Geographic Variation in Household Disaster Preparedness in the U.S.

Abstract

Disaster events, such as floods, wildfires, and earthquakes increasingly cause damage to livelihoods, the economy, and the environment. Preparing for disasters is noted as one of the most effective ways to adapt and increase resilience to these events, but research has shown that many people in the U.S. have not adopted recommended household preparedness actions. Moreso, there is currently no geospatial dataset or tool for mapping geographic variation in disaster preparedness behavior, despite the availability of appropriate survey data. Using the FEMA National Household Survey (NHS) from 2017 – 2020, we develop a multilevel regression and poststratification (MRP) model that provides estimates at the state, county, and zip-code tabulation area (ZCTA) scales of several preparedness actions and a general disaster preparedness index. Results show regional and state-level variation among preparedness levels, with the southeast and Utah being generally more prepared than other regions of the US. Additionally, we introduce an online interactive mapping tool for these results that practitioners, academics, and the public can use to identify preparedness levels in their area of interest. The outcomes of this study can be used to inform future work in hazard risk assessment and to further develop comparisons between risk perceptions and hazard preparedness. Finally, findings from this study contribute to the suite of geospatial models and methods used to assess the human dimensions of hazard risk and resilience.

Keywords: disaster preparedness, preparedness behaviors, multilevel regression and poststratification, behavior modeling, hazards

Introduction

Disaster events, such as floods, earthquakes, severe storms, and technological disasters can have costly and deadly consequences to society and the environment (Dilley 2005; Visser, Petersen, and Ligtvoet 2014), especially considering that these events are increasing in frequency and intensity (Field et al. 2012; Thomas and López 2015). Exposure to such hazards is also increasing with urban development and population growth (Wood, Boruff, and Smith 2013), amplifying damages and leading to more billion dollar disasters (A. B. Smith and Katz 2013). Such an increase has implications for disaster resilience, as disasters impose economic, environmental, and community damage (Dilley 2005; Visser, Petersen, and Ligtvoet 2014). Responses to disaster risk include adaptive measures that increase preparedness and resilience and decrease vulnerability and damages (K. Smith 2013). These measures range in efforts from national, state and local government activities (Collins and Kapucu 2008) as well as individual, household, and community level activities (K. Smith 2013; Visser, Petersen, and Ligtvoet 2014); Of particular concern is the capacity for households and communities to become more disaster resilient.

Past research has identified disaster preparedness as a major component of disaster resilience (Nukpezah and Soujaa 2018; Shannon 2015; K. Smith 2013) yet multiple studies indicate that preparedness among households and communities is lacking worldwide, including in the United States (Basolo et al. 2009; Kapucu 2008; Kohn et al. 2012; Najafi et al. 2017). When it comes to measuring disaster preparedness across geographies, studies tend to focus on individual (Kohler et al. 2020), household (Bronfman et al. 2019; Howe 2018) or community (Bogdan et al. 2021) preparedness activities of a given region. However, there is a lack of systematic data comparable across geographies at the subnational level. Furthermore, disaster

preparedness metrics are not typically available as geospatial datasets or tools, preventing analysis and mapping of how prepared places are across geographic scales. To address this gap, we introduce a new model and map of household disaster preparedness at the state, county, and ZIP code tabulation area (ZCTA) level based on national survey data. Below, we first provide background on household disaster preparedness, which includes preparedness actions, behavioral and sociodemographic predictors, and social-cognitive factors. This information is used to inform both our methods and provide context on our results.

Literature Review

To provide relevant background on hazard and disaster preparedness, we conducted a non-systematic literature review. Background information are separated into respective subsections, first for *Preparedness Behaviors*, outlining the actions taken by individuals and households to prepare for these events. *Individual and Sociodemographic Characteristics* provides context on how different sociodemographic characteristics can influence preparedness behaviors and perceptions. Finally, *Psychological Perspectives* contributes theoretical evidence to the social-cognitive factors that are known to influence preparedness.

Preparedness actions and predictors

Disaster preparedness refers to the capacity, knowledge, perceptions and behaviors taken prior to a disaster event occurs to efficiently anticipate, respond to and recover from the impacts of a disaster (Kohler et al. 2020). This includes public authorities and practitioners, community groups and workshops, and the individual or household. Different terms are given to describe preparedness actions and behaviors, specifically hazard adjustments (MacPherson-Krutsky, Lindell, and D. Brand 2022; M. K. Lindell 1997; M. Lindell and Perry 2000; Whitney, Lindell, and Nguyen 2004). From here on, we refer to these simply as preparedness actions. It should also

be noted that quantifying the concept of "preparedness" has yet to be settled and differences may exist among culture, geography, hazard and threat level (MacPherson-Krutsky, Lindell, and D. Brand 2022), making it difficult to quantify location-specific preparedness needs.

Studies commonly employ surveys to determine how prepared members of the public or specific groups are, especially for specific locations. For example, Kapucu (2008) found that 61 percent of respondents representing households in central Florida perceived themselves as being sufficiently prepared for a disaster event, but only 50 percent had an evacuation plan in place for their families. Some of the actions necessary to become more prepared for a disaster require sufficient monetary resources, such as having a 3-day stockpile of supplies, an emergency kit set aside, a set amount of funds set aside, or hazard-specific insurance. Other actions that are not as reliant on funds that improve preparedness within a community or household include participation in an evacuation or safety drill, developing a communication and evacuation plan with your household or community, and simply discussing with others on how to get prepared and why it is important (Bogdan et al. 2021; Bronfman et al. 2019; Diekman et al. 2007; Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Kohler et al. 2020; Kohn et al. 2012; Perry and Lindell 2003). While many of these reflect household or community level actions, other actions taken at a public or private level include retrofitting buildings for specific hazards, such as earthquakes, or other structural modifications to infrastructure (M. Lindell and Perry 2000; Spittal et al. 2008).

While participating in different behaviors improves overall preparedness, studies have found a variety of predictors that may influence an individual or household's decision or ability to become more prepared. For instance, having prior experience of a disaster increases one's preparedness action engagement (Becker et al. 2017; Bogdan et al. 2021; Hoffmann and

Muttarak 2017; Kohler et al. 2020; Kohn et al. 2012; Najafi et al. 2017; Onuma, Shin, and Managi 2017). Specifically, four main types of experience have been identified that influence preparedness: direct experience with a hazard, indirect experience (small events without direct impact), adverse life experiences (such as an accident or experience with violence), and vicarious experiences (such as a media report and account from family and friends) (Becker et al. 2017). Risk perceptions also play a role in influencing preparedness behavior (Kohn et al. 2012). For example, people may overestimate how prepared they are if they also have low risk perceptions (Donahue, Eckel, and Wilson 2014). However, MacPherson-Krustky, Lindell, and Brand (2023) found that risk perception was not significantly related to intending to engage in preparedness actions for earthquakes. Furthermore, some individuals may take less action if they do not feel responsible for reducing that risk (Wachinger et al. 2013). Access to resources may also be associated with preparedness: one study found that the greatest barriers to improving household preparedness were a lack of time and / or lack of financial resources (Blessman et al. 2007). Related to this point, self-efficacy is another factor known to influence preparedness, whereas those who are more confident in their ability to prepare, the more likely they are to be prepared and having supplies (Paek et al. 2010).

Expectations and levels of trust in the government also influence an individual or household's decision to prepare (Bogdan et al. 2021; Levac, Toal-Sullivan, and O`Sullivan 2012; Kohn et al. 2012; Wachinger et al. 2013). Having more confidence in government disaster management may be associated with a higher level of perceived preparedness (Basolo et al. 2009). Conversely, mistrust in the government's ability to provide adequate support may provide an incentive to prepare (Bogdan et al. 2021; Carter-Pokras et al. 2007; US Department of Homeland Security and Terrorism 2006). Further, compliance with protocol has been found to

influence whether a preparedness action is taken, specifically among women and those with poor health conditions (Murphy et al. 2009). Many of these factors are associated with various sociodemographic characteristics, including gender, income, and disability (Levac, Toal-Sullivan, and O`Sullivan 2012), which are discussed further in the next section. Table 1 outlines a list of preparedness actions, predictors, and sociodemographic characteristics of preparedness measured in the reviewed literature. While this list may not be comprehensive, it covers variables that are cited frequently in the literature.

