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How Risk Perceptions Influence Evacuations From Hurricanes

By

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Abstract

In this study, we present evidence supporting the view that people's perceived risk to hurricane-related hazards can be reduced to a single score that spans different hurricane-induced risk types, and that evacuation behavior is strongly dependent on whether one perceives a high risk to any type of hurricane-related hazards regardless of the hazard type. Our analysis suggests that people are less sensitive to risk type than they are to the general seriousness of the risks. Using this single score, representing a composite risk measure, emergency managers can be informed about the severity of the public's risk perceptions and might better craft their public directives in ways that minimize disruptive evacuations and achieve greater compliance with government directives.

Keywords: Severe weather, hurricanes, risk perception, composite risk measure, evacuation behavior, Texas, multiple correspondence analysis.

Introduction

Risk, perceived and real, is known to shape and determine an individual's response to threats from severe weather, such as approaching hurricanes. There are a host of other determinants of evacuation behavior from pending severe weather, including socio-demographic factors (age, income, education, age, etc.), prior experience, ethnicity, and information and warnings about pending severe weather events (Sorenson 2000; Mileti and O'Brien 1992; Mileti and Beck 1975; Mileti and Sorenson 1990). Risk, perceived or real, remains one if not the dominant determinant of evacuation behavior (Slovic 1987; Baker 1991; Perry 1994; Dow and Cutter 1998; Whitehead et al. 2000).

Moreover, the importance of risk from severe weather as a determinant of evacuation behavior is underscored by its prominent role in first responders messaging to the public. The likelihood that an individual evacuates and/or takes specific precautions before severe weather events increases with the risk of the event, either perceived or real. Different risk factors, however, predict different responses to the pending weather threat. For example, residents who live in a neighborhood in a non-evacuation zone with low risk relative to the surge hazard might still evacuate depending on the degree of their risk perception for other hurricane-related hazards. This poses a serious challenge for emergency planners who seek to implement a common directive on the basis of one specific hurricane hazard—surge—(e.g., evacuation or sheltering in place) to a population with heterogeneous real and perceived risks. As a consequence, many citizens either do not comply with official directives pertaining to evacuation or inappropriately time their evacuation decision, resulting in significant roadway congestion, personal harm, and property damage (Dow and Cutter 1998; 2001). In this paper we ask whether a single measure of perceived risk that considers the totality of risk from hurricane-related hazards including wind, storm surge, and rainfall flooding can provide a viable means of predicting residential populations' responses to severe weather episodes.

The paper draws on survey data from residential populations in the upper Gulf Coast areas of Texas after Hurricanes Rita in 2005 and Ike in 2008. Our goal is to synthesize an interpretation of evacuation behavior using different types of perceived risks from four hurricane-related hazards (wind, flood, personal injury, or storm surge risk) measured on a four-point scale (high, medium, low, and no risk) without specific identification of the type of hazard. This is important because it tells policymakers that people's perceived risk can be summarized by a single or a small number of composite risk scores that span risks of different types of hazards so that the government takes multiple risk types into account in the formulation of evacuation zone designations. Our thesis is that composite measures of risk better capture the totality of circumstances that respondents perceive in their communities than do hazard-specific risk perceptions, and that composite measures of risk better explain individual evacuation behavior than hazard-specific perceptions of risk.

The plan of the paper is as follows. In section two, we review the literature on behavioral responses to severe weather events. Section three presents an alternative explanation for a risk theory of evacuation behavior based on a composite notion of perceived risk. Section four introduces various measures of perceived risk to test our hypotheses. Section five presents our findings on the composite measure of perceived risk. Section six discusses the policy implications of our findings for emergency planning and the viability of targeted strategies to affect behavioral responses to severe weather episodes with a composite measure of risk. It also provides a set of research questions for future study. Section seven highlights the key conclusions of our work.

Literature Review

Risk is the consequence of exposure to hazards (Henley and Kumamato 1981; Todinov 2007). It is well established that behavioral responses to severe weather events are mostly explained by a person's perception of risk triggered by the hazards those events entail (Dash and Galdwin 2007; Bouyer et al. 2001; Aguirre 1991; Riad and Norris 1998; Peters and Slovic 1996; Whitehead et al. 2000; Whitehead 2005; Stein et al. 2010). In the case of severe weather, such as approaching hurricanes, hazards include storm surge, rainfall-induced flooding, and wind. The risk of these hazards can range from the mild inconvenience of a power outage caused by high-speed winds to drowning that occurs from storm surge. As previously noted, "people respond to hazards according to their perceptions of the risks they pose (Dow and Cutter 2001; Dash and Gladwin 2007; Peters and Slovic 1996)." Other factors, including knowledge of hazards and risks, risk mismatch with technical estimates of risk, advisory or mandatory evacuation orders, prior experience with severe weather and the actions of others, most notably neighbors, have also been found to have a significant and independent effect on responses to severe weather (Stein et al. 2010; Dueñas-Osorio et al. 2011).

Perceived risk operates to shape behavioral responses to hurricanes and severe weather at several levels of specificity or detail. For example a person may believe their house, car, or other personal possessions will flood from an approaching hurricane. The combination of these specific perceptions of flood risk defines one's overall perception of risk from flooding. Similarly, we believe individuals possess a generic or composite perception of risk that combines all the hazards they confront from a hurricane. Rather, a composite perception of risk, comprised of each relevant hazard is what best characterizes the general population's perceptions of risk. More importantly, it is this generic or composite risk perception that shapes behavioral responses to approaching hurricanes, independent of rival explanations of evacuation behavior.

Of course perceptions of risk are not always accurate, at least from the perspective of engineers and emergency planners. Moreover, individuals may perceive their risk in ways that do not conform to the expectations of public officials, ultimately affecting evacuation behavior (Stein et al. 2010; Dueñas-Osorio et al. 2011; Baker et al. 2009a; 2009b). In particular, ‘‘if individuals do not believe warnings are valid or the risk is real, then the likelihood of response [read, evacuation] is decreased (Sorensen 2000).” A consequence of this disparity between officially designated areas for evacuation/non-evacuation and perceived risk is non-compliance with official directives during severe weather episodes. Why?

Stein et al. (2010) find that “a significant number of warning and evacuation orders from natural hazards are mainly based on a single potential hazard,” such as storm surge. Sorensen (2000) and others (Mileti and Sorensen 1987; Mileti and O’Brien 1992) note that “one important finding is that a single warning concept will not equally serve the requirements of all hazards (p.120) (Sorensen 2000).” Stein et al. (2010) find that different risk perceptions are associated with different behaviors in different geographies (e.g., inside and outside designated evacuation areas) and across different demographic groups. This would suggest that even the same measure of risk will not produce a uniform response to a severe weather episode.

