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Exploring Uncertainties in Households' Hurricane Evacuations

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EXPLORING UNCERTAINTIES IN HOUSEHOLDS' HURRICANE EVACUATIONS

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ABSTRACT

Hurricane Matthew was the most powerful hurricane during the Atlantic Hurricane Season in 2016. It caused tremendous damages to infrastructure and coastal areas of the United States. This thesis uses survey data collected in 2017 from residents in the Jacksonville Metropolitan Area after Hurricane Matthew. Survey questions were designed to capture evacuation-related decisions, information sources usage, socio-economic factors, perceived certainty and intra-familial interactions. The first part of the thesis modeled households' perceived certainty to identify factors that affect different perceived certainty topics. Certainty topics included were: whether one lives in an evacuation zone, time of hurricane impact, evacuation preparation time needed, when to evacuate, evacuation travel mode, evacuation route, and evacuation destination. The modeling results showed similarities and disparities among perceived certainty topics. Household archetypes were created to offer insights for both decision makers and stakeholders for hurricane emergency management. The second part of this thesis explored the connection between the evacuation decision and perceived certainty using a two-stage modeling concept. Adding contextual factors usually leads to endogeneity bias which means parameters of variables will be overestimated or underestimated. A control function approach was used to account for potential endogeneity bias when linking perceived certainty with the evacuate/stay decision caused by unobserved attributes. The uncorrected base model was found to have a downward bias of the perceived certainty of evacuation destination, and with endogeneity bias corrected the parameter for this variable increased by 91.6%.

DEDICATION

My journey for my master's study has been a mixture of struggles and joy. I did not expect two short years at Clemson would bring so much growth for me both academically and mentally. I would like to thank my parents for their unconditional support. My study will not be possible without your love and trust. This thesis is also dedicated to my friends at Clemson. Evacuation study is naturally an interdisciplinary subject; thanks to my friends and their various academic backgrounds which provided me a think tank for my study. I appreciate Lan Lan, Yao Chen, and Jun Li, who helped me with economic theories and guidance for my graduate study. I am fortunate and blessed to have you as my friends.

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CHAPTER ONE

INTRODUCTION

Before impact, natural disasters are usually associated with uncertainty. The presence, path, and consequences of natural disasters are not easy to predict accurately. Take hurricane monitoring and forecasting as an example; the predicted movement of a hurricane has many variations even with close monitoring. The hurricane can speed up, maintain its speed, slow down or stall and the intensity could also change over time (Lindell, Murray-Tuite, Wolshon, & Baker, 2018). Disaster management not only faces challenges of the constantly changing and evolving nature of the hazard but also human behavior. The compliance of residents and households' evacuation participation rates vary greatly from place to place and event to event. Lindell and Prater (2007) found that rarely would the evacuation participation rate reach 100%, despite many analysts assuming this rate when an evacuation warning is issued for a disaster. This thesis posits that part of the variation in human behavior during a disaster is because of uncertainty. The relationship between perceived uncertainty and evacuation behavior has been recognized by researchers. Pan et al. (2007) found that under high uncertainty and stressful situations, individuals are likely to follow others' actions as a guide causing herding behavior. Mileti et al. (1985) categorized uncertainty officials face in decision making from various disasters. But, to the knowledge of author the relationship of households' evacuation decision and perceived uncertainty, has rarely been studied explicitly by researchers.

Households residing near coastal areas during a hurricane event receive different types of information from various sources. Households receiving risk information perceive and process it differently depending on the environmental, social, and psychological attributes of the information receivers (Mileti & O'Brien, 1992). These aspects were also mentioned by Lindell and Perry (2012) in the Protective Action Decision Model (PADM), taking environmental cues, social cues and psychological cues as determinants in evacuation decision-making. Incomplete and conflicting information, misinterpretation of warning information, and false notice all raise uncertainties among receivers (Lindell & Perry, 2012).

Unlike commonly practiced evacuation behavioral modeling which directly links the evacuation decision with explanatory factors, this thesis explores the potential of adding perceived certainty as a contextual factor in evacuation modeling. Using survey data collected after Hurricane Matthew, the first part of this study uses linear regression to identify factors associated with hurricane evacuation-related perceived certainty topics. The second part of the thesis links models that predict perceived certainty with models that predict households' evacuate/stay decisions as a hurricane approaches. This enables exploration of how households' certainty levels could be influenced and then affect their evacuate/stay decisions.

Furthermore, many previous evacuation studies analyzed the effect of external factors (e.g., social influences and warning information) on households' decisions (Dash & Gladwin, 2007; Hasan, Ukkusuri, Gladwin, & Murray-Tuite, 2011; Murray-Tuite & Wolshon, 2013; Thompson, Garfin, & Silver, 2017) while neglecting the process of households' internal communication and information-sharing that lead to final evacuation decisions. In this study, we examine external factors (e.g., official notice, information sources, and social network), socio-demographic factors, and households' internal actions (e.g., relative sequence of decisions and information sharing) that could contribute to certainty and behaviors.

1.1 Research Objectives

Hurricane Matthew is recognized as the most powerful Atlantic Basin hurricane of the 2016 season (Martín, Li, & Cutter, 2017). Evacuation order compliance rates for hurricanes are often significantly below 100% (Lindell and Prater, 2007). From the University of South Carolina's Hurricane Matthew Evacuation Research, the online survey showed that Florida residents' evacuation rate was 62.2% (Pham, 2018). While it might be better to be conservative and overestimate the evacuation compliance rate for emergency planning, accurate predictions of evacuation participation help emergency managers to allocate traffic management and disaster relief resources better especially during natural disasters.

In this thesis, multiple regression analyses and probit models are developed based on a mail-in survey in the Jacksonville Metropolitan Statistical Area after Hurricane Matthew. The main goal of this thesis is to improve hurricane evacuation modeling and understanding by exploring the often-omitted role of uncertainty in evacuate/stay decisions and factors associated with uncertainty. The objectives of studying the perceived certainty are to:

- Understand whether households utilize social networks and information sources to manage certainty,
- Identify socio-demographics and household characteristics associated with certainty, and
- Investigate the relationships between relative sequences of evacuation logistics decisions and certainty.

The second part of the thesis links perceived certainty with the evacuate/stay choice by modifying models developed from the first part of the thesis and using perceived certainty in the evacuation decision model. The objective of this part of the research is to understand how variables affect the evacuate/stay decision through households' perceived certainty.

1.2 Contribution

An overview of current practice on evacuation transportation modeling suggests there are only a few factors that are consistent across disaster types in predicting the likelihood of evacuating or staying (Murray-Tuite & Wolshon, 2013). Up to the present, most social scientists and engineers in this field still link different factors directly with evacuation decisions. A next step for research is to find contextual factors (e.g., certainty, location, involved population etc.) that moderate the role of identified behavioral predictors in hurricane evacuation. The contribution this thesis makes to the current practice is that it explicitly models perceived certainty in households and treats certainty as a mediator in the evacuation modeling process. The Protective Action Decision Model (PADM) proposed by Lindell and Perry (2012) has recognized that threat perceptions, protective action perceptions, and stakeholder perceptions can all contribute to protective action decision making. Uncertainty is an impediment in household evacuation decision; once resolved, they are able to proceed to the next stage of the decision-making process (Lindell & Perry, 2012). In this thesis, we are adding another component to the mediators for PADM by quantifying certainty and linking the behavioral models with certainty models.

1.3 Outline

This thesis has five total chapters, including this one. Chapter 2 presents the literature review, which has three parts. The first part is about households and information sources. The second part is about certainty and evacuation behavior. The third part is about methodologies to link perceived certainty and evacuation behavior. Chapter 3 presents the first manuscript titled Household Perceived Certainty in Hurricane Evacuation Decision-Making Contexts. Chapter 4 presents the second manuscript titled Perceived Certainty's Effect on households' Evacuation

Decisions. Chapter 5 summarizes and concludes the thesis and presents the contributions and future directions.

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CHAPTER TWO

LITERATURE REVIEW

Natural disasters are inevitable phenomena that could cause huge impacts to natural systems and some disasters could be catastrophic to residents and local communities. Hurricanes, along with other disasters like floods, tsunamis, and wildfires require evacuation management to ensure an effective and safe evacuation (Lindell et al., 2018). Many entities are involved in hurricane evacuation management, such as: weather forecasting and monitoring agencies and emergency management agencies. Forecast and evacuation-related information is processed by each entity before reaching households from different channels. Each entity faces different types of uncertainty (state uncertainty and/or effect uncertainty and/or response uncertainty, see (Milliken, 1987)) when processing the information. Figure 1 is an updated theoretical framework of uncertainty and information flow in hurricane evacuation originally constructed by Ali et al. (Unpublished). The theoretical framework reviewed existing hurricane studies and the structure of how information and uncertainty are passed to households. This thesis primarily focuses on block 11 (Individual Household) and block 16 (Household Decision Making) and their connected information sources (block 7 (Authorities); block 8(Mass Media and Social Media); and block 9 (Social Network)).

The next few sections of this literature review focus on the issue of uncertainty and evacuation decision studies to provide some understanding and theoretical background for the thesis.