Table 1: Variables measuring disaster preparedness outcomes or used as correlates of disaster preparedness.

Variable	Type	Citations
Duplication of Important / Vital Documents	Action / Hazard Adjustment	Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Nukpezah and Soujaa, 2018
Emergency Kit	Action / Hazard Adjustment	Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Kapucu 2008; Kohler et al. 2020; Levac, Toal-Sullivan, and O`Sullivan 2012
Evacuation & Communication Plan	Action / Hazard Adjustment	Bogdan et al. 2021; Bronfman et al. 2019; Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Kapucu 2008; Kohler et al. 2020; Kohn et al. 2012; Levac, Toal-Sullivan, and O`Sullivan 2012; Najafi et al. 2017; Nukpezah and Soujaa, 2018
First Aid Training	Action / Hazard Adjustment	Kohler et al. 2020; Levac, Toal-Sullivan, and O`Sullivan 2012; Najafi et al. 2017; Olympia et al. 2010
Gathering Information (Media or Talking with Others)	Action / Hazard Adjustment	Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Kohler et al. 2020; Maduz et al. 2019; Nukpezah and Soujaa 2018
Participating in a Practice Drill	Action / Hazard Adjustment	Bogdan et al. 2021; Bronfman et al. 2019; Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Levac, Toal-Sullivan, and O`Sullivan 2012; Najafi et al. 2017
Stockpile of Supplies	Action / Hazard Adjustment	Bronfman et al. 2019; Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Kapucu 2008; Kohler et al. 2020; Kohn et al. 2012; Levac, Toal-Sullivan, and O`Sullivan 2012; Najafi et al.

		2017; Nukpezah and Soujaa 2018
Availability of Resources	Predictor & Sociodemographic	Blessman et al. 2007; Levac, Toal-Sullivan, and O`Sullivan 2012; Najafi et al. 2017
Compliance with Protocol	Predictor	Kohn et al. 2012; Murphy et al. 2009
Experience with Disasters (direct, indirect, adverse life experience, & vicarious)	Predictor	Becker et al. 2017; Bogdan et al. 2021; Boscarino et al. 2006; Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Hoffman and Muttarak 2017; Kohler et al. 2020; Kohn et al. 2012; Maduz et al. 2019
Media	Predictor	MacPherson-Krustky, Lindell, and Brand; Nukpezah and Soujaa 2018; Wachinger et al. 2013
Perceived & Placed Responsibility	Predictor	Levac, Toal-Sullivan, and O`Sullivan 2012; Najafi et al. 2017; Wachinger et al. 2013
Risk Perceptions	Predictor	Appleby-Arnold et al. 2018; Bronfman et al. 2019; Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Kohler et al. 2020; Kohn et al. 2012; Maduz et al. 2019; Mulilis, Duval, and Rogers 2003; Najafi et al. 2017
Role of Government, Expectations, and Trust	Predictor	Bogdan et al. 2021; Basolo et al. 2009; Levac, Toal-Sullivan, and O`Sullivan 2012; Kohn et al. 2012; Wachinger et al. 2013
Self-Efficacy[1]	Predictor	Bogdan et al. 2021; Bronfman et al. 2019; Federal Emergency Management Agency and U.S. Department of Homeland Security 2020; Kohn et al. 2012; Murphy et al. 2009; Najafi et al. 2017; Paek et al. 2010
Social Capital	Predictor	Albrecht 2018; Appleby-Arnold et al. 2018; Bogdan et al. 2021; Bronfman et al. 2019; Hausman, Hanlon, and Seals 2007; Levac, Toal-Sullivan, and O`Sullivan 2012; Mathbor 2007; Murphy et al. 2009; Najafi et al. 2017; Nukpezah and Soujaa 2018
Age	Sociodemographic	Boscarino et al. 2006; Bronfman et al. 2019; Maduz et al. 2019; Mishra and Saur 2005; Murphy et al. 2009; Nukpezah and Soujaa 2018
Disability	Sociodemographic	Eisenman et al. 2009; Levac, Toal-Sullivan, and O`Sullivan 2012; Smith and Notaro 2009
Education	Sociodemographic	Hausman, Hanlon, and Seals 2007; Maduz et al. 2019; Murphy et al. 2009; Kohn et al. 2012; Levac, Toal-Sullivan, and O`Sullivan 2012; Smith and Notaro 2009
Gender	Sociodemographic	Bronfman et al. 2019; Maduz et al. 2019; Murphy et al. 2009; Nukpezah and Soujaa 2018
Household Composition (Presence of Children & Married Households)	Sociodemographic	Basolo et al. 2009; Bronfman et al. 2019; Kohn et al. 2012; Mishra and Saur 2005; Murphy et al. 2009; Nukpezah and Soujaa 2018

[1] Self-efficacy can be defined as an individual's belief in their capacity to perform or produce certain outcomes or attainments (Bandura, Freeman, and Lightsey 1999)

Income	Sociodemographic	Levac, Toal-Sullivan, and O`Sullivan 2012; Maduz et al. 2019; Mishra and Saur 2005; Murphy et al. 2009; Nukpezah and Soujaa 2018
Language	Sociodemographic	Appleby-Arnold et al. 2018; Eisenman et al. 2009; Teo et al. 2019; Xiang, Gerber, and Zhang 2021
Race/Ethnicity	Sociodemographic	Maduz et al. 2019; Murphy et al. 2009; Nukpezah and Soujaa 2018

Individual and sociodemographic Characteristics

Preparedness activity engagement is found to differ among sociodemographic groups. For example, some studies have found that disaster preparedness is associated with gender and age (Mishra and Suar 2005; Nukpezah and Soujaa 2018), where, preparedness positively correlates with identifying as female and being older (Bronfman et al. 2019; Maduz et al. 2019). Another study found that women also have higher risk perceptions than men when it comes to disasters (Mulilis, Duval, and Rogers 2003) and climate (Showalter, López-Carr, and Ervin 2019). Other studies found that married households or those with children exhibit higher levels of preparedness (Bronfman et al. 2019; Kohn et al. 2012; Nukpezah and Soujaa 2018). Studies also identify that those with higher levels of educational attainment engage in more disaster preparedness actions (Levac, Toal-Sullivan, and O`Sullivan 2012; Maduz et al. 2019; Mishra and Suar 2005; Murphy et al. 2009; D. L. Smith and Notaro 2009). Income is another demographic factor of interest that has been studied, often with differing results. Research has found that higher income households engage in more preparedness measures than lower income households (Mishra and Suar 2005; Nukpezah and Soujaa 2018), while Hausman, Hanlon, and Seals (2007) found that neither income nor education were significant predictors. Other literature states that income, race, and gender do not necessarily make a person more or less prepared but are sometimes indicative of social inequalities and social structures associated with varying disaster impacts (Appleby-Arnold et al. 2018; Kohler et al. 2020; Kohn et al. 2012; Nukpezah and Soujaa

2018). Furthermore, research on primary language spoken and language access to preparedness information emphasize the need to improve language accessible documents, outreach, and overall disaster management (Eisenman et al. 2009; Teo et al. 2019; Xiang, Gerber, and Zhang 2021). While there is little evidence that access to transportation (public or private) affects preparedness directly, it is a known variable that impacts an individual's or household's social vulnerability (Cutter, Boruff, and Shirley 2003) and is further emphasized during response and recovery phases of a hazard or disaster event (US Department of Homeland Security and Terrorism 2006). Housing tenure status is another variable that has received little attention in the literature.