A Multidimensional Notion of Risk and Evacuation Behavior

Risk perceptions of hurricane-induced hazards are often intercorrelated (Stein et al. 2010). “If a set of risk ratings are correlated, it is almost always found that they correlate positively and rather strongly. In turn, this suggests that a common underlying factor is measured by all risk ratings, no matter what type of hazard is being investigated (p. 8) (Sjoberg 2000).” Sjoberg (2000) and others (Wildavsky and Dake 1990) suggests that the attitude of “risk sensitivity” can explain a significant portion of risk perceptions across different hazards. The implication of this explanation of risk perceptions is that individuals construct a combined perception of risk about a number of hazards, not just one (e.g., storm surge).

The implications of Sjoberg’s (2000) explanation of risk perception for emergency management policy and planning are substantial. First, his approach recommends considering risk and then the ensuing behavior from a composite perspective, which suggests that the totality of hazards creates a sensitivity to risk from all potential hazards an individual might perceive in their specific locale/geography. The composite dimension of perceived risk might be more closely related to the degree of sensitivity of risk (i.e., low, medium, and high) than to the subject of the hazard (i.e., wind, flood, storm surge, power outages, etc.). If risk perceptions shape behavior, then our predictions and explanation of evacuation will improve if we consider the totality of risk perceptions from individual hazards as opposed to any one hazard or related hazards.

A dimensional analysis of perceived risk is not new to the literature on risk perceptions. Researchers (Slovic et al. 1980; Slovic et al. 1981; Slovic 1987; Fischhoff et al. 1978; Johnson and Tversky 1984) have identified several persistent dimensions to risk perceptions across different populations (e.g., lay persons and experts) and types of hazards (e.g., diseases, natural hazards, activities, and products). Though the dimensional analyses of these researchers have produced diverse results two findings persist: there are several instances in which perceptions of risk are organized around physical attributes of the hazard (e.g., water in the case of flooding and storm surge from hurricanes) and the identification of a strong dimension of perceived risk defined as “dread risk...perceived lack of control, dread, catastrophic potential, fatal consequences and the inequitable distribution of risks and benefits (p. 283).” Slovic’s (1987) identification of a “dread risk” dimension fits well with our thesis that an underlying dimension to hurricane related risks is the overall severity of the severe weather episodes like hurricanes.

For emergency planners, this perspective on risk and its influence on evacuation behavior can be problematic. Emergency planners are accustomed to delivering a single directive (e.g., evacuate or shelter in place) to a large population based on a single dominant indicator of risk, most often storm surge. Sjoberg (2000) suggests that his view of risk perception in shaping responses to severe storms would imply that “risk communication would, with such a stance, require a very different approach from that implied by other models (p. 9).” As Stein et al. (2010) (p. 816) suggest “efforts to persuade residential populations about risk and when, where, and how to evacuate or shelter in place should originate at the neighborhood level rather than originating from blanket directives for action from the media or public officials.” We return to this policy challenge in communicating risk about severe weather later in the paper.

There are several natural questions and hypotheses that can be derived and tested from the concept of composite risk perception. First is whether risk perceptions across multiple hazards can be reduced to a smaller number of coherent dimensions or concepts. Second, whether a composite measure of risk is a better predictor of behavioral responses to severe storms including evacuation. And third, whether the composite risk measure is a robust and strong predictor of evacuation behavior under different circumstances. We hypothesize that:

H_1: Perceptions of risk are reducible to a multidimensional composite measure of risk based on the severity level of perceived risk.

H_2: A composite measure of risk is more explanatory of responses to severe weather than hazard-specific perceptions of risk.

H_3: The composite risk measure is a more robust and significant predictor of evacuation behavior when other factors influencing evacuation behavior (prior experience, neighbor effect, prior experience, location in an evacuation zone age, income, education, and children in the household, etc.) are taken into account than hazard-specific perceptions of risk.

Research Design and Measures

Survey samples

To test our hypotheses we draw on two random-digit dial telephone surveys conducted in the Houston area with the residential population following Hurricanes Rita in 2005 and Ike in 2008. Less than three weeks after Hurricane Katrina devastated New Orleans in September of 2005, a category 5 hurricane in the Gulf of Mexico threatened the Houston metropolitan area. Approximately 1.5 million residents (Henk et al. 2007) evacuated or attempted to evacuate their residences between September 21 and September 24, 2005 when Hurricane Rita made landfall as a category 3 hurricane in the Beaumont/Port Arthur area. The "Rita survey" was conducted with 651 persons in the eight-county[1] Houston metropolitan area between September 29 and October 3, 2005. The response rate for the survey was 24% (i.e., AAPOR 2004 #3 response rate), well within the range of response rates for contemporary random digit telephone surveys (Curtin et al. 2005). Except for a slight under-representation of Hispanics,[2] the sample is representative of the proportion of persons residing in each of the eight counties and its major city, Houston.

Hurricane Ike was a Category 2 hurricane when it made landfall on September 13, 2008, near Galveston, Texas, and was accompanied by what can be considered a Category 5 equivalent storm surge, given the approximately 4.5-6.1 m (15-20 feet) above normal tide levels along the Bolivar Peninsula of Texas and in most of the Galveston Bay area.[2] The "Ike survey" was conducted with 1,503 residents in Harris County. The error for the sample was +/-2.5% at the 95% confidence level. The response rate for the survey was 24% (i.e., AAPOR 204 #3 response rate).

Testing our hypotheses with two independent samples from the same population (i.e., Upper Gulf Coast residents) for two different hurricanes provides us with a greater opportunity for determining the robustness, veracity, and breadth of our findings. Hurricanes Rita and Ike were sufficiently different to pose residents of the Upper Gulf Coast with a very different set of risks and associated levels before and after each hurricane made landfall.

Measures of Risk

Respondents in both surveys were asked a series of questions about their perceived risk from different hazards associated with each hurricane. In the Rita survey respondents were asked, "In your opinion, was your residence located in a high risk, a medium risk, or a low-risk area for flooding from [rain, storm surge, wind damage, personal injury] from Hurricane Rita?" Respondents in the Ike survey were asked, "In your opinion, was your residence located in an area where there was no risk, low risk, some risk, or high risk of [storm surge, wind, flooding from rainfall, injury to you or your family, power loss, loss of water and sewage service, and property damage] from Hurricane Ike?" In the following sections, the analyses of the survey data were limited to four indices of risk including consequences from wind, storm surge, flooding from rainfall, and injury that are common in both surveys.

Data Analysis

The underlying notions guiding this research are that risk perception is among the most significant factors in determining whether or not an individual will evacuate or shelter in place from an approaching storm, and that an overall measure of risk perception would be more effective in determining the evacuation behavior than the hazard-specific risk perception variables alone. Therefore, the first step is to determine composite dimensions of perceived risk using a statistical procedure known as multiple correspondence analysis (MCA) (Greenacre and Hastie 1987).