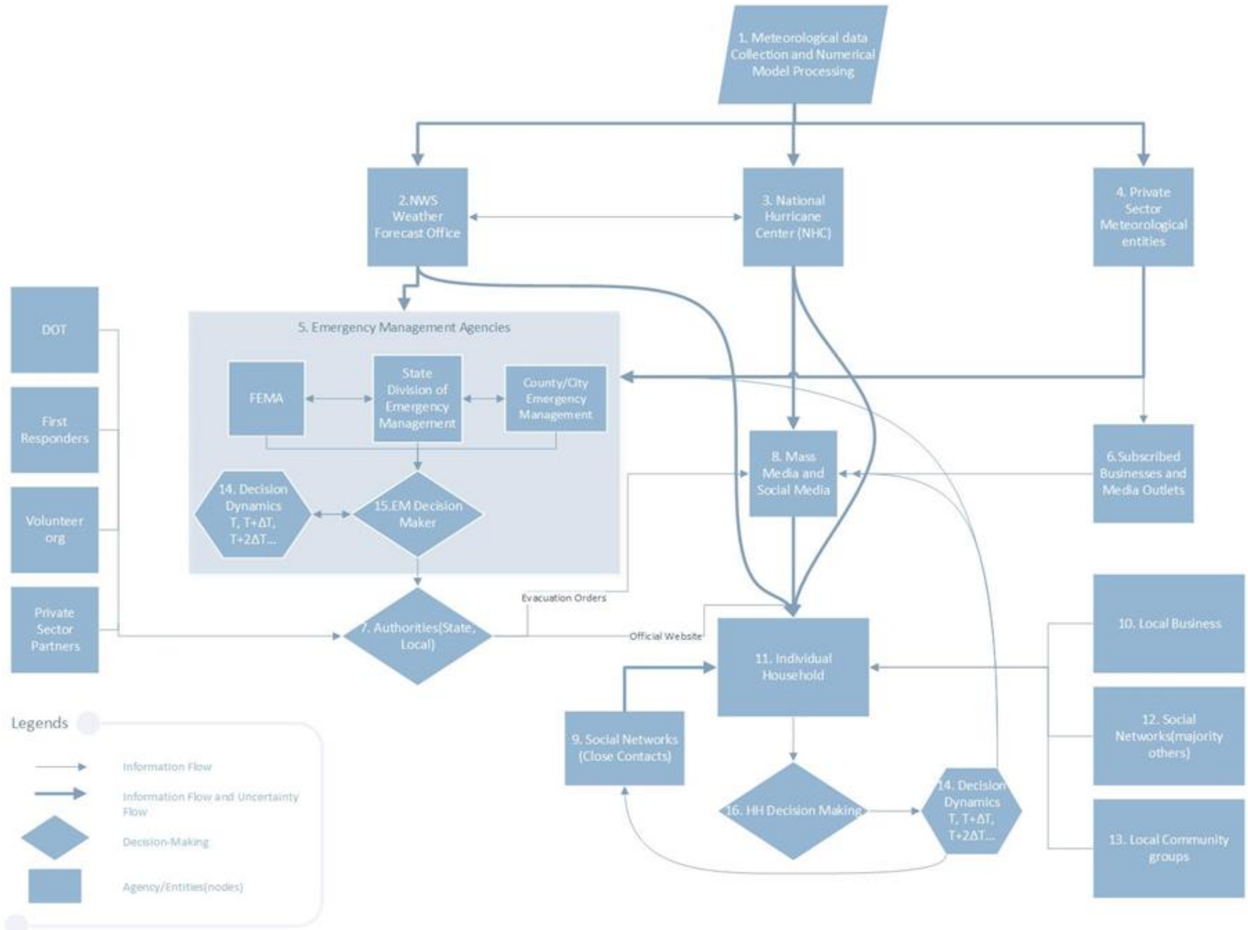

Figure 1. Theoretical Framework of Uncertainty and Information Flow in Hurricane Evacuation

2.1 Households and Information Sources

The literature review starts with households' information sources during a hurricane. For households to be motivated to evacuate, there must be information about an upcoming hurricane. Households engaged in the initial phase of information gathering passively (e.g., hearing or seeing close contacts talking about or preparing for hurricane) or actively (e.g., seeking information from mass media or social media). In the PADM, the initial information gathering is a necessary process before households comprehend all information to believe that there is a threat (Lindell, Michael K. & Perry, 2012b).

Block 8 represents the most commonly used information sources for households. Mass media and social media are common mediums for hurricane information distribution. Common mass media and social media include: radio, local TV, national TV, and social media websites and apps: Twitter, Facebook, Instagram, etc. Depending on the type of information channel, the coverage of geographic specialty varies as does the subject matter specialty. Local television and radio are mediums recognized by researchers as the most effective in promoting evacuation (Sadri et al. 2017). And they are the most common channels of hurricane information for the public (Demuth, Morss, Morrow, & Lazo, 2012; Morss & Hayden, 2010). Local television and radio obtain their information from their partners (Block 2,3,6,7) and they synthesize pieces of information and present it to their audiences (Demuth et al., 2012). Information is processed and tailored by TV and radio personnel so that they can provide useful information to their specific, targeted audiences. Here, information could be left out if the producers and managers of the program think the information is not related to their audience and media personnel also have flexibility in deciding when and how they communicate hurricane risk, meaning information is also subject to potential distortion and lag-time. Information disseminated by radio and TV contains uncertainties from sources (probability of the hurricane hitting, chances of rain, etc.). With rapid growth of the internet in the past decades, how people access and interpret hazardous weather information has changed (Demuth et al., 2012). Social media is gaining more attention from evacuation researchers. For example, Twitter data was used to analyze disaster preparedness, emergency response, and evacuation compliance (Huang & Xiao, 2015; Martín, Li, & Cutter, 2017).

Humans are social beings; this statement is still found to be true in case of approaching disasters. Perry (1981) reported people’s social network is helping to transmit warning massages for impending threats. Cutter et al. (2011) identified friends and neighbors as information sources that affect decision making. Lindell et al. (2011) also found close contacts to be considered reliable sources for older or female respondents.

2.2 Perceived Certainty in Evacuation Behavior Studies

Certainty itself is not a completely novel topic in evacuation studies. Certainty was listed as an important component in Fitzpatrick and Mileti's (1991) discussion about using information factors as evacuation stimulus. Public information could increase likelihood of evacuation compliance if the information conveys a high level of certainty about the event (Baker, 1991). Messages with certainty impact public belief and affect people's decision making (Perry, Lindell, & Greene, 1982; Turner, Nigg, Paz, & Young, 1979). These studies' certainty is about the style and tone in which information should be conveyed and the fact that certainty could promote evacuation behavior. It is nearly impossible to trace every piece of information households received during a hurricane event. In this thesis, there is a slight tweak of the consideration of certainty. We recorded the perceived certainty of households instead of information certainty, and we anticipate this perceived certainty would affect evacuation behavior. This certainty aligns with Lindell and Perry (2012)'s PADM model, which indicated low certainty impedes people's decision making at any stage of the decision-making process.

A limited number of studies investigate how people's perceived certainty would change. One research that is close to the context of certainty this thesis is focusing on is in He et al. (2007)'s study. In their research, students' certainty of evacuation response was used to label their awareness of future response (He, Tiefenbacher, & Samson, 2007). Because their dependent variable is the certainty of evacuation behavior of a hypothetical hurricane, we could not learn how people's behavior are affected by certainty.

Since there are limited studies that modeled household certainty, the reviewed literature are behavioral studies along with predictors of these behaviors. This part of the literature review is embedded in Chapter 3: Household Certainty in Hurricane Evacuation Decision-Making Contexts, part 2.

2.3 Motivators of Linking Perceived Certainty with Evacuation Decision

There are two motivators to link perceived certainty with evacuation decision. One is from the evacuation research's theoretical background and the other one comes from a methodological aspect. This part of the literature review investigates both motivators and identifies the methodology applicable for the research purpose.

Certainty as an evacuation determinant lends itself well to the conceptualization of two-stage modeling, as there are variables (such as information mediums and evacuation experience) that would logically influence certainty instead of the final decision outcome. The previously mentioned PADM represents a repetitive process; a protective action will not be implemented until uncertainty has been resolved and reduction in certainty at any stage transition can result in harmful delays or even sequence reset (Lindell, Michael K. & Perry, 2012a). There are also multiple evacuation studies that pointed out the need for multi-stage modeling in evacuation decisions (Gladwin, Gladwin, & Peacock, 2001; Huang Shih-Kai, Lindell Michael, Prater Carla, Wu Hao-Che, & Siebeneck Laura, 2012; Mileti & Beck, 1975). Having multi-stage in modeling will capture the complexity and messiness of real-world decision-making processes and help emergency managers to understand how people react to the approach of a hurricane (Gladwin, Gladwin, & Peacock, 2001). These studies provide a solid theoretical background which motivated the research effort to link perceived certainty with evacuation decision with a two-stage approach.

