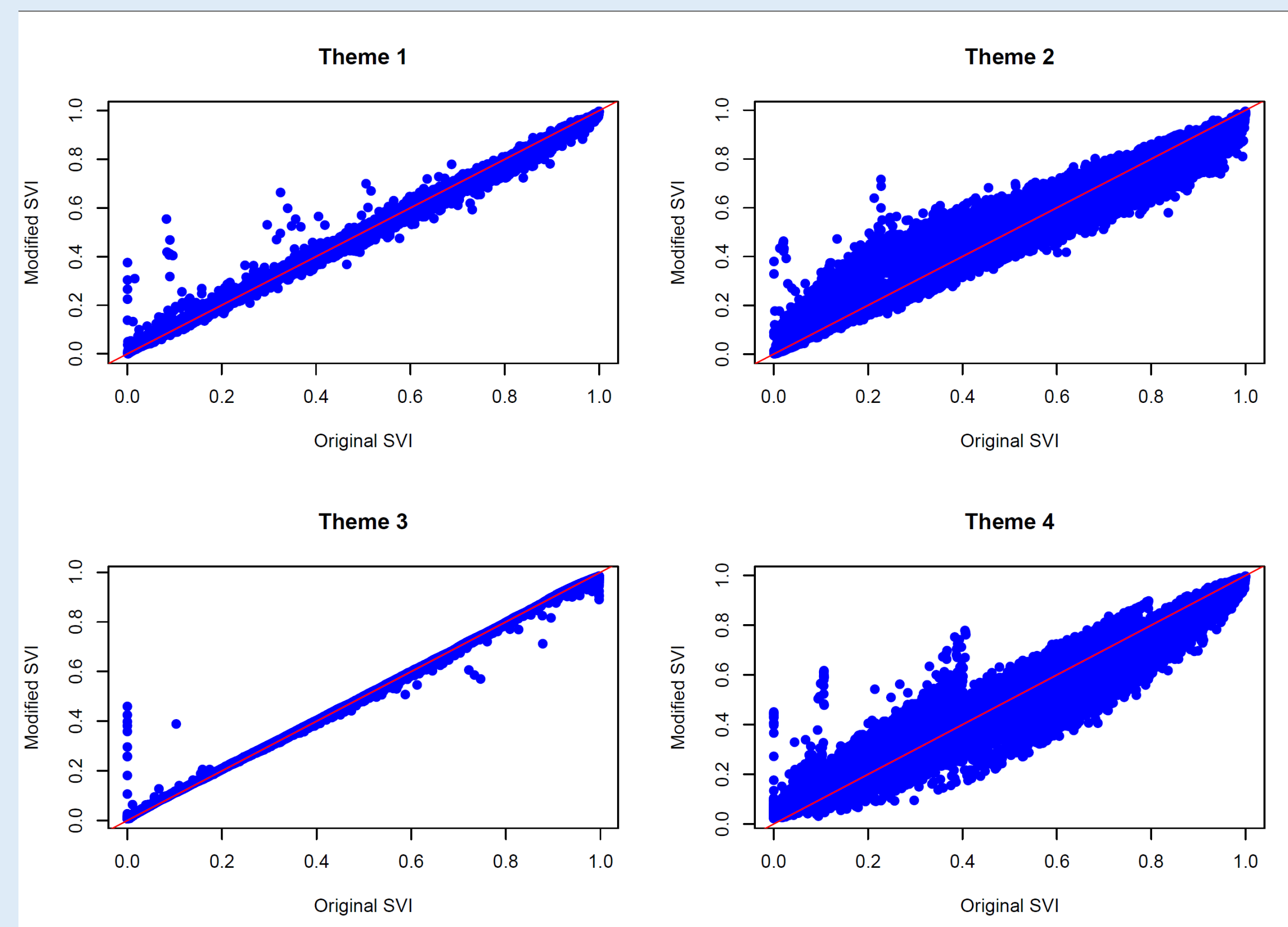
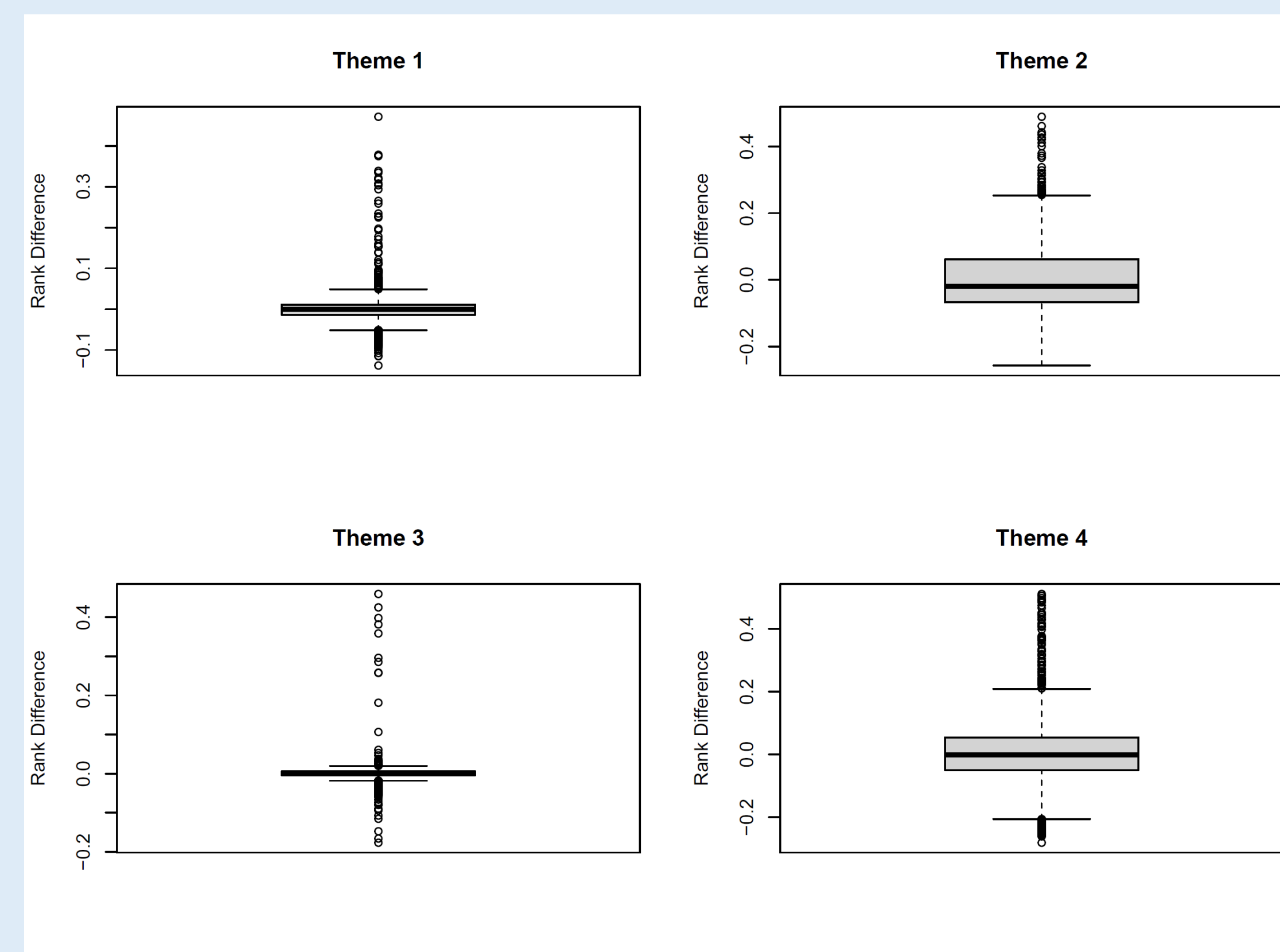