MCA is used to reduce the dimensionality of a dataset by maximizing the correlation or covariance in the data. It is analogous to principal components analysis (PCA) as they both aim to calculate a linear combination of the variables in the dataset with minimum loss of information (Kohn 2011). The main difference between MCA and PCA is that PCA is applied to continuous variables whereas MCA is appropriate for categorical variables, especially ordered categories. The dimensions extracted by MCA are interpreted based on the categories of the variables analyzed. The plots of the categories of all variables in a multidimensional space display category relationships. Categories that are plotted close to each other are frequently simultaneously expressed in the data set, whereas the ones that are far apart are only rarely observed together.

In this study, variables of perceived risk of wind damage, storm surge, rainfall flooding, and injury are selected from the two surveys to identify their reduced dimensions. All the analyses are performed using STATA's *mca module* (STATA/IC 11.0). *Object scores* (analogous to factor scores in PCA) are computed and used in a binary logistic regression model (logit) to determine the predictive power of the extracted dimensions (cf. principal components) on evacuation behavior. Because respondent evacuation behavior consisted of either "Evacuated" or "Did not evacuate," the response was essentially binary in nature, and therefore the logistic model is an appropriate regression model. Due to the nonlinear response surface of logistic regression, traditional R^2 values cannot be computed to explain variance in the model and pseudo-R^2 (*Nagelkerke* R^2) values are used in evaluating the goodness-of-fitness of the models. It provides an approximation of the variance explained in a normalized form with $0 \leq R^2 \leq 1$, with a perfect model in which 100% of the variance is explained, resulting in $R^2 = 1$. Logit predictions for the evacuation decisions are also calculated using the hazard-specific risk variables to compare their predictive power with those of the composite risk variables from the MCA solution.

Research Findings

The results of the analyses are presented first for the Hurricane Ike survey, as it has more data points, and then for the Hurricane Rita survey. This section intends to demonstrate the robustness of the results within and between the two surveys by testing the three hypotheses presented earlier for each survey separately.

Hurricane Ike

1. Identification of the composite measure of risk (H_1)

MCA extracted three dimensions from the Hurricane Ike survey data that explain 97.9% of the total inertia (amount that quantifies total variance)[3]: the first dimension, 45.2%; the second dimension, 30.5%; and the third dimension, 22.1%. MCA module in STATA reports the contribution of each category (high, medium, low, and no risk) to each dimension, which reveals that dimension 1 is contributed mostly by the "high risk" category, dimension 2 by the "no/low risk" category, and dimension 3 by the "medium risk" category. In Fig. 1, the four groups of clusters of the categories are clearly seen. Variables in the "high risk" category are discriminated well in dimension 1, whereas variables in the "medium risk" category are discriminated in dimension 3. The "no risk" and "low risk" category clusters are best discriminated in dimension 2.

Consistent with our hypothesis, the salient dimension that emerges from our hazard-specific indicators of perceived risk is a generic severity of risk (none, low, medium, and high) rather than the shared nature of the hazards (e.g., water in the case of flooding and storm surge). Although the grouping of the risk perceptions by the attributes of the hazards (e.g., wind or water) is considered more intuitive and practical, the clustering of respondents' answers to queries about perceived risk from specific hazards forms around the ordinal rankings of "no," "low," "medium," and "high" risk. Moreover, these findings are strongly suggestive of an alternative strategy for communicating public directives about evacuating.

2. Risk Measures and Evacuation Behavior (H_2)

To test our hypothesis that a composite measure of risk perception outperforms any single hazard-specific perception of risk in predicting evacuation behavior (1 = evacuate, 0 = did not evacuate), we estimated separate logistic models for evacuation behavior using the *object scores* (cf. component or factor scores) for each dimension extracted by MCA and with measures of perceived risk by hazard (Table 1). Although the statistical significance of logit coefficients can be used to test our hypothesis, to assess in a practical way the magnitude and significance of the hypothesized correlates of evacuation behavior in terms of the probabilities we use Clarify (Tomz et al. 1999). We calculate the change in the probability of evacuating across the range of values for each independent variable while setting all other independent variables at their mean values. The object scores were first transformed to a scale of 0 to 4 to facilitate the comparisons with the scores of the risk types, which range from 1 to 4 (1 for no risk, 4 for high risk).[4] The results are presented in the last column of Table 1.

Despite the small difference between the pseudo R^2 values of the two models, the odds ratio of the risk dimension 1 is much larger than that of dimension 3 and any of the statistically significant hazard-specific risk perceptions (Table 1). The estimated probabilities for evacuating by risk perceptions are shown in Fig. 2a-e. A change in the severity of risk perception on dimension 1 (Fig. 2a) from its lowest to highest score is associated with a 0.71 change in the probability of evacuating. No other dimension or hazard-specific perception is associated with more than a 0.20 change in the probability of evacuating. We can interpret this as follows: People do not weight their risk separately for different hazards (i.e., wind, flood, or storm surge) when making an evacuation decision; rather, they assess the degree of their overall risk from all hazards. And if they think that they have a high risk on this overall scale of being adversely affected by the approaching hurricane, they tend to evacuate. The predictive power of the composite measure of "high" risk perception is greater than each of the hazard-specific risk perceptions and any other dimension.

3. Risk Measures and Evacuation Behavior with Other Control Variables (H_3)

To test the robustness of H_2 we fit a logistic model of evacuation behavior with additional controls including eight non-risk variables. These include coordination with family members, neighbor evacuation, received help from or provided help to others prior to the hurricane's arrival, and reliance on the media for information (Table 2). These independent regressors have been identified in the literature to be significant predictors of evacuation behavior (Dow and

Cutter 2001; Dash and Galdwin 2007; Stein et al. 2010; Dash and Morrow 2001; Gladwin and Peacock 1997; Lindell et al. (2005).

The odds ratios, change in probability, and the probability plots (not shown) indicate that dimension 1, which represents the "high risk" category from all hazards, is still significant and a strong predictor of the evacuation behavior, whereas only the risk perceptions of storm surge and rainfall flooding are significant, but they are much weaker predictors.

More importantly, a change in general sensitivity to risk (i.e., dimension 1), which is associated with a 0.48 change in the probability of evacuating from its lowest to highest score, continues to have a substantial impact on the likelihood of evacuating. No other dimension or hazard-specific perception of risk increases the likelihood of evacuating by more than 0.10. Again, the general sensitivity to risk produced a stronger prediction of evacuation behavior than any single hazard-specific perception of risk. This includes the most lethal form of hazard—storm surge.

Hypothesis 3 also posited that the composite risk measure would still be a significant factor in making evacuation decisions regardless of whether people lived inside or outside the evacuation zone where people's perception of risk for different hazards might vary. To test this hypothesis, two logistic models were fit with the same control variables as in the previous model for those living inside and outside the evacuation zone. The results are reported in Table 3 and generate two main conclusions. The first is that the composite risk perception variable (dimension 1) was found to be among the most significant factors both inside and outside of the evacuation zone, but the odds ratio vary by location, with an *Odds Ratio* = 1.78 and *Δ in Probability* = 0.63 inside the evacuation zone, and an *Odds Ratio* = 1.49 and *Δ in Probability* = 0.38 outside of the evacuation zone. This tells us that no matter where people live, if they have a high risk perception from any or all of the hurricane-related hazards, they tend to make decisions to evacuate. When the logistic model is fit with the hazard-specific perceived risk variables and the same non-risk variables, none of the perceived risk types was statistically significant for inside evacuation zone model, and only the risk of rainfall flooding was significant for the outside evacuation zone model (*Odds Ratio* = 1.38, and *Δ in Probability* = 0.12) (Table 3). This finding also implies that the composite risk measure is a better and more robust predictor of the evacuation behavior than the hazard-specific risk types. Even when respondents live in an area designated for evacuation because of storm surge risk, their general sensitivity to risk is a stronger predictor of their evacuation behavior than perceived risk from storm surge alone.