Huang et al. (2012) employed a two-stage modeling concept to investigate an abbreviated form of the PADM. Their hypotheses were that environmental and social cues' effects on evacuation decisions and departure timing are mediated by perceived storm characteristics and unnecessary evacuation experience's effect on evacuation decision is mediated by perceived evacuation impediments (Huang Shih-Kai et al., 2012). Huang et al. used this approach again in 2017 for an evacuation decision study for Hurricanes Katrina and Rita (Huang Shih-Kai, Lindell Michael, & Prater Carla, 2017). Both studies lead by Huang did not mention accounting for the potential endogenous bias that may be present when studying only variables of interests. While Huang's work is valuable in the sense of investigating positive and negative predictors of evacuation decision, the parameter of each predictor might be biased and inconsistent. However, Mileti and Beck (1975) when using the two-stage modeling concept recognized the possibility of excluding important unobserved variables. Instead of using a direct regression approach, Mileti and Beck employed Indirect Least Squares (ILS) which can also be called "two stage least squares." This methodology uses a reduced form of endogenous variables (warning confirmation and warning belief) to enter the final model (warning response model). Their methodology accounts for the effect of unobserved factors and therefore the parameter estimates were consistent and unbiased.

Endogeneity bias has many causes: omitted variables, measurement error, and simultaneous causality (Zaefarian, Kadile, Henneberg, & Leischnig, 2017). In the context of evacuation study, endogeneity caused by omitted variables (Mileti & Beck, 1975); measurement error (Dekker, Hess, Brouwer, & Hofkes, 2016); simultaneous causality (Gehlot, Sadri, & Ukkusuri, 2019; Tahsin, 2014) have all been addressed by evacuation researchers to some degree. This thesis adds perceived certainty as a new mediator in evacuation decisions, and it is likely that the unobserved factors include other variables that would affect the evacuation decision. Thus, the most applicable endogeneity bias should come from omitted variables.

Mileti and Beck (1975)'s work kept all variables in all stages to be dichotomous to conduct the ILS analysis. For this thesis, the original survey design has perceived certainty as a 5-point Likert scale variable and there are other socio-demographic and information sources variables that are continuous. Although all variables could be recoded into binary indicator variables, variation in the dataset would be lost. For this thesis, the potentially endogenous variable - perceived certainty – is kept as a continuous variable, and the evacuate/stay decision variable is maintained as a binary variable. The structure of the models has perceived certainty in the first stage estimated using weighted ordinary least squares (OLS) model, and the second stage has a binary evacuate/stay outcome that is estimated using discrete choice. This prohibits application of the two-stage modeling procedure directly as linear projection will not carry through nonlinear functions (Wooldridge, 2010).The literature review then extended to econometric studies to seek a methodology that would better serve the research interest.

For a continuous-discrete modeling structure, an easy to apply method to solve for potential endogenous bias is the Control Function introduced by Heckman and Robb (1985) and improved later on by Rivers and Vuong (1988). Regardless of the endogeneity bias's cause, the error term will be correlated with the endogenous variable and the independence assumption of the error term is violated. The control function transfers the error term in the first stage regression to the second stage as a new variable along with the endogenous variable and other variables. If the error term is significant in the second stage, the null hypothesis of the endogenous variable being exogenous is rejected and it is proved statistically that it is endogenous. More discussion on the employment of the methodology can be found in Chapter 4: Households Perceived Certainty's Effect on Evacuation Decision, Part 4.

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CHAPTER THREE

Household Perceived Certainty in Hurricane Evacuation Decision-Making Contexts

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ABSTRACT

This study considers households' perceived certainties related to hurricane impact and evacuation decisions. A post-Hurricane Matthew survey was sent to households in Jacksonville, Florida. We use weighted linear regressions to model seven perceived certainty topics (i.e., whether one lives in an evacuation zone, time of hurricane impact, evacuation preparation time, when to evacuate, evacuation destination, evacuation travel mode, and evacuation route) and investigate how various information sources, socio-demographic factors, intra-household communications, and relative decision sequences predict the levels of certainty perceived by respondents. Results show that significant explanatory variables vary across the seven different perceived certainty topics. Using archetypes to identify disparities in perceived certainty, hurricane experienced households have the greatest perceived certainty (average of 91% across certainty topics), followed by active information seekers (average of 88%), and then socially vulnerable households (average of 64.3%). Social vulnerability does not always mean the group perceives less certainty in evacuation. Women as decision makers and when a household member(s) has medical needs both lead to higher perceived certainty. Archetypal disparities suggest targeted information strategies could assist different groups with their evacuation certainties and potentially decisions by extension.

Keywords: Hurricane evacuation decision-making, household perceived certainty, archetypes, linear regression, Hurricane Matthew

1. Introduction

Two recognized areas of uncertainty related to hurricane evacuations are the hurricane itself and evacuees' behavior. Uncertainty in the hurricane itself is due to uncertainty in forecasting its path and landfall, which includes its track, speed, intensity and size at landfall (Dash, 2002; Dash and Gladwin, 2007; Lindell and Prater, 2007; Regnier, 2008). In the context of evacuees' behavior, uncertainty comes from decision making with incomplete or/and inadequate understanding about the hurricane (Lipshitz and Strauss, 1997). Warning information helps to form households' perception and understanding of the hurricane; conflicting or/and insufficient warning information are other contributing factors to uncertainty.

Individuals perceive and process risk information (from a variety of sources) differently depending on their environmental, social, and psychological attributes (Mileti and O'Brien, 1992). Personal characteristics (including psychological attributes) along with environmental and social cues and information sources, channels, and messages form a basis for the formation of threat and protective action perceptions. These factors shape protective action decision making and behavioral response, as suggested in Lindell and Perry's (2012) Protective Action Decision Model (PADM). One of the behavioral responses in the PADM is information search (Lindell et al., 2019), which helps overcome initial disbelief to disaster warnings (Drabek, 1999; Tierney et al., 2001), reinforce information, and resolve some uncertainty. However, subsequent information may conflict with previous information, increasing uncertainty rather than resolving it. Uncertainty is an impediment in any decision-making stage, limiting progress through the decision-making process, and arriving at an outcome (Lindell and Perry, 2012).

While several studies investigate information search patterns using experimental platforms, such as DynaSearch (e.g., Wu et al., 2015a, 2015b), few have developed models representing the level of perceived certainty about the hurricane as well as household evacuation-related decisions beyond the evacuate/stay choice. In the current study, we address this gap and posit that households' certainties as a condition of the psychological processes in the PADM are tied with household behaviors and decision making.

This study does not focus on modeling household evacuation decisions but rather modeling hurricane hazard and evacuation-related perceived certainty topics to understand factors associated with them, based on survey data collected after Hurricane Matthew. In this study, we use linear regression to examine external factors (e.g., official notice, information sources, and social network), socio-demographic factors, and households' internal actions (e.g., information sharing (Savitt and Ge, 2019) and relative sequence of decisions) that contribute to perceived certainty topics including: 1. Whether one lives in an evacuation zone, 2. Time of hurricane impact, 3. Evacuation preparation time needed, 4. When to evacuate, 5. Evacuation destination, 6. Evacuation travel mode, and 7. Evacuation route. Based on our analysis, we use archetypes to highlight disparities among certainties for different households. Archetypes use was previously illustrated for Australian wildfire studies (Berry et al., 2008; Strahan et al., 2018). The archetype analysis results suggest information dissemination recommendations and strategies for emergency mangers and stakeholders to reduce these disparities in certainty.

The remainder of this paper is divided into six parts. Section 2 discusses background and hypotheses based on selected literature. Section 3 describes the data and modeling technique. Section 4 presents the results, the discussion of which is expanded in Section 5. Section 6 presents an archetype analysis to examine disparities in certainty among archetypes based on modeling results. The final portion of this paper provides conclusions and future directions.

2. Research Questions, and Hypotheses

To build our hypotheses, we first categorized the perceived certainty topics in our study into two groups. The first category is the perceived certainty of characteristics of the hazard and resident's home. Two certainty topics included in this category are: whether one lives in an evacuation zone and time of hurricane impact. Living in an evacuation zone is a geospatial characteristic of a resident's home. The time of hurricane impact is about how imminent the respondent thinks the threat is.

The second category is the perceived certainty of residents' hurricane evacuation logistics. Five certainty topics included in this category are: evacuation preparation time needed; when to evacuate; evacuation destination; evacuation travel mode; and evacuation route.

Almost no literature that directly models households' perceived certainty in hurricane evacuation exists. The most closely related literature on this topic is related to risk and threat perception and evacuation behavior (Dash and Morrow, 2000; Demuth et al., 2016; Huang et al., 2017; Murray-Tuite and Wolshon, 2013; Peacock et al., 2005). These studies inform the hypotheses and the variables to consider in the modeling effort. These hypotheses along with the supporting literature follow.

2.1 How do experience, higher social-vulnerability, and household dynamics affect perceived certainty?

Time of hurricane impact and whether a resident lives in an evacuation zone are evaluations of expected personal impacts and hazard intrusiveness which are related to personal experience with hazard events (Lindell and Perry, 2012). Hurricane experience has positive impacts on cognitive risk perception (e.g., "it is likely that Hurricane Julia will hit my residence" (Demuth et al., 2016: p. 332)) and negative affective risk perception (e.g., fear, worry, and anxiety), which may be reflected in perceived certainty positively. (See Morss et al., 2016, Demuth et al., 2016 for in-depth discussion on risk perception and experience). We hypothesize that:

- H1: *Hurricane* experience is positively related to the perceived certainty of time of hurricane impact and whether a respondent lives in an evacuation zone.