Figure 3 & 4: Scatter plot and boxplot showing the deviation from original SVI



Themes	Variables	ACS 2020 table
Socioeconomic Status (Theme 1)	Persons below 150% poverty	S1701
	Civilian (age 16+) unemployed	DP03
	Housing cost-burdened occupied housing units with annual income less than \$75,000	S2503
	Persons (age 25+) with no high school diploma	B06009
	Uninsured in the total civilian noninstitutionalized population	S2701
Household Characteristics (Theme 2)	Persons aged 65 and older	S0101
	Persons aged 17 and younger	B09001
	Civilian noninstitutionalized population with a disability	DP02
	Single-parent household with children under 18	B11012
	Persons (age 5+) who speak English "less than well"	B16005
Racial & Ethnic Minority Status (Theme 3)	Minority (Hispanic or Latino (of any race); Black and African American, Not Hispanic or Latino; American Indian and Alaska Native, Not Hispanic or Latino; Asian, Not Hispanic or Latino; Native Hawaiian and Other Pacific Islander, Not Hispanic or Latino; Two or More Races, Not Hispanic or Latino; Other Races, Not Hispanic or Latino)	DP05
Housing Type & Transportation (Theme 4)	Housing in structures with 10 or more units	DP04
	Mobile homes	DP04
	At household level (occupied housing units), more people than rooms	DP04
	Households with no vehicle available	DP04
	Persons in group quarters	B26001

### Key Findings

The analysis shows a strong linear relationship between the Original SVI and Modified SVI for Theme 1. Themes 1 and 3 show the strongest linear relationships, suggesting less impact from modifications. Themes 2 and 4 show more scatter, particularly Theme 4, indicating greater modifications to the original SVI values. The red line in each plot serves as a reference, and points deviating from this line indicate differences introduced by the modifications. Themes 1 and 3 remain more stable, while Themes 2 and 4 show increased variability.

### Methodology

A new approach has been developed to quantify and visualize the uncertainty in the Social Vector Inequality (SVI). The methodology involves defining upper and lower bounds for each variable and observation, recalibrating the MoE to establish a 99% confidence interval (CI), and computing the upper and lower bounds for each variable. Monte Carlo simulations are used to simulate one thousand random numbers within the defined range for each variable. The percentile rank (SPL) is calculated for each simulation, and the RPL variables are calculated by determining the percentile rank of the four SPL variables. The margin of errors and coefficient of variation (CV) are also calculated to assess the variability within the data.

### References

- (1) Tate, E. 2012. Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. *Natural Hazards* 63 (2):325-347.
- (2) ———. 2013. Uncertainty Analysis for a Social Vulnerability Index. *Annals of the Association of American Geographers* 103 (3):526-543.
- (3) FEMA. 2024. How a Disaster Gets Declared. Federal Emergency Management Agency 2024a [cited March 6, 2024 2024]. Available from <https://www.fema.gov/disaster/how-declared>