Disability status and general health are also variables that are frequently studied alongside preparedness. Eisenman et al. (2009) found that only 29.5 percent of those with a mental illness have disaster supplies on hand, compared to the 49 percent of those who do not have a mental illness. Research using the Behavioral Risk Factor Surveillance System indicates that people with disabilities are significantly more likely to state that they are not prepared for an emergency at all, and are 1.22 times more likely to be unprepared versus those who do not have a disability (D. L. Smith and Notaro 2009).

Additionally, geographic differences in disaster management may influence how well prepared a place is. For example, rural communities have more limited access to basic necessities like healthcare, food, and other services (Reschovsky and Staiti 2005). Cutter, Ash, and Emrich (2016) found that indicators of disaster resilience in rural counties were lower than in urban counties. Media attention and disaster relief also focus more on urban areas than rural areas, leaving rural communities less able to recover from the aftermath of a disaster (Domingue and Emrich 2019; Pyles et al. 2018). Rural communities tend to rely on intra-community ties and

must take on multiple roles among themselves to fill positions in volunteer disaster management and response (Straub et al. 2020), whereas urban areas tend to have the resources to adequately respond through government response. Furthermore, the quality and quantity of social interaction may be greater in rural communities than in some urban areas (Lev-Wiesel 2003). However, urban areas also provide opportunities to produce and uphold social networks larger than their rural counterparts (Straub et al. 2020). Regardless of geography, the concept of "neighboring" and being a good neighbor has shown to increase disaster resilience (Cheshire 2015), while economic conditions and conservative politics are attributed to diminishing levels of social capital (Straub et al. 2020).

Mathbor (2007) defines social capital in three parts: community bonding, bridging groups together, and linking through connections with financial, public, and other institutions that possess power. Social capital is also defined as social trust and networks formed by individuals within a community (Albrecht 2018). Bogdan et al. (2021) found that community workshops improved overall preparedness and social capital. Allen (2006) argues that a community-based approach to disaster and climate preparedness has the capacity to empower communities to act and become self-reliant, but also warns that the inverse effect is possible since this approach may lack the resources and legislative power to make the necessary regulatory changes.

While much research has documented that rural America is not monolithic and the rural experience is different across the country (Ulrich-Schad and Duncan 2018), recognizing these differences between urban-rural areas, especially as it pertains to social capital and disasters, may provide insight on the geographic variation in disaster preparedness.

Psychological Perspectives

In addition to sociodemographic characteristics, previous research has also examined social-cognitive factors that influence disaster preparedness behavior. The most prominent theoretical frameworks cited in the literature on disaster preparedness are the Protective Action Decision Model (PADM), the Social-Cognitive Model, and the Theory of Planned Behavior (TPB) (Bronfman et al. 2019; M. Lindell and Perry 2004, chap. 2; M. K. Lindell and Perry 2012; Najafi et al. 2017; Paton 2003; 2019). The PADM describes preparedness as an interaction between a) people's perceptions of the hazard threats and identifying actions available to them to protect themselves and (b) a search and evaluation of varying information needs and sources (M. Lindell and Perry 2004, chap. 2; M. K. Lindell and Perry 2012; Paton 2019). PADM also incorporates experience with disasters as a variable. The Social-Cognitive Model emphasizes the role of motivational factors in the decision to adopt preparedness actions. Motivational factors include social capital, self-efficacy, awareness of the threat, and anxiety (Bronfman et al. 2019; Paton 2003). By contrast, TPB focuses on someone's intentions to perform a certain action, based on their own attitudes and perceived behavioral control towards the threat and the subjective norms or social pressure to participate in those actions (Najafi et al. 2017; Paton 2019).

Research Questions

The goal of this study is to measure and map household preparedness across the U.S. at the state, county and ZCTA scales. The following research questions drive this effort:

RQ1: What are the primary geographic, demographic, and individual-level predictors of national household preparedness activity?

RQ2: To what extent does a multilevel regression and poststratification model predict self-reported household preparedness?

RQ3: How does self-reported household disaster preparedness vary:

a. *Across spatial scales*
b. *Between different preparedness actions and overall preparedness*

Thus, our subsequent objectives for this study are to provide researchers, practitioners, and the public with tools to assess adoption of specific disaster preparedness behaviors among households at geographic scales relevant to disaster management and risk communication.

Research Design

We employ multilevel regression and poststratification (MRP) to map preparedness across states, counties, and ZCTAs. MRP is a common method used to develop small-area estimates from national survey data (Buttice and Highton 2013; Downes et al. 2018; Downes and Carlin 2020; Howe et al. 2015; Howe 2018; Warshaw and Rodden 2012). Similar to disaggregation techniques (Erikson, Wright, and McIver 1993), MRP relies on nationally representative survey data, but in addition models individual responses as a function of demographic, geographic, and individual-level identifiers. The second step, poststratification, takes results from a fitted multilevel model, applies them to the joint population distribution within a given geographic unit, and weights the results based on the proportion of the population represented by each demographic subgroups in each geographic unit (Buttice and Highton 2013; Kastellec, Lax, and Phillips 2019). MRP is particularly useful in providing estimates in places not surveyed as often or have a smaller population, since the poststratification step can correct for non-response and sampling bias (Lax and Phillips 2013). Howe (2018) uses this technique to model a single disaster preparedness action across state subunits and metropolitan areas, while

Rufat and Howe (2023) implement a hybrid model with synthetic poststratification to map flood risk and evacuation behaviors in France. Similarly, other fields of study use MRP to estimate population health outcomes in epidemiological studies (Downes and Carlin 2020; Zhang et al. 2014).

Data Acquisition

We employ publicly available survey data from the annual Federal Emergency Management Agency (FEMA) National Household Survey (NHS) (Federal Emergency Management Agency 2019; 2020; 2021a; 2021b). The NHS is a nationally representative poll that asks members of the public questions regarding their household disaster preparedness behaviors and perceptions while also gathering demographic and geographic information. The surveys include both a broad set of preparedness questions and hazard-specific questions in oversamples for regions that are exposed to a certain hazard type. For this study, we used only general questions asked in the nationally representative portion of the survey, not those in the hazard-specific oversamples. NHS data are currently available for the years 2017 – 2020 and include respondents all U.S. states, the District of Columbia, and Puerto Rico. The number of respondents each year is 5042, 5003, 5025, and 5020 (for 2017 – 2020 respectively), for a cumulative total of 20,090 respondents. Table 2 provides an overview of each question about preparedness actions used in this study and its short variable code. The specific actions include developing an emergency plan; having a surplus of supplies on hand; having a disaster aid/emergency kit; participating in a drill within the household, at work, school, or in the community; attending a local meeting; talking with others; seeking information to get prepared; and duplication of important documents. For variables “SEEK”, “TALK” and “ATTEND”, response variables are recoded from multiple options to a binary code, e.g., if the respondent

answered that they had performed that action more than a year ago, we recoded the response to indicate that they took this action regardless of time versus those who have never engaged in that action. We also calculate a preparedness index using the total number of actions participated in, divided by the number of total possible actions (resulting in scores from 0-1).

Table 2: Survey codebook for disaster preparedness variables from FEMA National Household Surveys.