Due to different measurements of "experience," recent reviews rarely found consistent positive relationships between evacuation behavior and experience (Lindell et al., 2019) (see Huang et al., 2016; Lindell et al., 2019; Morss et al., 2016; Thompson et al. 2017 for details). Other elements of experience have been explored for their influence on evacuate/stay and route choices. Past evacuation experience and the emotional impact caused by a hurricane raise evacuation intentions, while property damage experience impedes evacuation intentions (Demuth et al., 2016). Route selection is dependent on evacuation experience (Lindell and Prater, 2007; Lindell et al., 2011; Sadri et al 2015) or previous route selection experience in general (Murray-Tuite et al., 2012). Based on these prior studies, we hypothesize that:

- H2: Hurricane *evacuation* experience is positively related to perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

Preexisting social vulnerability factors of households lead to the variation of capacity, information, power and resources households have during a disaster event and hence cause disparities in response (Cutter et al., 2003; Peacock et al., 2012). The conceptual model of how vulnerabilities lead to different disaster response is further discussed in Peacock et al. (2011). When looking at evacuation decisions overall, aged, lower-income groups are less likely to comply with warnings (Peacock et al., 2011). Some factors that repeatedly appear in hurricane evacuation behavior studies are: older age (Dash and Gladwin, 2007; Gladwin, 1997; Lindell et al., 2005;

Lindell et al., 2011), larger households (Golshani et al., 2019; Lindell et al., 2011), female (Fothergill, 1996; Golshani et al.; 2019; Lindell et al., 2011), and disability (Golshani et al., 2019; Hasan et al. 2013). However, due to predictive power and significance issues, they are not viewed as consistent predictors for evacuation (Lindell et al., 2019). But, they might play a role in evacuation decision processes (Ricchetti-Masterson and Horney, 2013; Huang et al., 2016).

Socially vulnerable families are associated with higher risk perception, however, they are also associated with lower levels of preparedness (Peacock et al., 2011). It is possible that although socially vulnerable households have raised awareness about hurricanes, due to lack of economic and social resources to cope with disaster, they may be less certain about their hurricane protective response. Older residents face challenges physically and mentally (fear of being away from family and friends) in an evacuation event (Fairchild et al., 2006). Even though they may be aware of the potential risk of hurricanes from past experience, they may not be certain if their needs can be fully accommodated at their evacuation destinations. For elders living in poverty, evacuation is more challenging due to a lack of financial resources.

We hypothesize that:

- H3.1: Socio-demographic factors potentially indicating higher social vulnerability (older age, larger households, female, medical needs) are positively related to perceived certainty topics of time of hurricane impact and whether a respondent lives in an evacuation zone.
- H3.2: Socio-demographic factors potentially indicating higher social vulnerability (older age, larger households, female, medical needs) are negatively related to perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

The importance of family considerations and cohesion is illustrated by Perry (1979) who found that evacuation is delayed until household members are together or missing members are known to be safe. Familial closeness was considered positively related to the probability of evacuation. Gladwin et al. (2001) recognized the importance of capturing intra-household discussion in evacuation decision making. Household members may have different opinions on evacuation decisions which are resolved through discussions (Gladwin et al., 2001). Familial communication coerciveness and control each family member has over the decision-making process affect the consensus and outcome (Godwin and Scanzoni, 1989; Gottman and Notarius, 2002). Frequent discussion could influence, positively, both the perceived hurricane/home characteristics certainty and protective response certainty. We hypothesize that:

- H4: Frequent household discussion is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.
- H5: A household's ability to make decisions under stressful situations is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

2.2 How do households' social networks and information sources affect perceived certainty?

How the public complies with warning information partially depends on their information sources, channels, and messages. Uncertainty drives households to seek further information from outside sources (Lindell and Perry, 2012). Once decisions are made, households avoid further information regarding feasibility or effectiveness of that decision (Goodall and Reed, 2013). This is also known as emotion-focused coping which reduces negative emotions (Lindell et al., 2019). Households' information seeking patterns, social networks and perceived certainty are intertwined in hurricane evacuation.

Lindell et al. (2011) identified local officials as an important source providing evacuation route information. Local TV was the most used information source for residents to check updates during and after a hurricane (Cutter et al., 2011). Local radio and television also promoted self-evacuation in Australian bushfires (Strahan et al., 2018). Local sources have the greatest credibility and increase evacuation compliance (Thompson et al., 2017). Ongoing discussions debate whether the source itself or the information disseminated through it promotes evacuation compliance (Huang et al., 2016; Lindell et al., 2019). Whether local sources are directly related to evacuation decisions or not, we anticipate that when households consult with local sources before or during the decision-making process, their certainty is influenced.

- H6: Using local information channels (local TV, radio, or print media) before or during the evacuation decision process is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

Official evacuation notices increase the evacuation rate, especially when residents have no doubts that the notice applies to them and are the strongest predictor of evacuation decisions (Baker, 1991, 2000; Huang et al., 2016). Strahan (2018) added that official warnings have a decisive effect when there is uncertainty or disagreement among household members. Considering the content that may be contained in an evacuation order (predicted hurricane impact time, evacuation zone, route information, and evacuation starting time), receiving a notice should increase the perceived certainty of time of hurricane impact, whether a respondent lives in an evacuation zone, and evacuation route. We hypothesize that:

- H7: Evacuation notices are positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, and evacuation route.

Information people receive from close contacts can raise social cues. Observations of close contacts taking action or preparing for a potential threat can promote evacuation (Lindell et al., 2019). Cutter et al. (2011) identified friends and neighbors as information sources that affect decision making. Lindell et al. (2011) also found close contacts to be considered reliable sources for older or female respondents. Consulting with close contacts could raise awareness of the potential hurricane threat. Recent studies identified how the source and the strength and quality of social networks that relay the warning information impact evacuation decision making (Sadri et al., 2017a). Other related studies explored the joint evacuation decisions of individuals in personal networks by using ego-centric social network data obtained from Hurricane Sandy (Sadri et al., 2017b). In this research, we extend these research efforts in a general sense and hypothesize that:

- H8: More frequent contacts within the social network before or during decision-making processes is positively related to certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

2.3 How does relative sequence of decisions affect evacuation logistics-related perceived certainty?

Households make multiple decisions before and during the evacuation process. Gladwin et al. (2011) performed an analysis of evacuation decisions using an ethnographic decision tree with 'Evacuate Now/Do not Evacuate' as two possible outcomes. However, their model was not able to capture how previous decisions could impact latter decisions.

We can categorize households' decisions depending on the time horizon. Strategic decisions are for long term, tactical decisions are for medium term, and operational decisions are for short term (Schadchneider et al., 2009). This partitioning approach was taken by Schadschneider et al. (2009) in the context of pedestrian and evacuation dynamics. Pedestrians' desire to evacuate is treated as a strategic goal while body motion to avoid collision is treated as tactical decision. Studies of drivers' behavior have a similar approach of viewing decisions from a hierarchical perspective, where strategic decisions of the higher level are trip planning related and operational and tactical decisions execute the plan (speed, passing, etc) (Michon 1979; Kilpeläinen and Summala, 2007). Based on this idea of partitioning evacuation logistics into decision levels, we hypothesize that:

- H9.1: Making the evacuation departure time decision before the mode decision is negatively related with certainty of when to evacuate and travel mode.
- H9.2: Making the evacuation destination decision before the mode decision is positively related with certainty of destination and travel mode.
- H9.3: Making the evacuation mode decision before the route decision is positively related with certainty of travel mode and route.

3. Data and Methods

In 2017, a self-administered mail survey (with an online option) was distributed to 5,000 households in the Jacksonville metropolitan area, following Dillman et al.'s (2014) four-wave survey procedure. Survey questions were designed to capture households' Hurricane Matthew (2016) evacuation-related decisions, information sources, social network characteristics, family characterization, certainty levels, and socio-demographic characteristics. There were 498 respondents present in the overall dataset. Individuals who were older and/or female and with higher education levels were oversampled, relative to Census reports. An overview of the data is provided in Table 1.

3.1 Weights

To offset the bias, weights are introduced. Rake weighting takes multiple demographic variables and compares the variables in each observation to the frequencies in the population. Weights are applied to the observations based on the comparisons, with the goal of making the observed distribution closer to the real distribution (Daza, 2019). Since "raking" is conducted on a chosen set of uncorrelated demographic variables, other variables confirm whether the procedure had the desired effect (Kennedy et al., 2018). In this study, gender (female or male), education level (4-year degree or lack thereof), and age group (18 to 44, 45 to 59, and 60+) are chosen for the raking procedure, using 2016 demographic data from the American Community Survey (Data USA, 2017; U.S. Census Bureau, 2017). The marital status (married or not married) and income (six levels) variables were then available for bias reduction testing. Weighting, on average, reduced the bias to 10.2% compared to the original dataset which had a bias of 14.5%.