The second conclusion gleaned from the models is that the influential determinants of evacuation in combination with risk perceptions do not vary notably between areas that are within the delineated evacuation zones and those outside (Table 3). The stronger predictors are the same in both models, indicating the robustness of the model interpretation to the evacuation zone differences. However, because of the higher predictive power of the significant predictors in general for the evacuation zone sample, the logistic model resulted in an explanation of 49% of the variance, while the model outside of the evacuation zone explained 30% of the variance.

Hurricane Rita

In order to assess the robustness of the methods across different hurricanes and the results between the two surveys, the same three hypotheses used for Hurricane Ike are tested for the Hurricane Rita sample and the findings are presented in the following subsections.

1. Identification of the composite measure of risk (H_1)

The MCA extracted two dimensions from the four risk types (wind damage, storm surge, rainfall flooding, and injury to self and family) for the Hurricane Rita survey. The two dimensions explain 98.5% of the total inertia: the first dimension, 81.2%; and the second dimension, 17.3%. The contribution of each category to each dimension shows that dimension 1 is contributed most by the "high risk" category, while dimension 2 by the "medium risk" category. The coordinate values for each dimension present the categories of the variables graphically in Figure 3. The three clusters of risk perceptions (high, medium, and low risk) are clearly seen.

Consistent with our hypothesis and the findings from the Hurricane Ike survey, the dimensionality that emerges from our indices of perceived risk is a generic sensitivity to risk as opposed to the shared nature of hazards contributing to risk perception (e.g., wind- or water-related). The respondents' answers to discrete queries about perceived risk cluster around the ordinal rankings of risk, specifically "high" and "medium" risk. The "low risk" category is not represented by either dimension as it is discriminated almost equally between the two dimensions. Note that Hurricane Rita struck the Gulf Coast weeks after Hurricane Katrina and very few people in the Houston-Galveston area were thinking that hurricanes posed a low risk as they still had the devastating images from Hurricane Katrina.

2. Risk Measures and Evacuation Behavior (H_2)

In order to test H_2, a similar analysis to the one for Hurricane Ike was performed for the Hurricane Rita data. To test the effectiveness of risk perceptions alone in predicting evacuation behavior, a logistic model was developed first using the object scores of two dimensions and then repeated using the hazard-specific perceived risk types (Table 4). The odds ratio and the change in probability of evacuating by increasing the score of the dimension 1 are much greater than that of dimension 2 and the statistically significant hazard-specific risk perceptions. This implies that any high risk perception, regardless of the hazard, has a significant and positive effect on evacuating.

As hypothesized in H_2, having high risk perception for any or all hurricane hazards has a positive and statistically significant effect on the evacuation decision. Despite their statistically significant and positive effect on evacuation behavior, changing the perceived risk variables from low risk to high risk does not increase the probability of evacuation as strongly as doing the same for dimension 1. Fig. 4 shows the relationship between the statistically significant risk variables and the probability that a respondent evacuated. The increase in probability of evacuating is far more pronounced for each unit increase in the oversensitivity to risk measure for dimension 1 compared to dimension 2 and the perceived risk for wind damage, storm surge, and injury, consistent with H_2 and findings from Hurricane Ike.

3. Risk Measures and Evacuation Behavior with Other Control Variables (H_3)

This section includes an extended model for the Hurricane Rita survey as was developed for the Ike survey to evaluate the significance and robustness of the composite risk measures in predicting the evacuation behavior in the presence of the other control factors. Since the questions asked in the Rita survey were not identical to those asked in the Ike survey, a different but similar set of questions were selected in the larger logistic model. The factors that best explained the variance in the model and best predicted evacuation when added included neighbor evacuation, reliance on the media for information, ethnicity, and having children. These results are reported in Table 5 using the MCA dimensions and hazard-specific perceived risks separately.

Again, as reported for Hurricane Ike, a general sensitivity to risk is the strongest single predictor of the likelihood of evacuation relative to other hazard-specific risks. There is a 0.47 increase in the likelihood of evacuating from a low to high sensitivity to risk (dimension 1). No hazard-specific risk perception has a greater than 0.21 effect on the change in the probability of evacuating.

When separate models of evacuation behavior are estimated for respondents living inside and outside the evacuation zone, the composite variable (dimension 1) was among the strongest predictors of evacuation in both models (Table 6). The predictive power of dimension 1 was again stronger for the respondents living inside the evacuation zone and the odds ratio was about the same magnitude as the other significant factors, including neighbors' decisions and the reliance on the media sources.

When the logit model of evacuation behavior was estimated with the four hazard-specific measures of perceived risk and the same control factors, none of the hazard-specific risk perceptions were statistically significant (Table 6). For non-evacuation zone respondents on the other hand, the perceived risk of wind damage and personal injury significantly influenced the evacuation decision with statistical significance values of slightly larger than 0.05. The magnitude of these effects, however, was somewhat smaller than observed for the composite measure of perceived risk.

Test of robustness for the dimensions of perceived risk

Our dimensionality analysis of perceived risk is among the few focused on hurricane risk, although our findings are not without precedent (Slovic 1987). There remains, however, some reason to believe that our finding of a strong severity dimension to risk perceptions may have several rival explanations. These include the possibility that the dimensions obtained from MCA are related to the number and specific types of hazards respondents were questioned about and the confidence that respondents had in their perceptions of risk by type (i.e., less confident respondents may have given more moderate and non-extreme responses).

To test for the robustness of our dimensionality analysis and the possibility of rival explanations for our findings we conducted several additional assessments of our analyses. First, we replicated MCA of perceived risk for the Hurricane Ike data using different combinations of hazard-specific risk perceptions. Our expectation is that all combinations of risk perceptions produce the same dimensional structure defined by the severity of perceived risk. The findings, reported in the Appendix (Fig. A-1 to A-8), support this conclusion. In every instance the MCA results identify the dominant shared dimension to be the severity of the perceived risk rather than any hazard-specific trait.

As evidenced in the previous field studies (Bateman and Edwards 2002), women are more risk averse than men and their risk perceptions are generally more realistic. In order to test the effect of the gender difference on the MCA analysis results, we analyzed male (47.5%) and female (52.5%) respondents separately and found the same type clustering of risk perception around the severity level for the sample of female and male respondents (Fig. A-9 and A-10).