Variable	FEMA NHS Questionnaire Prompt	Response Code
PLAN	"Has your household developed and discussed an emergency plan that includes instructions for household members about where to go and what to do in the event of a local disaster?"	0: NO 1: YES
STOCK	"Do you have enough supplies set aside in your home to get you through three days or more without power or running water and without transportation?"	0: NO 1: YES
EVAC	"Do you have emergency supplies already packed that you can grab easily in case you have to evacuate your home quickly?"	0: NO 1: YES
DRILL	"In the past year, have you practiced what to do in a disaster by participating in a disaster preparedness exercise or drill ... At home / At work / At school / At another community location?"	0: NO 1: YES
TALK	"How recently have you talked with others in your community about getting prepared for a disaster?"	0: I have not done this 1: Done within past year or more
SEEK	"How recently have you sought information about preparedness?"	0: I have not done this 1: Done within past year or more
ATTEND	"How recently have you attended a meeting or training on preparedness about your local disasters?"	0: I have not done this 1: Done within past year or more
DOCUMENT	"Do you have copies of critical documents, such as identification, insurance, and banking information, stored in a fireproof/waterproof location or stored electronically?"	0: NO 1: YES
IDX	*Cumulative index* (not an NHS question). Calculated by taking the sum of actions participated in divided by total number of actions (8).	NA

Implementation of MRP requires joint distributions of population counts for the subunits of interest, cross-tabulated by the demographic variables used as individual-level predictors in the regression model. We use population counts from the Census American Community Survey (ACS) for the U.S., including Puerto Rico. Cross tabulations for combinations of age, sex and race or age, sex and educational attainment are available. For this study, we use the age, sex, and race/ethnicity crosstabulations from the 2019 5-year estimates. We also use additional geographic covariates from the ACS for each state, county, and ZCTA, as well as census division and region. Since the NHS data do not provide the respondents county of residence, we match respondents to counties using a Zip-code to County crosswalk file (Din and Wilson 2020; Wilson and Din 2018). A full list of all data required and used in this study can be found in the Supplementary Materials (Supplementary Table 1).

Preliminary Testing

We first tested a set of demographic predictors to determine which variables to test in our MRP model. Association tests for each demographic variable of interest were performed against the preparedness index score to determine the primary demographic variables associated with high or low preparedness. Variables tested include sex, age, race/ethnicity, income, housing status, whether the respondent has or cares for someone with a disability, primary language spoken at home, whether children are present in the home, the number of adults present in the home, the overall household composition, access to transportation and educational attainment. Based on whether the variable was binary, continuous, or had multiple groups, we ran T-tests, Pearson correlation coefficient, or analysis of variance tests, respectively, using a significance level of $P < 0.05$. Income was the only tested variable that did not have a significant association with overall preparedness. Of the remaining variables, caring for someone with a disability was

only slightly associated with overall preparedness. Variables with any association were included in the next phase of model testing as either an individual-level predictor (for age, sex, and race/ethnicity which are available in joint distribution format necessary for poststratification) or as an independent geography-level covariate. For association test results, see Supplementary Table 2.

We next developed and tested a set of candidate regression models for the MRP analysis. The Akaike information criterion estimator was used to select the model with the best fit. Akaike information criterion is an indicator of model performance, where model(s) with the lowest score indicate the best fit (Vrieze 2012). Akaike information criterion is used here over the Bayesian information criterion due to model complexity and the number of potential random effects present in the data (Vrieze 2012). We compare each candidate model against a base model with geographic identifiers (state, county, or ZCTA based on the scale, census region, and census division codes) and individual level age, sex, and race/ethnicity. The final model uses the base model variables plus the percent of the adult population who 1) are married; 2) have children under the age of 18 present in the house; 3) are homeowners; 4) speak a primary language other than English; 5) rely on public transportation; and 6) have attained at least a bachelor's degree. Results for the preliminary testing can be found in the supplementary materials.

Equation 1 below illustrates the regression equation used in the MRP model, described as the probability (Pr) that each respondent is in a household that (i) engages in each preparedness activity (h), signified by $y_{h[i]}$, and indexed over response categories for each predictor g, j, k l, m and n for geography (flexible for state, county, and ZCTA), age, gender, race/ethnicity, census region and census division, respectively, plus the fixed effect of each geography-level covariate (signified by $\gamma^{covariate}$). For this study, MRP models were fitted individually for each

variable at each scale. For example, the PLAN variable is modeled as a function of the interactions between each demographic and geographic variable in the model, thus producing estimates for each variable at each spatial scale separately. Models at the ZCTA level also included state and county-level predictors; models at the county level also included state-level predictors.

$$\Pr(y_i = 1) = logit^{-1}(y_{h[i]} \sim \alpha_{j[i]}^{age} + \alpha_{k[i]}^{gender} + \alpha_{l[i]}^{race:ethnicity} + \alpha_{g[i]}^{geography} + \alpha_{m[i]}^{region} + \alpha_{n[i]}^{division} + \gamma^{children} + \gamma^{married} + \gamma^{tenure} + \gamma^{educ} + \gamma^{trans} + \gamma^{language}) \quad (01)$$

Results

Model Validation

We used an internal validation technique to assess the accuracy of our MRP models. This technique leveraged the unique structure of the FEMA NHS dataset, which contains hazard-specific oversamples of a set of U.S. counties. As a result, there are counties that have a higher number of respondents than would be expected in a true nationally representative sample. We used respondents from the six counties with the most respondents (includes Cook County, Illinois, Harris County, Texas, Maricopa County, Arizona, Palm Beach County, Florida, and Los Angeles and San Diego Counties, California). For each validation county we set aside a repeated random sample with replacement (80 percent from each county, repeated 99 times), creating a set of simulated datasets with only 20 percent of responses from the selected county on which to fit a model for validation. Each preparedness action was tested in each new validation dataset for each county by comparing the average validation score in the final model results against the "true" value using the average score from each county (based on the 80 percent set-aside sample). Figure 1 below illustrates the validation results.

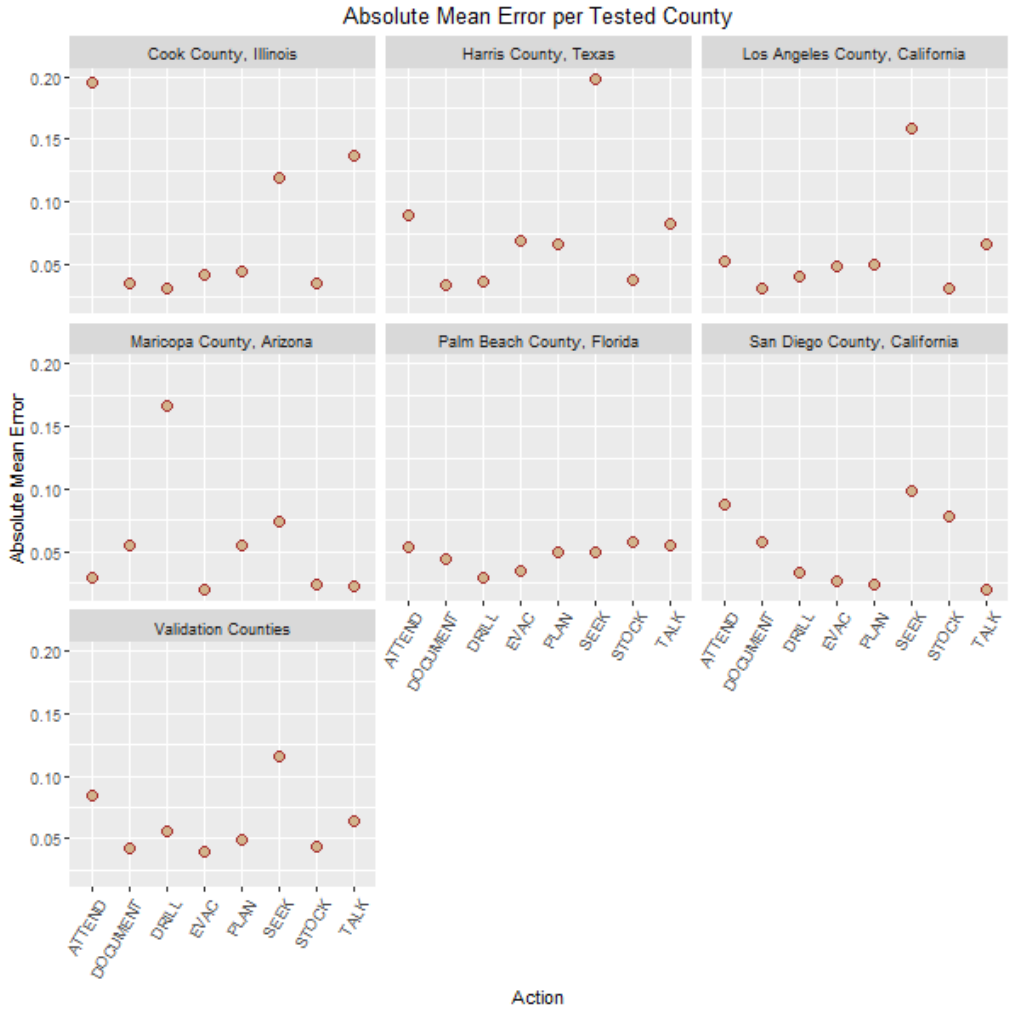

Figure 1: Absolute mean error for each preparedness action and preparedness index per validation county and across all validation counties.