3.2 Percent of Maximum Possible Score Transformation

Certainty questions were asked in a Likert-scale format from 1 (not at all certain) to 5 (very certain). Similarly, household cohesion questions were framed based on how well statements described family interactions: from 1 (not at all) to 5 (very well). Two of the questions were: “In stressful situations, my family can figure out what to do” and “My family members always share information with each other.” These data are quantitative measures with numerical intensity and intervals; they can be treated as continuous variables if they have five or more response levels (Norman et al., 2010). For analysis purposes, both certainty and cohesion variables were linearly transformed into percent of maximum possible score. This conversion does not affect the F statistic, t score, or R^2 for the model but provides a more easily understood metric (Cohen et al., 1999).

3.3 Evacuation Logistics-Related Decision Sequence Variables

Respondents were asked to report their travel-related decisions starting with 1 for the first decision. If decisions were made simultaneously, the same number was assigned. Decisions included evacuation, departure time, accommodation, destination, travel mode, and route. The difference between the recorded numbers was calculated to account for the relative sequence. For example: one of the relative sequences was departure time decision before mode; the difference between their numbers ranged from -5 to 5. Any number less than zero indicated that the mode decision was made before the departure time decision. These numbers were then recoded into 0 and positive numbers were coded into 1 indicating the departure time decision was made before mode. These dummy variables were tested in the corresponding certainty topics: when to evacuate, evacuation mode, route, and destination.

3.4 Information Sources Variables

Respondents identified the time frame for accessing different information sources. We created a set of dummy variables indicating whether each source was used before or during the evacuation decision process (compared to not at all or after decisions were made). A quantitative variable of how many times per day respondents consulted the source was also interacted with these dummy variables.

3.5 Methods

Weighted Ordinary Least Square (WOLS) regressions were developed with IBM SPSS Statistics 25 for different certainty topics. (For details on linear regression modeling and parameter estimation, see Tasker, 1980.) WOLS regression assigns calculated weights to each observation to generate unbiased parameter estimates (Winship and Radbill, 1994). Socio-demographic variables and information sources that we hypothesized to be significant were all tested in models. Strongly correlated variables (0.4 or greater) were not included in the same model (see Table 4). A manual backward stepwise-based method was employed to eliminate non-significant independent variables one at a time.

Table 1. Summary of Variables

Category	Variable and Description	N	Min	Max	Mean	Std. Deviation
Certainty (dependent variables)	*EvacZone:* Percentage of perceived certainty level for whether or not respondent lives in an evacuation zone. From 0 (not certain at all) to 100 (very certain)	473	0	100	84.30	28.84
	TimeofImpact: Percentage of perceived certainty level for hurricane impact time	463	0	100	74.13	27.41
	Timetoprepare: Percentage of respondent's perceived certainty level for time needed to prepare for evacuation	449	0	100	74.94	29.57
	WhenEvac: Percentage of respondent's perceived certainty level for evacuation time	442	0	100	74.43	30.34
	Mode: Percentage of perceived certainty level about mode used for evacuation	428	0	100	70.73	36.42
	Route: Percentage of perceived certainty level about evacuation route	425	0	100	84.58	28.54
	Destination: Percentage of perceived certainty level about evacuation destination	426	0	100	74.64	33.47
Experience[1]	HurricaneExp: Dummy variable: 1 if respondent has any hurricane experience, 0 otherwise	382	0	1	0.81	0.39
	HurrExp_Hit: Dummy variable: 1 if respondent lived in an area that has been affected by a hurricane, 0 otherwise	382	0	1	0.27	0.44
	HurrExpStayHit: Dummy variable: 1 if respondent stayed in an area that has been advised to evacuate and hurricane hit, 0 otherwise	382	0	1	0.22	0.41
Social-Demographics and Vulnerability	Male: Dummy variable: 1 if respondent's gender is male, 0 otherwise	477	0	1	0.39	0.48
	Married: Dummy variable: 1 if respondent is married, 0 otherwise	477	0	1	0.68	0.46
	HHsize: Size of respondent's household	481	1	8	2.25	1.17
	Und18yr: Number of children in respondent's household	481	0	6	0.36	0.84
	Adult18_65yr: Number of adults in respondent's household	481	0	6	1.28	1.08
	Medicalneeds: Dummy variable: 1 if there is anyone with medical needs in the household, 0 otherwise	472	0	1	0.18	0.38
	YrsinCommunity: Years respondent has lived in current community	480	0	63	14.36	12.54
	Vehicle: Dummy variable: 1 if personal vehicle(s) was used for evacuation, 0 otherwise	215	0	1	0.98	0.15
Information Sources	Official Notice[2] — Officialnotice: Dummy variable: 1 if a mandatory or voluntary evacuation warning is received, 0 otherwise	414	0	1	0.61	0.48
	Official Notice[2] — MandatoryNotice: Dummy variable: 1 if a mandatory evacuation warning is received, 0 otherwise	414	0	1	0.39	0.48
	Modealternum: Total number of close contacts that provided mode related information	350	0	5	0.67	1.14
	Networksize: Size of respondent's close contact network	350	1	5	2.63	1.43
	Bdpeople: Dummy variable: 1 if consulted with close contacts before/during decision-making process as an information source, 0 otherwise	475	0	1	0.64	0.48
	Bdsomedia[3]: Dummy variable: 1 if news sources on social media were used before/during the decision-making process, 0 otherwise	475	0	1	0.38	0.48
	Bdonline[3]: Number of online sources that were used before/during the decision-making process	475	0	2	0.72	0.85
	Bdonline_d[3]: Dummy variable: 1 if any online source was used before/during the decision-making process, 0 otherwise	475	0	1	0.46	0.49

	Freqsomedia_bd: Frequency of checking news source on social media every day interacted with if news sources on social media were used before/during the decision-making process.	477	0	100	2.70	8.66
	Freqlotv_bd: Frequency of checking local TV every day interacted with whether local TV was used before/during decision-making process	475	0	100	7.31	10.02
Relative Decision Sequence	Departbeforemode: Dummy variable: 1 if departure time is chosen before evacuation mode, 0 otherwise	201	0	1	0.37	0.48
	Destinationbeforemode: Dummy variable: 1 if destination is chosen before mode, 0 otherwise	202	0	1	0.73	0.44
	Modebeforeroute: Dummy variable: 1 if evacuation mode is chosen before route, 0 otherwise	199	0	1	0.58	0.49
Family Cohesion	Infosharing: Percentage of how well the statement 'My family members always share information with each other' described respondent's household	427	0	100	82.08	22.48
	HHundstress: Percentage of how well the statement 'In stressful situations, my family can figure out what to do' described respondent's household	422	0	100	86.84	20.21

Note:

1. This set of variables is derived from same survey question about hurricane experience; these variables were individually tested. The selected variable in each model explains the most variation.
2. This set of variables is derived from same survey question about hurricane evacuation notices; these variables were individually tested. The selected variable in each model explains the most variation.
3. *bdonline* emerged from two dummy variables, internet only media and news sources on social media, to record the number of online sources respondents used. *Bdonline_d* was derived from *bdonline* indicating if any online sources were used. *Bdonline, bdonline_d, bdsomedia* were individually tested in each model.