We might expect that respondents who live in an area designated for evacuation would be more aware of their risk and therefore more confident about their perceptions of risk than respondents who reside outside of a designated evacuation area. This also may be true for individuals who believe (rightly or wrongly) they live inside an evacuation area. If this were case, we might have reason to believe that our MCA structure would vary by location inside and outside an evacuation area and/or the belief that one lives inside or outside an evacuation area. Again we replicated our dimensional analysis by location and belief about the location of one's residence inside and outside an evacuation area. The findings, reported in the Appendix (Fig. A-11 to A-16), show that the MCA structure is still the same.

In addition to these considerations, it is possible that respondents' first answer to a risk perception question determines or influences their responses to subsequent queries about risk from other hazards. This might produce little variation or worse invariance among the responses to different risk perception questions at least for some or a consequential portion of the sample. In order to test the effect of such samples on the findings, we performed the classification analysis on the samples with non-zero variance (89% of the total sample size). We might expect that these respondents are more certain in their responses to different types of perceived risk questions as they did not choose to give the same score to all the risk factors. The findings of these additional assessments (Fig. A-17) show that the same clustering based on the severity level holds.

Finally, it is possible that there are still other factors that we have not considered which are creating the structure seen in the MCA or for which our analysis is invalid. In an effort to mitigate against these kinds of unforeseen confounding effects, MCA was performed on 10,000 bootstrapped data sets; that is, data sets formed by sampling at random (uniformly) with replacement from the original data set to create a data set of the same size. For each combination of hazard and perceived risk severity, bivariate kernel density estimators were constructed and regions of high density were plotted.[6] If the samples were drawn from a simple mixture of systematically distinguishable respondents, we would expect to see bifurcated or barbell shaped regions. If our hypothesis of severity based risk perception were false for any reasonably sized cohort, we would expect to see heavy overlapping of the regions. To the contrary, we see exactly the opposite kinds of regions. The various combinations of hazard and severity are clearly segregated into distinct unimodal clusters ordered in the same manner we observe in the original data set. The findings of the bootstrapped high-density regions illustrated in Fig. 5 therefore strongly resound the robustness of the MCA conclusions previously discussed.

These additional analyses provide us with greater confidence in our finding that perceived risk, at least from hurricane related hazards, is best summarized by a general perception of severity than any hazard-specific traits of perceived risk.

Discussion

Generic versus hazard-specific risk perception

The structure of risk perceptions about severe weather is not defined by specific hazards. Rather, our findings suggest that risk perception is defined by a strong sensitivity to risk that is grounded in the intensity or magnitude of one's sensitivity to risk, but not a specific hazard or group of related hazards (e.g., flood and storm surge as water-related hazards). Moreover, this composite structure to risk perceptions has significant consequences for behavioral responses to severe weather. We found that our composite measure of risk perception, defined as sensitivity to risk from most hurricane-induced hazards, is a significantly better predictor of evacuation behavior than any hazard-specific risk perception. The results imply that evacuation behavior is strongly dependent on whether one has a high perception of risk from different types of hurricane-related hazards, regardless of the specific type of risk, and that people are less sensitive to risk type than they are to the general seriousness of the risks. The results also showed that regardless of whether people live inside or outside the evacuation zone, if they have a high risk perception from any or all of the hurricane related hazards, they tend to make decisions to evacuate. Even when the residents live in an area designated for evacuation because of storm surge risk, their general sensitivity to risk is a stronger predictor of their evacuation behavior than their perceived risk for storm surge only.

Our findings are replicated in two separate studies conducted with a comparable sample (residents of the upper Texas Gulf Coast) for two very different hurricanes: Rita (Category 5 when approaching the coast) and Ike (Category 2). It is clear from the results that the composite measure of risk perception is robust to different storm events as opposed to hazard-specific measures of perceived risk that vary in different circumstances. Our findings about the structure and influence of risk perceptions are not unexpected. Individuals who experience severe weather do so episodically. Their experiences are often not the same over repeated trials. That is, different hazards may appear with each experience. Consequently it is difficult and unrealistic to expect that individuals experiencing severe weather and especially those who have no prior experiences with severe weather to have well formed and reliable hazard-specific perceptions of their risk to severe weather.

Consequences for organizing responses to severe weather

Our findings are highly suggestive of ways in which emergency planners and government officials might plan for severe weather and how to communicate directives to residential populations. A single hazard-based criterion for determining/recommending evacuations or sheltering in place is not likely to be an effective strategy for organizing residential responses to severe weather like hurricanes. Moreover, it might prove counterproductive, inducing more unnecessary and congesting "shadow evacuations." What should replace a single criterion for evacuation? Are generic perceptions of risk from severe weather shared across geographies? If so, could residential communities that share similar perceptions of risk be organized for collective action—evacuation or sheltering in place?

An area to be explored as a future research topic is to ascertain the specific geographies (super neighborhoods, census tracts, civic associations, etc.) that are homogeneous relative to composite and hazard-specific perceived risk and evacuation behavior. If the composite risk dimensions are found to be more homogeneous within a geographic unit than the hazard-specific perceived risk measures, this might have significant implications in understanding the motives behind hurricane evacuation. The homogeneity of risk is relevant to how emergency planners organize for evacuations and communicate their directives and recommendations to residential populations. Consider two neighborhoods. In the first neighborhood composite measures of risk perceptions are highly homogeneous, strongly correlated with intended and past evacuation behavior and congruent with emergency planners directive for evacuation. In the second community the same first two conditions prevail, but the intended behavior is *not* congruent with emergency planners directive for evacuation. Future research should test the effectiveness of focusing on the second community only where collective evacuation behavior would need redirection and how this redirection of evacuation behavior might be communicated in the case of this non-compliant neighborhood.

Recall that among the strongest non-risk correlates of evacuation behavior is neighbors' evacuation behavior. This might provide the basis of understanding how best to communicate evacuation directives to residential populations in non-compliant neighborhoods with homogeneous risk perceptions. Future research should also examine the efficacy of public information campaigns to direct evacuation behavior that originates in neighborhood associations, schools, and other neighborhood level organizations rather than relying on "Leviathan" or "top-down" messages from elective officials and local weather forecasters. This form of communication flow originates with those who are more aware of their risk and is reinforced by those who share a common risk perception.

Conclusion

This article has shown that risk perceptions of hurricane related hazards are not organized by the nature of the hazards (e.g. inland flooding or storm surge as water-related hazards), but rather by a strong sensitivity to risk levels as triggered by the acting hazards. The results suggest that people's perceived risk to different hazards can be reduced to a single dimension that spans all risk types and that is based on the severity of the perceived risk. We found that this composite dimension is a significantly better predictor of evacuation behavior than any hazard-specific perceived risk measure even in conjunction with other typical predictors of evacuation and it is robust to different hurricane events and potential sampling biases. The results imply that people are less sensitive to risk type than they are to the general seriousness of the risks. Our findings may help emergency managers better understand the public's risk perceptions and responses to hurricane hazards and therefore may improve the communication of real and perceived risks with the public to minimize unwanted evacuations.