Results from internal validation (Figure 1) show that the 'SEEK' variable has the highest overall absolute mean error across validation counties (mean error = ± 11.6 percentage points). Overall, most actions have an absolute mean error of less than 10 percentage points and the overall absolute mean error for all actions across all counties is ± 6 percentage points, suggesting high accuracy in the final model. For comparison, an average absolute error of 6 percentage points is

similar in accuracy to conducting random samples of approximately 300 respondents from every U.S. County.

In addition to our internal validation, we conducted an external validation by comparing our MRP estimates for the "EVAC" variable to results from Howe's (2018) study based on different survey data using a similar question (worded different, as "Do you have supplies set aside in your home to use in case of a disaster). The mean absolute error between our state-level estimates for this item and those of Howe (2018) was 1 percentage point.

Preparedness Estimates

We produced estimates for each preparedness action and created an overall preparedness index at the state, county, and ZCTA scales. Action estimates can be interpreted as "'X percent' of the population in 'Y subunit (e.g., state, county, ZCTA)'" while the index is interpreted as "the average score (from 0-1, 1 being the highest) for all households in 'Y subunit.'" For each action, the distribution varied somewhat across each scale (Figure 2). Stockpiling supplies (STOCK) had the highest reported engagement, with a weighted national average of 78 percent of the population. Figures 3 and 4 illustrate the percentage of the population with households that engage in each action and the average preparedness index score across the population in the given area on the state and county scales, respectively. We examine each preparedness action in the following section(s).

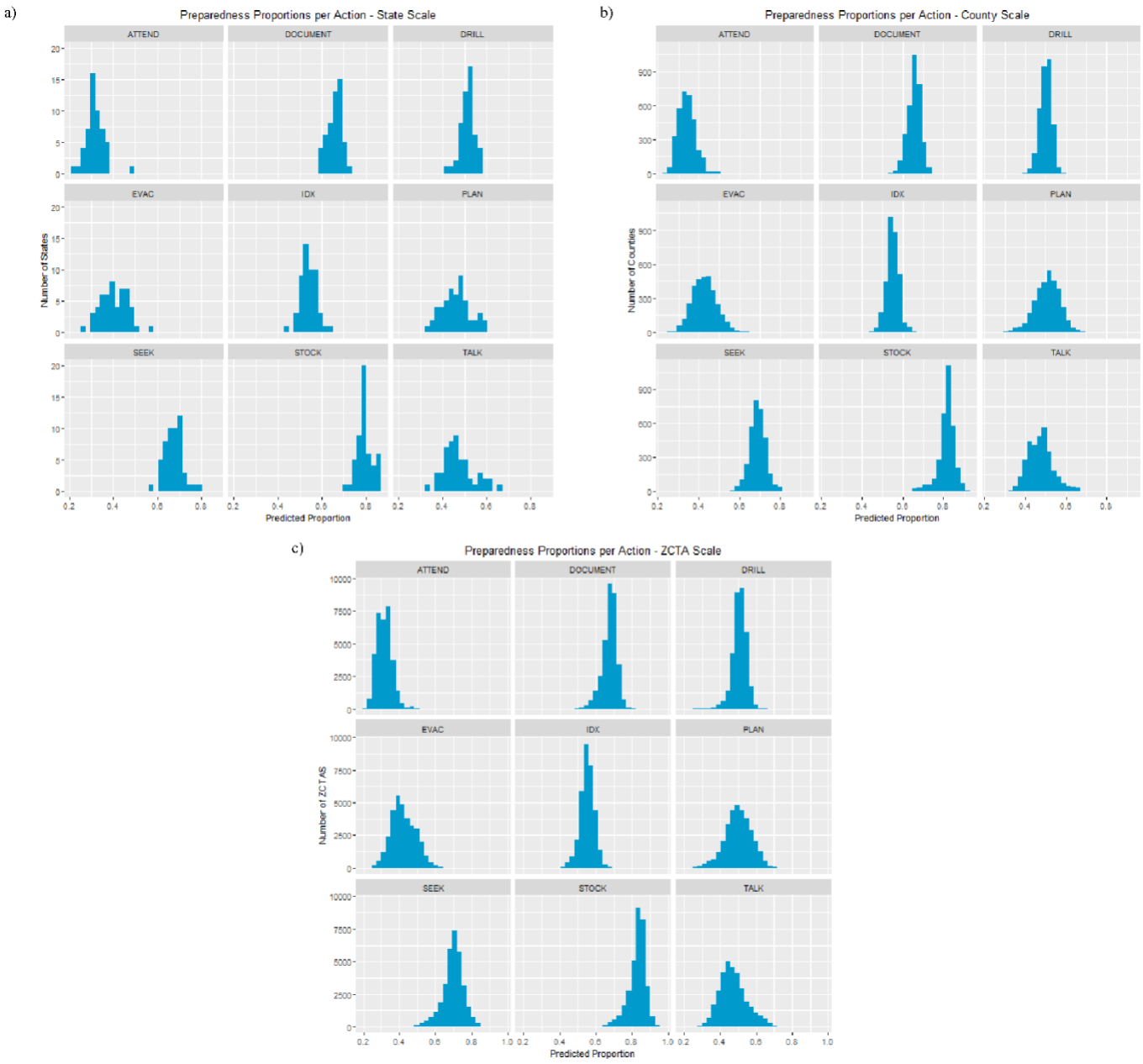

Figure 2 (a-c): Histograms illustrating the distribution of estimates for each action across a) the state scale, b) the county scale, and c) the ZCTA scale. X-axis in the proportion of the population that reports engaging in each household preparedness action.