Table 2. Correlation Table

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1. HurricaneExp	1.00																									
2. HurrExp_Hit	.633**	1.00																								
3. HurrExpStayHit	0.10	0.11	1.00																							
4.Officialnotice	-0.01	-.101*	-0.03	1.00																						
5. MandatoryNotice	0.02	0.01	0.06	.169**	1.00																					
6. Male	0.03	-0.09	0.01	.093*	-0.05	1.00																				
7. Married	0.03	-0.08	0.06	0.07	-0.06	.760**	1.00																			
8. HHsize	-.192**	-.215**	-0.10	.092*	-0.04	.226**	.297**	1.00																		
9. Und18yr	-0.04	-.118*	0.06	0.03	.386**	-0.05	-0.03	0.00	1.00																	
10. Adult18_65yr	-0.03	-.104*	0.01	0.01	.114*	-0.07	-0.02	0.01	.754**	1.00																
11. medicalneeds	-0.04	-0.06	0.02	-0.02	.256**	-0.04	-0.06	0.00	.620**	.234**	1.00															
12. Yrscurrent	-.121*	-.127*	0.05	-0.01	0.03	0.08	0.09	0.03	-0.03	-0.08	-0.05	1.00														
13. Vehicle	-0.08	-0.10	0.05	-0.04	-.141**	0.01	-0.01	-.095*	-.131**	-.171**	-.182**	0.09	1.00													
14. Modealternum	0.02	-0.01	.379**	-.122*	0.01	-0.04	-0.01	-0.08	-0.03	-0.02	-0.03	0.10	-0.03	1.00												
15. Networksize	0.05	0.00	0.04	-0.03	.092*	-0.01	0.05	0.07	0.05	0.02	0.06	-0.06	-0.06	.128*	1.00											
16. Bdpeople	-0.01	0.07	-0.02	0.02	0.06	-0.05	0.00	.126**	.105*	0.05	.149**	0.01	-.120**	.205**	.357**	1.00										
17. Bdsomedia	0.03	0.04	-0.03	0.05	0.07	-0.04	0.04	.146**	.112*	0.05	.144**	-0.01	-.104*	.197**	.358**	.889**	1.00									
18. Bdonline	0.03	0.05	0.02	0.02	0.07	-0.02	0.05	.132**	.152**	0.07	.187**	0.02	-.096*	.169**	.351**	.852**	.918**	1.00								
19. Bdonline_d	0.06	0.05	.136*	0.01	0.03	-0.07	-0.02	0.08	0.09	0.08	.135**	-0.03	-.108*	.121*	.166**	.397**	.297**	.339**	1.00							
20. Freqsomedia_bd	0.09	.103*	0.08	-0.04	-0.05	-0.02	0.00	-0.03	0.06	0.01	.134**	-0.01	0.04	-0.05	.160**	.153**	.116*	.149**	.350**	1.00						
21. Freqlotv_bd	0.04	0.03	-0.03	0.11	.249**	-0.07	-0.02	-0.07	.167*	0.06	.151*	-0.09	-.149*	0.03	.156*	.137*	.153*	.170*	0.05	0.02	1.00					
22. departbeforemode	-0.12	-0.06	-0.08	-0.06	-.232**	-0.04	-0.05	0.02	-0.02	0.02	-.164*	0.07	0.05	-0.11	-.187**	-0.12	-0.09	-.142*	-0.12	-0.06	-0.11	1.00				
23. destnmodeseq	-.153*	0.00	0.09	0.04	0.01	0.01	-0.03	-0.04	-0.04	-0.06	-0.04	-0.09	.165*	0.14	-0.10	0.13	.166*	0.13	0.09	0.07	0.02	.192**	1.00			
24. modebeforeroute	-0.01	0.02	-0.06	-.147*	-0.13	-0.03	-0.11	-0.07	-0.05	0.02	-.162*	-0.03	0.12	0.07	-.151*	-0.03	-0.01	0.01	-0.13	-0.03	-0.12	.239**	.314**	1.00		
25. Infosharing	0.06	0.00	-0.10	-0.01	0.07	0.04	0.00	-0.02	0.08	0.03	0.06	0.04	0.01	-0.03	0.01	-0.01	0.00	-0.01	-0.02	0.05	-0.02	-0.09	-0.07	0.07	1.00	
26. HHundstress	-0.02	0.02	-0.04	-0.03	0.06	0.07	0.05	0.07	0.04	-0.02	0.05	-0.01	0.01	-0.08	-0.05	0.04	0.03	0.05	-0.05	-0.01	0.00	-0.14	-0.03	0.02	.593**	1.00

Note: ** p < .05, * p <.1

Table 3. Linear Regression Model Specification for Certainty

Variable	EvacZone	TimeofImpact	Timetoprepare	WhenEvac	Mode	Route	Destination
	Coeff. (SE)	Coeff. (SE)	Coeff. (SE)	Coeff. (SE)	Coeff. (SE)	Coeff. (SE)	Coeff. (SE)
Intercept	34.972***(7.37)	29.076**(10.13)	18.441**(8.59)	12.353(13.05)	30.572*(17.06)	23.439**(9.93)	66.665***(6.07)
HurricaneExp	15.622**(4.65)	18.381**(5.25)			-8.063**(2.58)		-17.147***(4.11)
HurrExp_Hit			15.388***(3.38)				
HurrExpStayHit				12.256**(5.11)			
Male				-13.07**(4.47)			
Married	10.423**(3.07)						
HHsize		-4.105**(1.44)					-5.052***(1.41)
Und18yr						-5.641**(2.19)	
Adult18_65yr			4.525**(1.69)				
medicalneeds		9.888**(4.28)	7.926**(3.96)	20.293***(5.52)			
Yrscurrent			0.602***(.144)			0.785***(.19)	
Vehicle					57.312**(16.96)		
Officialnotice		12.256***(3.20)		21.964***(5.33)			
MandatoryNotice	18.451***(3.21)		7.728**(3.25)				
Modealternum					-.2.442**(.78)		
Networksize		3.203**(1.21)					
Bdpeople				20.976***(4.55)	9.916***(2.20)	16.268***(4.00)	19.931***(3.64)
Bdsomedia			-10.028**(3.05)		3.680*(1.87)		
Bdonline						8.432**(2.46)	
Bdonline_d							9.820**(3.53)
Freqsomedia_bd	-0.854***(.20)						
Freqlotv_bd				-0.557**(.158)			
departbeforemode				11.94**(4.62)			
destnmodeseq					7.712**(2.52)		30.723***(4.02)
modebeforeroute						16.566***(3.66)	
Infosharing	0.290***(.07)	0.281**(.08)					
HHundstress			0.456***(.09)	0.327**(.11)		0.262**(.09)	
Model Statistics							
R^2	.208	.212	.229	.403	.325	.381	.484

Adjusted R^2	.196	.192	.211	.369	.296	.356	.469
F	16.53***	10.63***	12.59***	11.74***	11.01***	15.77***	33.00***
n	323	243	304	147	143	160	181

[1]Note: *** p < .001, ** p < .05, * p <.1

Table 4. Models Testing Hypotheses (1)

Variable	EvacZone		TimeofImpact		Timetoprepare		WhenEvac		Mode		Route		Destination	
	Coefficient		Coefficient		Coefficient		Coefficient		Coefficient		Coefficient		Coefficient	
Intercept	28.30**	44.22***	28.68**	38.97**	46.06**	28.06**	22.85	14.52	-3.80	-7.85	39.02**	36.112**	68.25***	60.18***
MandatoryNotice	17.94***	-			-	6.09*(5)								
Modealternum									-3.81***	-3.31**				
Married	10.10**	10.128**												
HurrExpStayHit							14.3**	-						
HurrExp_Hit					14.95***	-								
Und18yr											-5.91**	-		
Adult18_65yr														
Yrscurrent					0.53***	0.71***					0.68**	0.68***		
Networksize			3.24**	2.96**										
Bdsomedia					-6.72**	-7.5**			2.563*	3.99*				
Bdonline											5.87**	6.45*		
Bdonline_d													10.01**	10.33**
Freqsomedia_bd	-0.88**	-0.722**												
Freqlotv_bd							-0.65***	-0.598***						
Vehicle									92.66***	99.01***				
H1HurricaneExp	16.88**	-	18.65**	-	14.945*** (6)	-	14.301** (7)	-	-10.26***	-	4.36	-	-16.29***	-
H2 evac exp	-	0.595(2)	-	14.58*** (2)	-	-3.84(2)	-	6.20(2)	-	0.41	-	6.75	-	-0.17
H3 Over_65yr	1.83	1.34	1.59	2.73	-0.988	0.90	-3.92	2.61	2.03	1.14	11.71	2.51	0.084	0.76
H3 Male	2.81	1.84	-2.66	-2.48	-0.06	0.85	-16.78**	-15.26**	-5.98	-5.78	8.93	9.32	-0.3	0.44
H3 HHsize	-1.31	-1.45	-4.02**	-3.69**	0.37	-0.09	-3.89	-2.79	-1.11	-1.16	-	-3.37*	-4.28**	-3.88*

H3 medicalneeds	-3.40	-0.49	9.59*	9.51**	5.66*	6.04*	24.16***	18.70**	-.19	-3.21	-7.16	-8.84	-10.32	-14.02
H4 Infosharing	0.32**	-	0.285*	-	0.26**	-	0.228**	-	.081	-	0.07*	-	-0.04	-
H5 HHundstress	-	0.29** (3)	-	0.29** (3)	-	0.47*** (3)	-	0.348** (3)	-	0.069	-	0.19*	-	-0.04
H6 bd local info.	4.49	1.53	-0.26	-2.04	1.72	3.27	4.89	4.46	2.14	1.12	5.91	4.87	1.046	1.96
H7 official notice	-	12.41*** (4)	12.36***	10.81**	2.89	-	28.71***	22.864***	1.65	-1.37	-4.32	-4.94	-2.67	-2.51
H8 bdpeople	3.45	4.87	0.52	0.42	8.73**	8.98**	23.33***	20.353***	9.28***	4.64*	15.47*	14.70**	17.96***	13.25**
Variable	EvacZone		TimeofImpact		Timetoprepare		WhenEvac		Mode		Route		Destination	
	Coefficient		Coefficient		Coefficient		Coefficient		Coefficient		Coefficient		Coefficient	
H9.1 departbeforemode	NA		NA		NA		11.11**	13.19**	-5.87	-7.51	NA		NA	
H9.2 destnmodeseq	NA		NA		NA		NA		6.42**	-	NA		29.854***	30.53***
H9.3 modebeforeroute	NA		NA		NA		NA		-	2.38 (2)	16.79***	16.27***	NA	
Model Statistics														
R^2	0.22	0.14	0.22	0.21	0.16	0.17	0.41	0.41	0.40	0.42	0.39	0.40	0.55	0.51
Adjusted R^2	0.19	0.11	0.18	0.18	0.13	0.15	0.35	0.35	0.35	0.35	0.34	0.35	0.51	0.47
F	7.96	4.59	6.34	6.21	5.71	6.28	8.46	8.46	8.29	5.47	7.28	7.61	15.15	12.61
p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
n	314	314	241	241	303	304	146	146	147	116	144	145	146	146

Note: *** p < .001, ** p < .05, * p <.1.