Endnotes

1. The counties include: Harris, Chambers, Montgomery, Brazoria, Galveston, Fort Bend, Matagorda, and Waller. In Harris County an estimated 22% of the population lives inside of a designated evacuation zone for Hurricane Ike (based on U.S. Census 2000). In the case of this analysis, the sample size for the residents living inside evacuation zone was 342 corresponding to 23% of the full set, which means that the number of residents both inside and outside the evacuation zone is correctly represented by the survey. For Hurricane Rita survey a random digit sample of area phone numbers was drawn from which interviews were conducted with 651 persons in eight counties between September 29 and October 3, 2005. The response rate for the survey was 35% (i.e., APPOR #3 response rate). The error rate for the sample is +/-3.95%. Respondents were not asked separate questions about their ethnic and racial identity. We suspect that some Hispanic respondents chose “White” for their racial identification rather than “Hispanic.” As a consequence, it is not likely that Hispanics are under-represented in the survey, but rather they are under-reported. Henk et al. (2007, 9) make the same assessment of their reported sample of Hispanic respondents. On three other demographic traits (age, education, and income) the sample closely matches the census reports for these measures in the eight-county area (U.S. Department of Commerce 2008).

Racial and ethnic makeup of survey sample in the Houston metropolitan area

	Race/ethnicity				Income	Age	Education	
Traits	White	Black	Asian	Hispanic	Median Family	% > 65	H.S. Grad	B.A. +
Survey	58%	20%	3%	15%	$42,500	11%	76%	41%
Census	46%	18%	6%	30%	$39,199	8%	80%	39%

2. See http://www.nhc.noaa.gov/HAW2/english/history.shtml#ike for more details.
3. Total inertia is the amount that quantifies the total variance in the cross-table (Greenacre and Blasius 2006).
4. The rescaled scores are calculated as (raw score–min)*4/(max–min).

5. For the computation of regions, some of the distributions are more dispersed than others, and no single density cutoff level could be reasonably used. Thus, for each hazard and severity combination the two-dimensional kernel density estimators were evaluated on a very fine rectangular grid in the MCA space and the 10th percentile of the evaluations was then used to for the cutoff density level for plotting purposes.

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Table 1: Logistic regression models of evacuation behavior during Hurricane Ike using MCA dimensions and perceived risk types. *Statistically significant variables (*p < 0.05*).

Variable	*Odds Ratio* (Δ in Prob*)
Dimension 1	1.92* (0.71)
Dimension 2	1.02
Dimension 3	1.13* (0.11)
Pseudo-R²/ Log likelihood 0.13/-753.85	
Perceived Wind Risk	1.18* (0.08)
Perceived Surge Risk	1.38* (0.18)
Perceived Flood Risk	1.35* (0.16)
Personal Injury	1.13
Pseudo-R²/ Log likelihood 0.13/-730.76	

* Δ Probability of evacuating for a change of each hazard specific risk variable from no risk to high risk while holding the other variables to their mean values.

Table 2: Logistic regression models of the variables best predicting evacuation behavior for Hurricane Ike extended model. *Statistically significant variables ($p < 0.05$).

Variable	*Odds Ratio* (Δ in Prob)	Variable	*Odds Ratio* (Δ in Prob)
Dimension 1	1.56* (0.48)	Wind Damage	1.00
Dimension 2	1.04	Storm Surge	1.22* (0.09)
Dimension 3	1.02	Rainfall Flooding	1.25* (0.10)
		Personal Injury	1.14
Evacuation during Rita	2.79*	Evacuation during Rita	2.72*
Age	1.19*	Age	1.18*
Neighbor evacuation	3.07*	Neighbor evacuation	3.07*
Coordination with family	0.64*	Coordination with family	0.61*
Reliance on the media	1.55*	Reliance on the media	1.55*
Received help from others	0.54*	Received help from others	0.58*
Provided help to others	2.42*	Provided help to others	2.31*
Length of Time in Houston	0.89	Length of Time in Houston	0.88*
Pseudo-R^2/ Log likelihood	*0.39/-485.30*	*Pseudo-R^2/ Log likelihood*	*0.38/-477.73*

Table 3: Extended logistic regression model for the Hurricane Ike survey for inside and outside the evacuation area. *Statistically significant variables ($p < 0.05$).

	Inside	Outside		Inside	Outside
Variable	*Odds Ratio* (Δ in Prob)	*Odds Ratio* (Δ in Prob)	*Variable*	*Odds Ratio* (Δ in Prob)	*Odds Ratio* (Δ in Prob)
Dimension 1	1.78* (0.63)	1.49* (0.38)	Per. Risk of Wind Damage	1.36	0.86
Dimension 2	0.79	1.15	Per. Risk of Storm Surge	1.33	1.09
Dimension 3	1.36	0.95	Per. Risk of Rain. Flooding	1.09	1.38* (0.12)
			Per. Risk of Personal Injur.	1.22	1.19
Evacuation during Rita	3.04*	2.60*	Evacuation during Rita	3.12*	2.41*
Age	1.34*	1.13	Age	1.35*	1.13
Neighbor evacuation	3.10*	2.87*	Neighbor evacuation	3.28*	2.90*
Coordination with family	1.03	0.61*	Coordination with family	0.95	0.57*
Reliance on the media	1.98*	1.52*	Reliance on the media	1.94*	1.52*
Received help from others	0.46*	0.60*	Received help from others	0.39*	0.65
Provided help to others	2.52*	2.31*	Provided help to others	2.80*	2.28*
Length of Time in Houston	0.80*	0.94	Length of Time in Houston	0.78*	0.93
Pseudo-R^2/ Log likelihood	*0.49/-134.76*	*0.30/-342.81*	*Pseudo-R^2/ Log likelihood*	*0.48/-132.20*	*0.30/-333.44*

Table 4: Logistic regression models using MCA dimensions and perceived risk types for Hurricane Rita. *Statistically significant variables ($p < 0.05$).

Variable	*Odds Ratio* (Δ in Prob)
Dimension 1	2.88* (0.61)
Dimension 2	1.22* (0.21)
Pseudo-R²/ Log likelihood 0.26/-367.79	
Perceived Wind Risk	1.56* (0.20)
Perceived Surge Risk	1.51* (0.18)
Perceived Flood Risk	1.33
Perceived Risk of Personal Injury	1.87* (0.27)
Pseudo-R²/ Log likelihood 0.26/-329.49	

Table 5: Logistic regression model of the variables best predicting evacuation for Hurricane Rita extended model. *Statistically significant variables ($p < 0.05$).