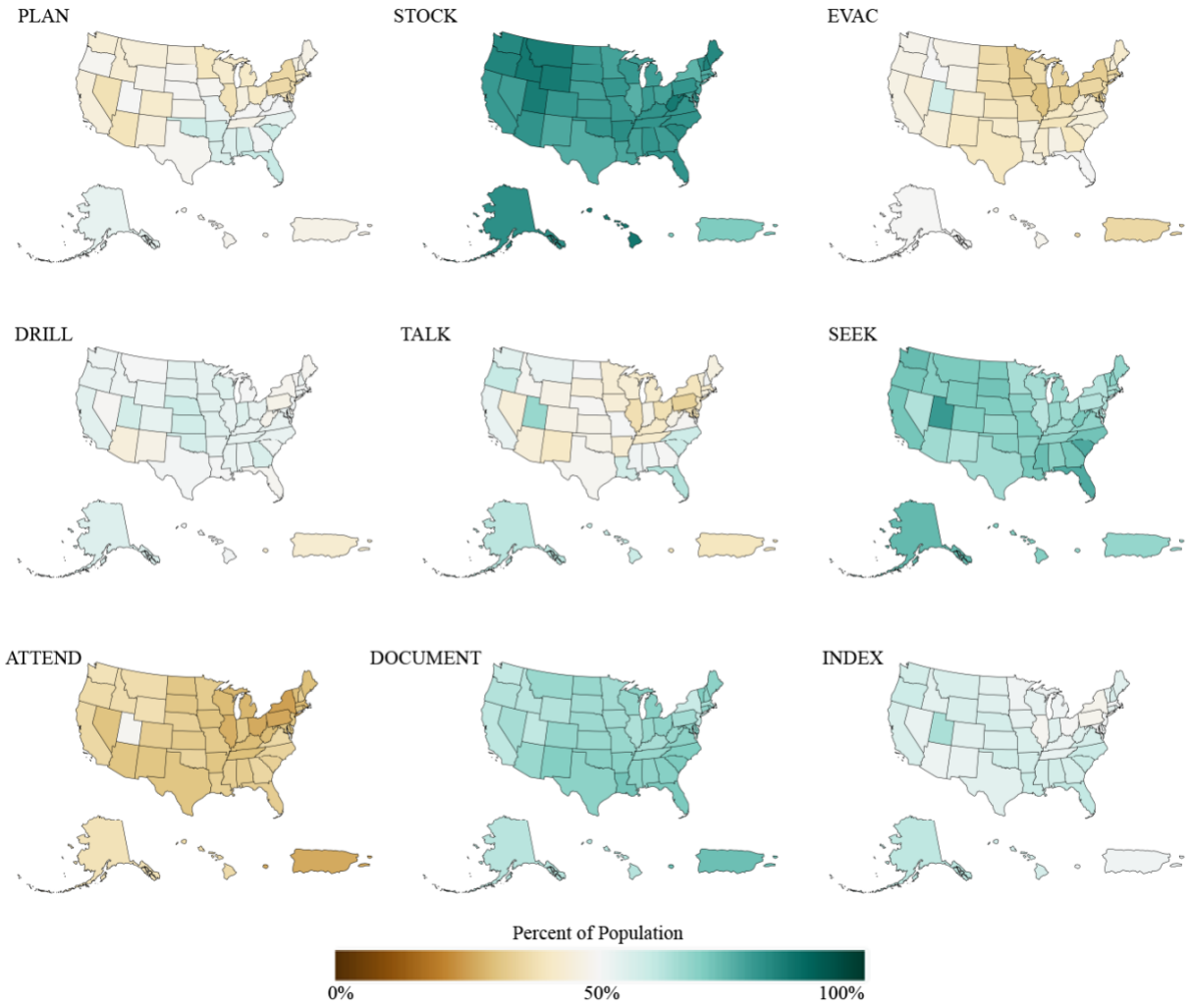

Figure 3: State scale MRP results visualized for each household preparedness action and the household preparedness index. The index can be translated as the average score across the population of the state rather than percent of the population.

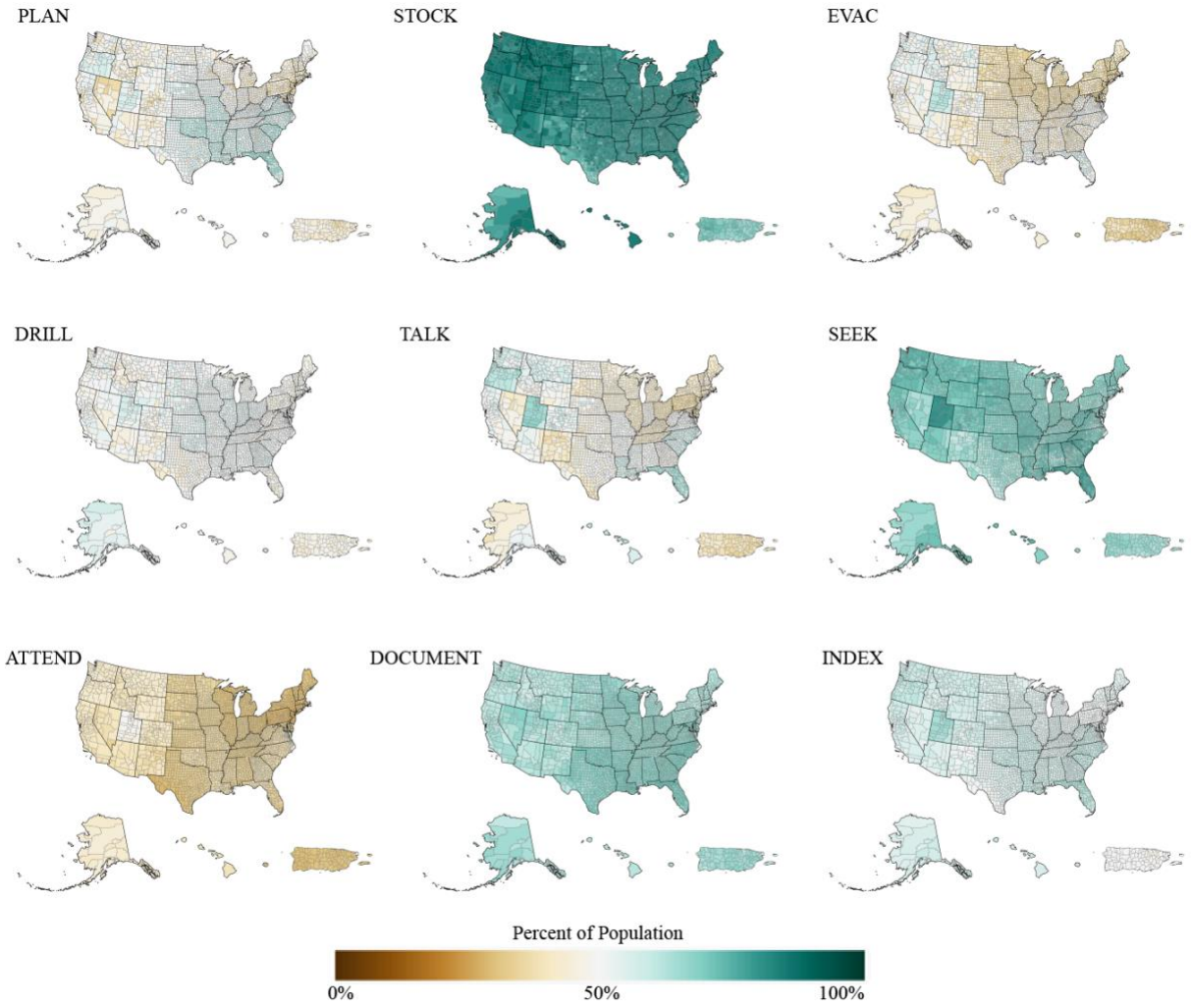

Figure 4: County scale MRP results visualized for each household preparedness action and the household preparedness index. The index can be translated as the average score across the population of the state rather than percent of the population.

PLAN

At the national level, we estimate that 46 percent of people live in households that would report having an emergency plan. At the state level, values are slightly higher for this action in the southeast (51 percent on average) and in Utah (49.5 percent). It could be inferred that residents prone to tropical storms and hurricanes are more likely to have an evacuation plan in place due to the frequency and severity of these types of hazards. On both the state and county

scales, the northeast (41 percent) and southwest (44 percent) have lower values for this preparedness action, except for Utah as an outlier.

STOCK

At the national level, we estimate that 78 percent of people live in households with enough supplies set aside to get through three days or more without power or running water and without transportation. At both the state and county scales the northwest (82 percent) and southwest (85 percent) tend to have higher engagement with action, along with West Virginia, Idaho, and Hawaii (85, 85 and 86 percent, respectively). Puerto Rico, by contrast, has the lowest percentage of households with a 3-day stockpile of supplies at 70 percent.

EVAC

At the national level, we estimate that 40 percent of people live in households with emergency supplies packed in case of an evacuation. This closely resembles estimates from Howe (2018) that examine this question (albeit worded differently, resembling both the "STOCK" and "EVAC" questions) at 41 percent. Utah has the highest percentage of household participation in this action. On the state scale, we see states to the north and Midwest (such as Illinois and Minnesota both at 31 percent) and the northeast (37 percent) have lower estimates. These patterns show up on the county scale as well, with the addition of Puerto Rico having lower county estimates and an overall county average of 31 percent compared to the average of 35 percent. Washington D.C. has the lowest engagement with this action at 26 percent.