(1): Due to high correlation between variables, separate models were created to examine our hypotheses; (2): Examined in a second model due to high correlation with hurricane experience (3): Examined in a second model due to high correlation with household information sharing; (4): Examined in a second model due to high correlation with mandatory notice; (5): Examined in a second model due to high correlation with official notice; (6): Experience related variable used was when a hurricane hit the community; (7): Experience related variable used was when a hurricane hit the community and respodent stayed.

4. Results

Although the seven dependent variables are highly correlated (0.305-0.785), we model them separately to identify factors that differ across the models (Table 3). Adjusted R^2 values range from 0.196 to 0.469, indicating tolerable predictive power and that differences exist across the certainty topics. Across all models, F tests indicate that the models are better than intercept-only models. The correlations between variables are presented in Table 2. Models that include non-significant hypothesis variables are presented in Table 4.

4.1 Perceived Certainty of Evacuation Zone

The model for evacuation zone certainty with five independent variables explains 20.8% of the variance (see Table 3). Prior hurricane experience has a positive impact on certainty about living in an evacuation zone. Any hurricane experience may cause respondents to be more aware of their community and be more certain about whether they live in an evacuation zone. Being married has a positive impact on certainty about living in an evacuation zone. Married couples are more home-conscious and could have more intra-household conversations about the hurricane which could lead to greater zone certainty. Mandatory evacuation notices have a positive impact on respondents' perceived certainty that they live in an evacuation zone. These notices often identify evacuation zones, so respondents who are exposed to this information may be more certain about being in an evacuation zone or not. More frequent checking of news from social media before or during evacuation decision-making has a negative impact on certainty. A possible reason for this is information overload (Milord and Perry, 1977), where respondents could be confused by large quantities of information. Another possibility is that self-reported media usage is rarely accurate (Scharkow et al., 2016), more often respondents over-report internet use which could cause the opposite sign compared to our hypothesis. The more respondents think that the statement, ‘my family members always share information with each other’, describes their households, the greater zone certainty they have. Communicating with significant others or household members both increase certainty; these discussions possibly help respondents to reaffirm their evacuation zone knowledge.

4.2 Perceived Certainty of Time of Hurricane Impact

This model with six independent variables explains 21.2% of the variance. Prior hurricane experience increases certainty about the hurricane’s impact timing. Households with hurricane experience are more acutely aware of the hurricane threat and more convinced about the potential hurricane impact which in turns increase time of impact certainty. Household size is negatively associated with certainty about the time of hurricane impact. This could be due to the multiplicity of opinions among household members. Having a household member with medical needs is positively associated with hurricane impact time certainty. Such households could be more aware of hurricane impact time for planning purposes, increasing their certainty. Receiving voluntary or mandatory evacuation notices increases certainty for the time of hurricane impact. Evacuation notices often include recommended start times, which helps households get a general sense of the potential landfall time. Having a larger social network is positively associated with certainty about hurricane impact time, as people in their social networks can confirm and exchange information with the respondent. Households constantly discussing and sharing hurricane information are positively associated with certainty about hurricane timing.

4.3 Perceived Certainty of Time for Evacuation Preparation

This model with seven independent variables explains 22.9% of the variance. Respondents’ hurricane experience contributes to awareness of the hurricane (Baker, 1991). Having lived in a community that was previously advised to evacuate and was hit by a hurricane is positively associated with certainty about time to prepare. Potentially, this prior experience raised respondents' threat awareness and encouraged them to plan for evacuation, which leads to greater certainty. More adults in a household is positively associated with greater certainty for preparation time, as is a household who can stick together in a stressful situation and figure out what to do. Having a household member with special medical needs is positively associated with preparation time certainty; potentially, such households plan early, increasing their preparation time certainty. Respondents' preparation time certainty increases as the years lived in the current community increases, potentially because they are more familiar with the surroundings and packing from that residence. Receiving a mandatory evacuation notice is positively associated with preparation time certainty. These notices may allow respondents more time to prepare and think about preparation activities, increasing their certainty. Checking news from social media sources before or during the decision process is negatively associated with respondents' certainty; when checking these news channels for information, respondents may encounter comments that cause worry, or receive contradictory (highly variable) information for how much time they need to prepare.

4.4 Perceived Certainty of When to Evacuate

This model with seven independent variables explains 33.8% of the variance. Failure to evacuate for a past hurricane is positively associated with this certainty; such experience may have caused respondents to plan for evacuation more carefully this time, increasing certainty. Having a household member with special medical needs is positively associated with certainty about evacuation timing. Households with special-needs members are more likely to prepare for evacuation (Uscher-Pines et al., 2009). Being male is negatively associated with this certainty. Females perceive potential environmental threats better than males (Fothergill, 1996) and are more risk averse than males (Lindell et al., 2019), which may partially explain why males are less certain of when to evacuate. Evacuation notices (mandatory or voluntary) are positively associated with certainty about when to evacuate, potentially because they are often accompanied with advice on when to evacuate. Consulting close contacts before or during the decision making process is positively associated with certainty about when to evacuate. In social comparison theory, one person's certainty impacts another's; when facing uncertainty humans compare themselves to others who are in the same situation and behave similarly for self-affirmation (Festinger, 1954). Close contacts can be used to solidify and confirm respondents' decisions and increase their certainty. Use of local TV, interacted with frequency of this use, is negatively associated with certainty about when to evacuate. Although use of local TV is expected to increase certainty, frequent updates or presenting conflicting results from different hurricane models could decrease certainty. Households who can figure out what to do under stressful situations are positively associated with departure time certainty. Making the departure time decision before evacuation mode is positively associated with certainty about when to evacuate.

4.5 Perceived Certainty of Evacuation Mode

This model with six independent variables explains 32.5% of the variance. Evacuation experience is negatively associated with mode certainty. Respondents with this experience could be aware of alternatives other than driving personal vehicles, such as renting a car, taking transit, or obtaining a ride from peers. Having access to personal vehicles is positively associated with mode certainty and has a large coefficient, suggesting that if they have a personal vehicle, they are fairly certain they will use it to evacuate, as personal vehicle is the most often preferred mode for evacuation (Lindell et al., 2019). Consulting close contacts and news on social media before or during the decision-making process is positively associated with mode certainty. However, the certainty decreases when the number of close contacts offering mode related information increases, potentially due to information overload causing confusion when making a decision (Cohen, 1980). In addition, mode choice certainty increases if the destination is selected before the mode. The modes available to a given destination could be limited, narrowing the alternatives and increasing certainty, or the respondent could be more experienced using a particular mode to reach their destination, also increasing mode certainty.

4.6 Perceived Certainty of Evacuation Route

This model explains 28.1% of variance with six independent variables. Greater numbers of children in the household are negatively associated with route certainty; 19% of the households reported the presence of children. Evacuation trips involving children can decrease route certainty as parents need to plan for unexpected stops and potential rerouting for younger children (e.g., restrooms, food stops). Longer durations of living in the current community are positively associated with route certainty. Greater familiarity with the home and surrounding environment could increase the route certainty. Using online and close contacts as information sources before or during the evacuation decision process is positively associated with route certainty. Obtaining route and destination information from close contacts is negatively associated with route certainty. Sixty-one percent of respondents in the survey chose to stay at a peers' home for evacuation lodging. Communicating with more people could yield more potential routes and destinations and thus lead to a decreased evacuation route certainty. Selecting a transportation mode before the route is positively associated with route certainty. Finally, a household who can figure out what to do under a stressful situation is positively associated with route certainty, potentially due to a lack of differing opinions.

4.7 Perceived Certainty of Evacuation Destination

The evacuation destination certainty model explains 48.4% of the variance with five independent variables. Previous hurricane experience is negatively associated with destination certainty. Baker (1991) suggested that previous hurricane experience contributes to awareness of the danger. When decision-makers have been exposed to a hurricane, they may become more aware of potential evacuation destinations decreasing certainty. Another reason for the negative impact could be concern about peers' ability to accommodate the whole household. Smith and McCarty (2009) found that household size negatively impacts the decision of staying at a peer's home. The decision maker may then use their close contacts before/during decision-making process to increase their destination certainty. For the 33 percent of households who stayed in a hotel/motel, the internet could be used to check the availability of these accommodations, potentially explaining the positive effect of online sources on destination certainty. When the destination is selected before the transportation mode, destination certainty significantly increases.

5. Discussion of Hypotheses

This discussion is based on the hypotheses. See Table 4 for models including non-significant hypothesis variables.

- H1: Hurricane experience is positively related to the perceived certainty of time of hurricane impact and whether a respondent lives in an evacuation zone.

H1 is supported; any hurricane experience increases respondents' certainty in these two topics. Time to prepare and when to evacuate also showed positive and significant relationships with hurricane experience variables. These experience variables were kept in the final models since they add predictive power.

- H2: *Evacuation* experience is positively related to perceived certainty of time to prepare for evacuation; when to evacuate; evacuation mode; evacuation route; and evacuation destination.