Variable	*Odds Ratio* (Δ in Prob)	*Variable*	*Odds Ratio* (Δ in Prob)
Dimension 1	2.11* (0.47)	Per. Wind Risk	1.56* (0.21)
Dimension 2	1.04	Per. Surge Risk	1.28
		Per. Flood Risk	0.99
		Per. Risk of Personal Injury	1.61* (0.21)
Kids	1.41	Kids	1.60*
Anglo	1.38	Anglo	1.31
Neighbors	3.25*	Neighbors	3.51*
Reliance on media	1.82*	Reliance on media	1.80*
Correctly knew evacuation zone	0.61*	Correctly knew evacuation zone	0.67
Length in the residence	1.10	Length in the residence	1.11
Marital	0.87	Marital	0.73
Pseudo-R^2/ Log likelihood	*0.46/-282.93*	*Pseudo-R^2/ Log likelihood*	*0.47/-251.21*

Table 6: Extended logistic regression model for the Hurricane Rita survey for inside and outside the evacuation area. *Statistically significant variables ($p < 0.05$).

	Inside	Outside		Inside	Outside
Variable	*Odds Ratio* (Δ in Prob)	*Odds Ratio* (Δ in Prob)	*Variable*	*Odds Ratio*	*Odds Ratio*
Dimension 1	2.12* (0.43)	1.73* (0.26)	Per. Wind Risk	1.58	1.49
Dimension 2	1.09	1.01	Per. Surge Risk	1.34	1.03
			Per. Flood Risk	1.15	0.78
			Per. Risk of Pers. Injur.	1.65	1.61
Kids	0.78	1.85*	Kids	0.93	2.04*
Anglo	0.84	1.5	Anglo	0.99	1.35
Neighbors	2.11*	3.40*	Neighbors	2.45*	3.79*
Reliance on media	2.80*	1.68*	Reliance on media	2.43*	1.74*
Correctly knew evacuation zone	0.87	0.52*	Correctly knew evacuation zone	1.13	0.46*
Length in the residence	0.41*	1.69*	Length in the residence	0.34*	1.84*
Marital	1.82	0.62	Marital	1.09	0.52*
Pseudo-R^2 /Log likelihood	*0.35/-81.29*	*0.36/-185.93*	*Pseudo-R^2/ Log likelihood*	*0.39/-69.31*	*0.38/-167.41*

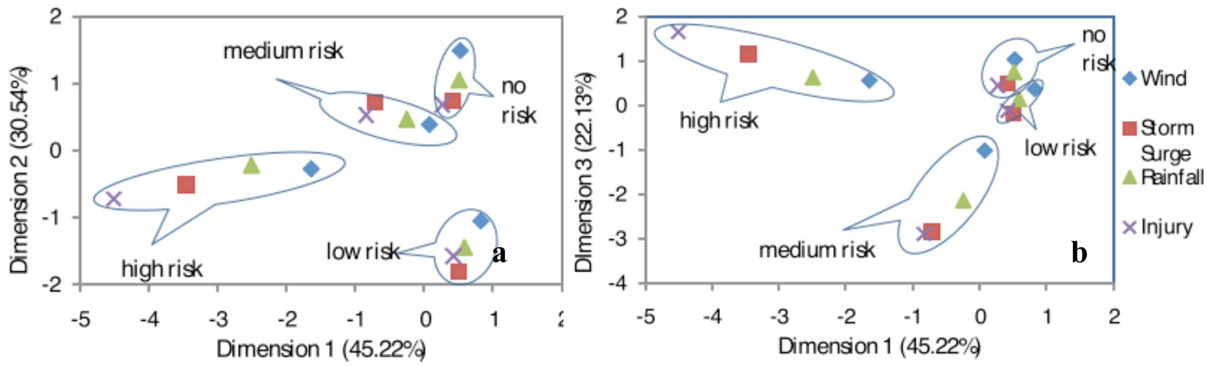

Fig. 1. Joint plot of variable categories for three dimensions (a. Dimension 1 and 2; b. Dimension 1 and 3) extracted by the MCA for the Hurricane Ike survey. Note: A separate figure for Dimensions 2 and 3 is not shown to avoid redundancy. The parentheses in the axes titles contain the percent inertia explained by each dimension.

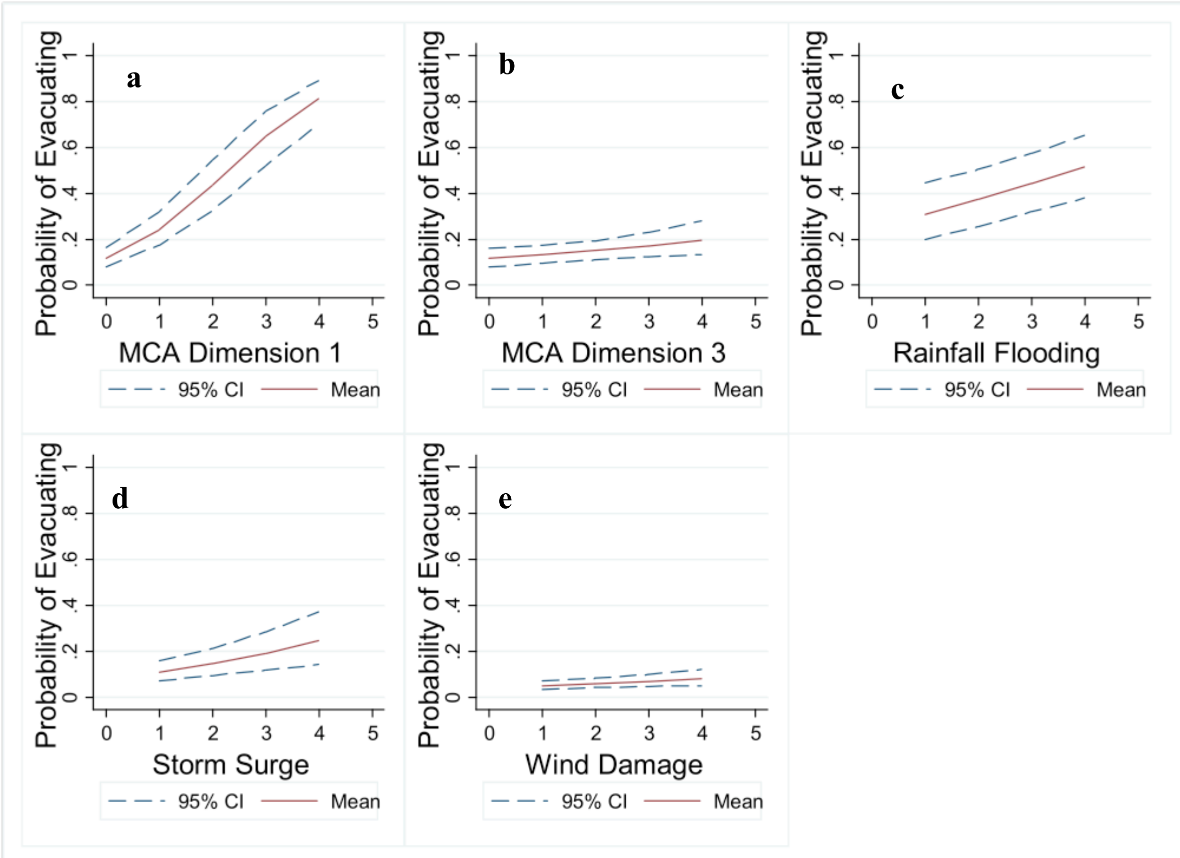

Fig. 2. Predicted probability of evacuating as the *statistically significant* composite and hazard specific risk perceptions vary for the Hurricane Ike survey.