DRILL

At the national level, we estimate that 51 percent of people have participated in a disaster preparedness exercise or drill. Interestingly, states in the Midwest have higher estimates than the rest of the nation, with Nebraska and Kansas being the highest at 54 and 57 percent, along with Utah (57 percent). Puerto Rico (42 percent), Arizona (44 percent), and Washington D.C. (46

percent) have the lowest percentages of people who report engaging in a preparedness drill at both the state and county scales.

TALK

At the national level, we estimate that 47 percent of people have talked with others in their community about disaster preparedness within the last year or longer. The states with the highest estimates are Utah, Florida, Alaska, and Oregon, all over 60 percent. States in the northeast such as Pennsylvania, Maryland, and New York, along with Ohio and Illinois, have the lowest estimates. On the county scale, Utah, Florida, and Oregon have the highest estimates and Pennsylvania, Delaware and Puerto Rico have the lowest. Across regions, the Midwest and the Northeast have consistently lower estimates.

SEEK

At the national level, we estimate that 67 percent of people have sought information about preparedness within the past year or longer, the second highest of all the actions. Again, Utah has the highest estimate on the state and county scales at 79 percent, followed closely by Florida and South Carolina at 76 percent each. On the lower end, states in the northeast have lower estimates for seeking information (64 percent), as well as New Mexico and Nevada (62 percent each) in the southwest and Illinois (61 percent). The remaining states are all relatively close to each other and the weighted national average.

ATTEND

At the national level, we estimate that 31 percent of people have attended a meeting or training on disaster preparedness within the last year or more. On the state scale, minor regional variance is observed with lower estimates in the Northeast (30 percent). Puerto Rico also has a noticeably lower estimate than the other states at 26 percent, with Washington D.C. holding the

lowest percentage at 22 percent. This variance is more prominent on the county scale, as we see defined darker brown (lower) estimates in these same regions. Once again, Utah has the highest estimates at 49 percent, over 10 percent higher than the second-highest state, Alaska, at 38 percent.

DOCUMENT

We estimate that 66 percent of people have copies of critical documents stored in a fireproof/waterproof location or stored electronically. For this action, Puerto Rico has the highest estimate with 72 percent of households reporting duplicating important documents, followed by states in the southeast (68 percent). States in the Northeast have lower estimates (65 percent on average), although the variation for this action is smaller than others, where the lowest state estimate is 59 percent with New York. The county scale follows similar patterns.

INDEX

Estimates for the cumulative household disaster preparedness index have a weighted national average of .54 (on a scale of 0-1). Patterns in this variable follow trends in specific actions, with Utah and Florida having higher estimates than other states. On the low end, the pattern is similar with states in the northeast, including D.C., and Puerto Rico having relatively lower estimates. ZCTA-level inset maps for large cities (Figure 5) illustrate the pattern of variation in overall preparedness index scores (IDX) in and around the urban metropolitan center. When examining the inset maps on the ZCTA scale for the index (Figure 5), zip codes closer to the main urbanized center tend to have lower estimates and as you move outward estimates increase. This could be due to the housing tenure independent variable included in the final model, which based on the demographic's association test and model selection (Supplemental Table 2 and Figure 1 respectively), are prominent variables. For example,

households in cities such as New York City are more likely to be renting than owning (Meltzer and Schwartz 2016) and also have a lower percentage of married households with children (U.S. Census Bureau 2020). Supplementary Table 4 provides an overview of the five highest and lowest estimates for each action and the index on the state and county scales. Maps at the state and county scales for each variable are available in an interactive ShinyApp widget (RStudio, Inc 2014), which is available in the supplementary documents.

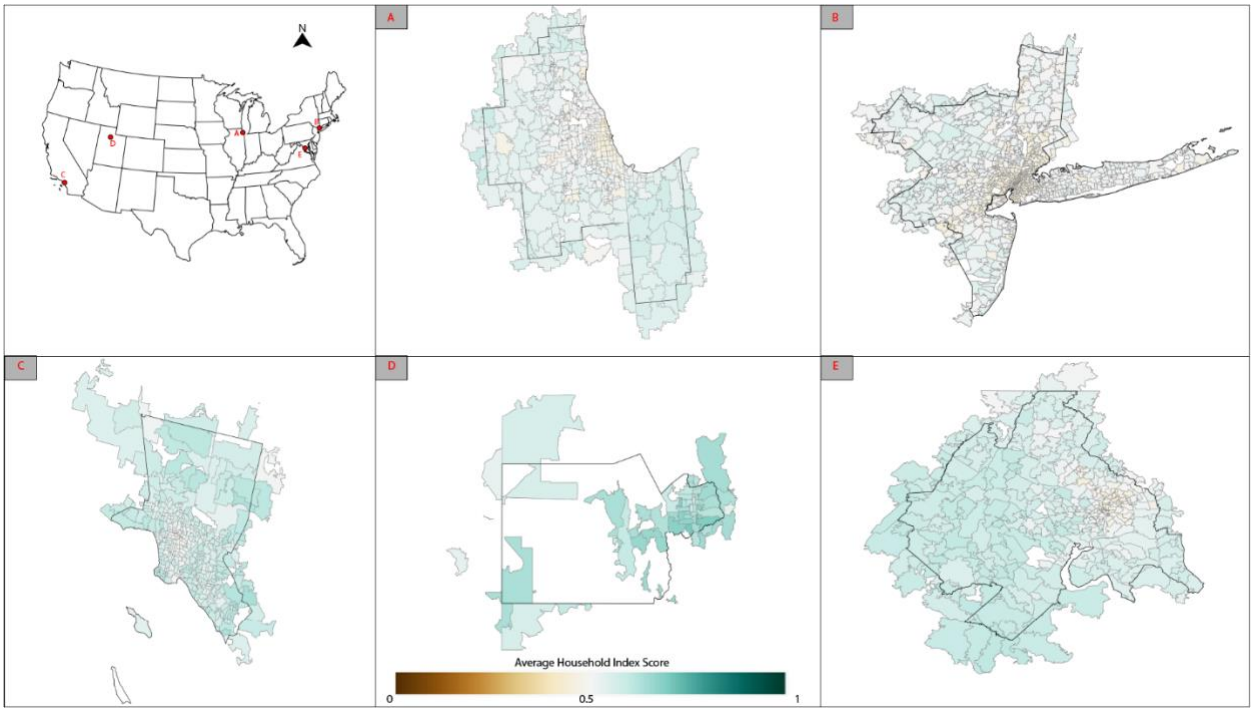

Figure 5: ZCTA maps for MRP estimates of the household preparedness index in selected Metropolitan Statistical Areas: A) Chicago, IL, B) New York City, NY, C) Los Angeles, CA, D) Salt Lake City, UT, and E) Washington D.C.

Predictive Interpretation

Addressing RQ1, *"What are the primary geographic, demographic, and individual-level predictors of household preparedness activity engagement?",* we demonstrate that geographic location and demographics have a significant association with preparedness. The combination of age, sex, and race/ethnicity alongside geographic identifiers provide a strong base model for

prediction, supplemented by geography-level covariates for household tenure status, household composition, education, primary language spoken, and access to transportation. However, some of the demographic information incorporated could be more indicative of systemic vulnerability rather than that demographics' capacity to prepare. Primary language spoken at home, race, disability, and access to transportation are among these demographics. For example, model results showed that Puerto Rico routinely had lower estimates across most preparedness actions and has a large proportion of people whose primary language spoken is not English (0.94). While non-English speakers tend to report lower levels of preparedness on the FEMA NHS, this pattern could also be indicative of the availability of resources and other socioeconomic factors associated with language. However, Puerto Rico ranked higher than 22 states in the "SEEK" variable, so this also suggests that the interaction between the independent variables could be playing a larger role than any single independent predictor.