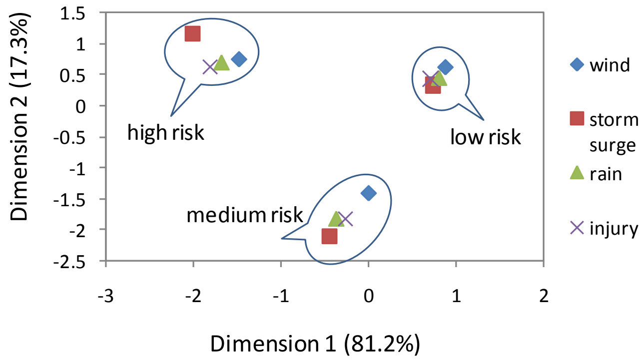

Fig. 3. Joint plot of variable categories for two dimensions extracted by the MCA for the Hurricane Rita survey data. The parentheses in the axes titles contain the percent inertia explained by each dimension.

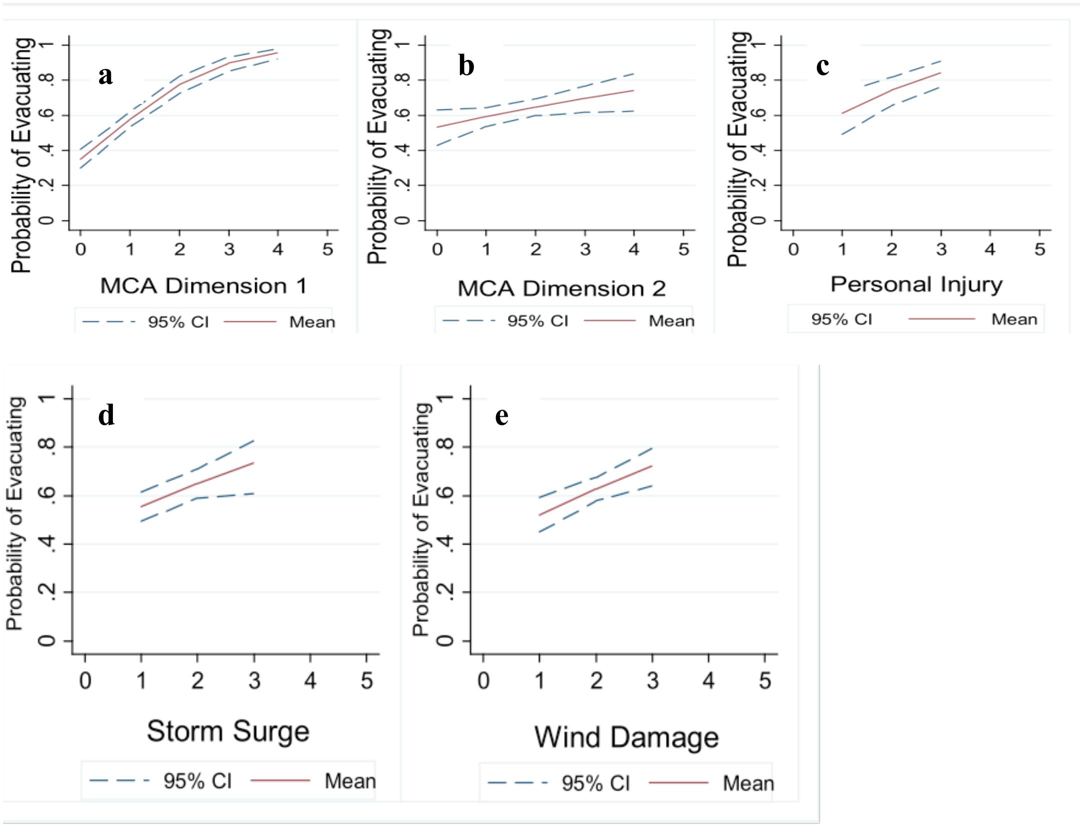

Fig. 4. Predicted probability of evacuating as the *statistically significant* composite (a,b) and hazard specific perceived risk variables (c-e) vary for the Hurricane Rita survey.

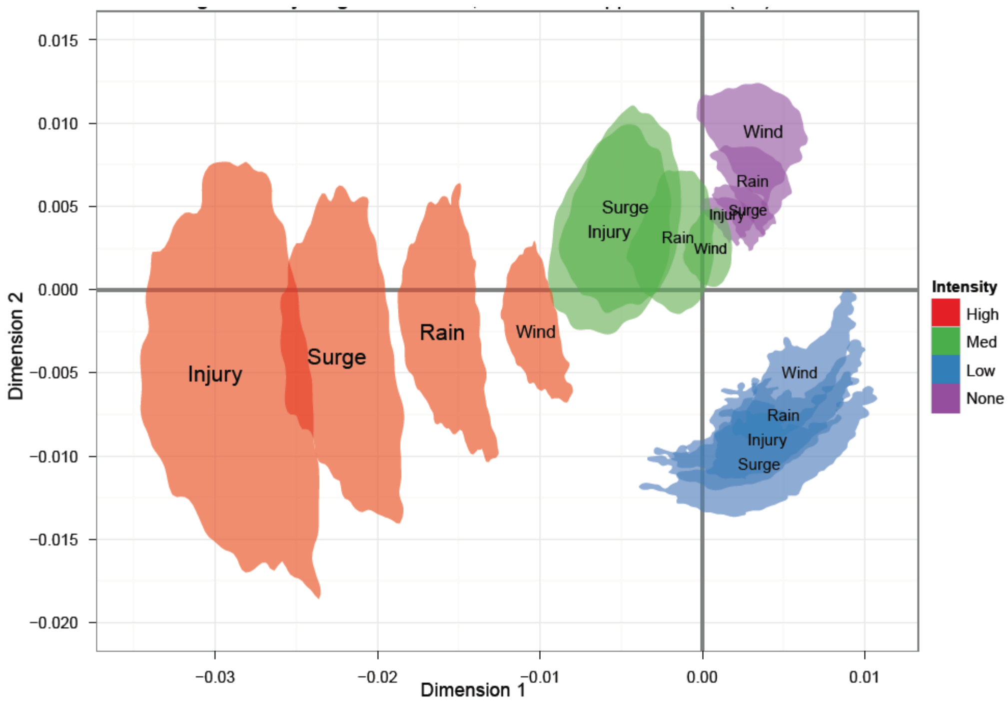

Fig. 5. High density regions of the MCA scores from 10,000 bootstrapped samples using the Hurricane Ike survey indicating the robustness of the MCA to underlying heterogeneity.