Our second research question asks, "*To what extent does a multilevel regression and poststratification model predict self-reported household preparedness accurately?"* Based on our validation tests the MRP model had a relatively high accuracy in predicting these behaviors but does leave room for improvement. Using the county-specific oversamples in the FEMA NHS, the "SEEK" variable had the highest average absolute mean error at ± 12 percentage points, the only variable to be more than 10 percentage points. This may suggest that in each iteration of the NHS, respondents should be gathered from an even wider variety of oversampled counties (rather than just the largest metro areas) to account for the geographic variations among the actions. But, when comparing MRP estimates to the averages of the NHS and, for the "EVAC" variable, estimates from Howe (2018), the weighted national averages are all within ± 3 percentage points.

Finally, to address our third research question, "*How does self-reported household disaster preparedness vary across a) spatial scales, b) different preparedness actions and overall preparedness",* our results illustrate a consistent theme along regional and state lines, as well as urban-rural differences, associated with household disaster preparedness. Utah routinely has higher estimates in most actions than other states, followed by the southeast. Puerto Rico, D.C., and several states in the northeast regularly had lower estimates. For Utah in particular, cultural differences may explain the observed variance. Approximately 68 percent of Utah's population identifies as a member of the Church of Jesus Christ of Latter-day Saints, compared to other states which are much lower. (U.S. Census Bureau 2023). Members of the Church of Jesus Christ of Latter-day Saints are often encouraged by church leadership to participate in preparedness actions (McGeehan and Baker 2017).

Across different preparedness actions, we found that "STOCK" has the highest overall engagement and "ATTEND" has the lowest. Having a 3-day stockpile of food and water on hand in case of power or water outages, however, has a vaguer question approach that does not directly indicate that the supplies are in case of a disaster emergency, like the "EVAC" variable states similarly. While "STOCK" does refer to having these supplies for those instances without water or power, respondents might answer differently if they consider anything they have on hand currently is available, rather than a specific set-aside inventory. It is important to distinguish between the two, as "EVAC" does refer to having supplies in case of evacuation.

Discussion

This research illustrates state, county, and zip code level patterns in household disaster preparedness. Utah has remarkably high estimates across the preparedness actions modeled. We also find regional differences among actions, with people in the northeast generally being less

prepared than those in the southeast, with state-by-state differences, however. Notably, we also provide estimates for Puerto Rico, which tends to be under-represented in U.S. social science research on natural hazards. Data collection in Puerto Rico and other island territories in disaster research is important due to their exposure to tropical storms and sea level rise, among other hazards, as well as their communities' potential for elevated social vulnerability due to economic and political marginalization.

Results of this study open the door for an array of analyses that can both utilize or expand upon the data. Specifically, preparedness estimates can be incorporated into research examining environmental risk and vulnerability. For example, hazard risk and exposure studies can apply this data to further understand where communities are both at high risk and are not prepared, among other patterns. Also, the connection between risk, vulnerability, and preparedness can be further explored within a spatial context. Methodologically, our results illustrate the application of MRP as an effective method of spatially estimating human behavior and opinion, which can be further expanded into other areas of geography and hazards and disaster research. Within a hazards context, MRP can be used to quantify response and recovery behaviors, further identifying areas that are not as hazard resilient.

Additionally, this work can be replicated with each new iteration of the NHS to follow and create year-by-year estimates that illustrate temporal changes in preparedness across geographies. This is especially relevant for the "SEEK", "TALK", and "ATTEND" variables that refer to actions taken in the past year in their original question from the NHS, moving from a binary representation of the action to a continuous representation in the results. Future work should consider incorporating additional predictor variables that may improve the accuracy of results, as well as including other actions that individuals and households take that are not

represented here, such as financial preparedness or having emergency alerts set up in case of a disaster. Also, the FEMA NHS data was collected via telephone interviews, both landline and mobile. Following a brief plateau in 2013-2016, telephone survey response rates have continued to decline for a variety of reasons (Kennedy and Hartig 2019). However, Lavrakas et al. (2017) argue that the use of telephone calls, particularly landline interviews, are still conducive as it collects information from the house-bound elderly. While MRP is robust enough to adjust for sample non-representativeness (the poststratification step weights the results to match census crosstabulations), it is important to understand how the data gathering step may influence the subsequent results. Future NHS data collection, or other related hazards survey work, should incorporate a mixed set of data collection, using both telephone and online administration to gather data to account for declining phone survey response rates.

In addition, future work can further examine the differences in preparedness between communities or types of communities (such as the urban-rural variation shown here), both quantitatively and qualitatively. Furthermore, only preparedness actions included in the NHS were modeled in this study, but further exploration can provide estimates for preparedness perceptions and self-efficacy questions from the NHS. Lastly, practitioners and emergency management agencies can utilize this data to identify areas where preparedness outreach and education can be improved, on a state scale or local scale.

There are also potential policy implications that this study highlights the need for. For example, areas that are underprepared could use policies that incentivize preparedness behaviors or hold trainings and drills to improve preparedness. Further, areas at higher risk of experiencing a hazard that are underprepared could develop policies that target other factors of response and recovery that further strengthen the areas' disaster resilience.

Limitations

This study does have limitations. First, the NHS containing self-reported responses. Respondents in the study may say they are more prepared than they actually are, either as a result of social desirability bias, where a respondent my provide what they consider the more desired outcome (Chung and Monroe 2003), or for other reasons. Next, we were limited by our MRP model to using existing Census questions regarding sex and gender, which do not include response options for those who do not identify as male or female. While the FEMA NHS provides alternative options, working to include options for the full spectrum of gender identities will help capture left out portions of the population; whereas LQBTQ+ communities make up nearly 16 million people in the U.S. (Goldsmith, Raditz, and Méndez 2021). This is especially important to consider when queer individuals are often marginalized and left out of disaster relief opportunities (Goldsmith, Raditz, and Méndez 2021). By having more inclusive gender data, this study could have further investigated the nuances between preparedness behaviors, perceptions, and efficacy based on the full spectrum of gender and sexuality identities. Other demographics that are not represented in the NHS that could further provide context to these results are political and religious affiliation.

Furthermore, this project examined self-reported household disaster preparedness activity rather than community preparedness since the NHS asks questions related to the individual or household. While the aggregation of households within an area may be a sign of the overall preparedness of the community, future studies could address aspects of community level preparedness and social capital. Also, only eight actions from the NHS are modeled and reported in this study. While financial preparedness is one aspect of preparedness that previous literature has identified as important and is present in the NHS, it was not modeled here as it could be

more indicative of social vulnerability. However, understanding the spatial variation of financial preparedness, whether it is money saved or a hazard insurance policy in place, could have further contributed to our understanding of the results. Lastly, as hazards are spatially relevant depending on geography, these results may not be fully representative of the hazard specific adjustments households can make and preparedness residuals may differ based on the hazard and its associated hazard-specific actions.

Conclusions

This project successfully describes geographic variation in self-reported household disaster preparedness activity for the U.S. and Puerto Rico at key decision-making scales. We show that adoption of certain key disaster preparedness actions varies between states, within states, within metropolitan areas in ways that may be consequential for disaster vulnerability, and regionally. The study also adds more evidence about which sociodemographic characteristics may serve as predictors of disaster preparedness, such as those who are married with children. However, it is important to consider that traits such as race, gender, and transportation access may be more indicative of systemic inequality and vulnerability and do not reflect one's intention to prepare. While there are limitations present, this study adequately demonstrates how MRP can accurately provide spatially explicit estimates of behavior related to hazards. Future work in broader hazards research and in geographic science can benefit from using this methodology to understand spatial patterns in human behavior. Results can be used to further explore relationships between preparedness, risk, and vulnerability, and provide disaster management with the tools to improve outreach, education, and policy related to preparedness and response.

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