H2 is rejected. No significant relationship between perceived certainty of hurricane evacuation logistics and evacuation experience was found. However, this hypothesis is supported for the perceived certainty of *time of hurricane impact*. This variable is not in the final *time of hurricane impact* model because evacuation experience and any hurricane experience are highly correlated, and any hurricane experience is able to explain more variance for the certainty of time of hurricane impact.

- H3.1: Socio-demographic factors potentially indicating higher social vulnerability (older aged household members, larger households, female gender, medical needs) are positively related to perceived certainty topics of time of hurricane impact and whether a respondent lives in an evacuation zone.

- H3.2: Socio-demographic factors potentially indicating higher social vulnerability are negatively related to perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

Testing for these hypotheses is split into four variables (number of household members over 65 years old, male gender, household size, and if there is anyone with medical needs in the household) to examine relationships with certainty topics. H3.1 is partially supported as having a family member with medical needs is positively related to perceived certainty of *time of hurricane impact*. Household size, on the other hand, shows significant negative association. Larger households may have greater numbers of information receivers and after exchanging potentially conflicting information, respondents are less certain. Male gender and older age have no significant association with the perceived certainty of *time of hurricane impact.* H3.1 is rejected in the *whether a respondent lives in an evacuation zone* certainty model.H3.2 is partially supported. Larger household size is negatively related to perceived certainties of *route*, and *destination*, supporting H3.2. The number of children is highly correlated with household size (0.754) and is negatively associated with perceived certainty of *route*. Contrary to expectations, male gender is negatively related with certainty in the *when to evacuate* model. Having household members with medical needs is the only factor positively related to certainty of time to prepare and when to evacuate, rejecting H3 for these contexts.

- H4: Frequent household discussion is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

- H5: A household's ability to make decisions under stressful situations is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

These two hypotheses are partially supported. Although they are not significant in all certainty models, their effects on perceived certainty are positive in: *evacuation zone*, *time of impact*, *time to prepare*, *when to evacuate*, and *route*. Due to high correlation (0.593) between these two variables, we select the one that explains more variance. The result is consistent with the literature that found households' evacuation behavior is positively related to cohesion and intra-household discussion (Perry, 1979), which may translate into certainty for the details of a household evacuation plan.

- H6: Using local information channels (local TV, radio, or print media) before or during the evacuation decision process is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

H6 is rejected. The dummy variable indicating whether the respondent checked any local information source during or before the evacuation decision does not have a significant relationship with certainty in this study. Only frequency of checking local TV before or during evacuation decision-making is significant and negatively related to certainty of *when to evacuate*. Self-reported media and internet usage is assumed to be accurate in this study, however, previous literature indicated that these values may not be exactly accurate (Boase and Ling, 2013). Over-reporting is more common than under-reporting for internet usage, TV accuracy is related to the actual usage, and the accuracy of self-reporting varies systematically across different socio-demographic groups (Wonneberger and Irazoqui, 2017).

- H7: Evacuation notices are positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, and evacuation route.

H7 is fully supported in three certainty models: *evacuation zone, time of impact,* and *when to evacuate*. This is consistent with literature that found official notices increase the evacuation rate (Baker, 1991, 2000; Huang et al., 2016). This also suggests that the messages conveyed in the evacuation notices increased certainty about their location's risk, hurricane timing, and departure time relative to the hurricane's impact.

- H8: Consulting close contacts before or during decision-making processes is positively related to certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

H8 is supported in five certainty topics: *time to prepare, when to evacuate, mode, route, and evacuation destination*. This is consistent with prior literature suggesting close contacts are significant information sources that affect evacuation decision making (Cutter et al., 2011; Lindell et al., 2019). Close contacts may also offer suggestions based on their experience and resources. Note that the close contacts are not associated with more scientific (hurricane impact time) and geographic (evacuation zone) certainty.

- H9.1: Evacuation departure time decision before the mode decision is negatively related with certainty topics of when to evacuate and evacuation mode.
- H9.2: Evacuation destination decision before the mode decision is positively related with certainty topics of evacuation destination and evacuation mode.

- H9.3: Evacuation mode decision before the route decision is positively related with certainty topics travel mode and route.

We anticipate that, for evacuation, several decisions fall within the strategic level, and within this set, the decisions fall between the highest strategic level and approaching the tactical level. We consider households' first level of strategic decisions as the choice to evacuate or stay. Later decisions during the planning phase help achieve this first strategic decision. Evacuation destination would be a higher-level decision compared to evacuation mode since the mode identifies how to get to destination. Evacuation route and departure time may be the last to be determined and could be considered tactical decisions. They are highly dependent on the current traffic and weather conditions and could be updated even during the evacuation process. The relative sequence indicates that the latter decision will not be reached until after the former.

From our results, departure time decision before mode decision is positively associated with *when to evacuate* certainty. The sign of the association is the opposite as what was hypothesized. It is possible that when to evacuate is more strategic than evacuation mode. In terms of *mode* certainty, the second part of H9.1 is rejected because of non-significance. H9.2 is fully supported. Mode decision before route decision is positively related with *route* certainty, supporting the second part of H9.3, however it showed a non-significant association with mode, rejecting the first part of H9.3. From these results, relative sequences of decisions could potentially extend current understanding of household behavior, though this set of variables is not always consistent across different certainty models (See Table 4 H9.1-H9.3). To the knowledge of authors, no former literature investigated the relationship between relative decision sequences and certainty.

6. Archetypes

The previous analysis provides an understanding of different perceived certainty topics with variables related to social networks and socio-demographics. In this part of the study, we categorize households into different archetypes based on their demographics, social networks, household characteristics, and decision sequences. Table 5 highlights variables that helped form different archetypes. Estimated certainty values (Figure 1) are calculated for each archetype. To simplify the analysis, variables that are not highlighted are assigned the mean value from the survey. The aim of the archetype analysis is to help policy makers to find marginalized groups who are more vulnerable in a natural disaster.

6.1 Active Information Seekers (AIS)

Active Information Seekers are characterized as gathering information. They perceive official notices as trustworthy and use more information sources to solidify their beliefs. A disadvantage to AIS is that checking information sources too frequently decreases *evacuation zone* and *when to evacuate* certainty (see Table 3). AIS are portrayed as newcomers to the area; they utilize many information sources and close contacts to overcome their unfamiliarity with the area or inadequate knowledge about hurricanes.

6.2 Hurricane Experienced Residents (HER)

Hurricane Experienced Residents have prior hurricane experience which leads to higher perceived hurricane risk. HER plan for evacuation more carefully and take collective opinions from the whole household in decision making. Their relative decision-making sequences are: departure time before mode, destination before mode, and mode before route. They have greater familiarity with the community because they lived there for 20-30 years. HER share evacuation related information frequently and make decisions together.

6.3 Socially Vulnerable Households (SVH)

Socially Vulnerable Households are more likely to be negatively affected by hazards. We portrayed SVH as headed by unmarried females. They have larger household sizes (8 people) and household members with medical needs that need to be considered. SVH have no access to personal vehicles.

6.4 Archetype Discussion

AIS utilize all possible information sources and receive an official evacuation notice. Close contacts play an important role, increasing certainty between 9.9% and 19.9%. The more complicated information sources are the internet and news channels on social media as they have mixed effects across models. News channels on social media decrease certainty of *time to prepare* by 10% for AIS. AIS' *route* certainty increases by 16% when they check both internet-only media and news on social media. Compared to non-active information seekers, AIS have 21% higher certainty on average across the seven certainty types. The only negative effect is in *time to prepare* where active information seeking behavior leads to a 2.3% certainty decrease.

Table 5. Archetypes Comparison

Certainty	Evacuation Zone	Time of Impact	Time to Prepare	When to Evacuate	Evacuation Mode	Evacuation Route	Evacuation Destination
Active Information Seekers							
Official Notice Related	MandatoryNotice=1	OfficialNotice=1	OfficialNotice=1	OfficialNotice=1	-	-	-
Information Source	Freqsomedia_bd=6	Networksize=5	Bdsomedia=1	Bdpeople=1 Freqlotv_bd=10	Bdpeople=1 Bdsomedia=1	Bdpeople=1 Bdonline=2	Bdpeople=1 Bdonline_d=1
Estimated %	91.84	87.84	75.76	83.78	87.22	96.93	93.59
Hurricane Experienced Residents							
Hurricane Experience	HurricaneExp=1	HurricaneExp=1	HurrExp_Hit=1	HurrExpStayHit=1	HurricaneExp=1	-	HurricaneExp=1
Household Cohesion	Infosharing=100	Infosharing=100	HHundstress=100	HHundstress=100	-	HHundstress=100	-
Household Characteristics	-	-	Yrscurrent=30	-	-	Yrscurrent=20	-
Relative Decision Sequence	-	-	-	Departbeforemode=1	Destnmodeseq=1	Modebeforeroute=1	Destnmodeseq=1
Estimated %	91.57	84.00	99.69	90.55	92.49	96.36	86.15
Socially Vulnerable Households							
Household Characteristics	Married=0	Medicalneeds=1 HHsize=8	Medicalneeds=1 Adult18_65yr=1	Male=0 Medicalneeds=1	Vehicle=0	Und18yr=6	HHsize=8
Estimated %	76.32	59.98	82.49	90.9	35.78	48.46	52.06

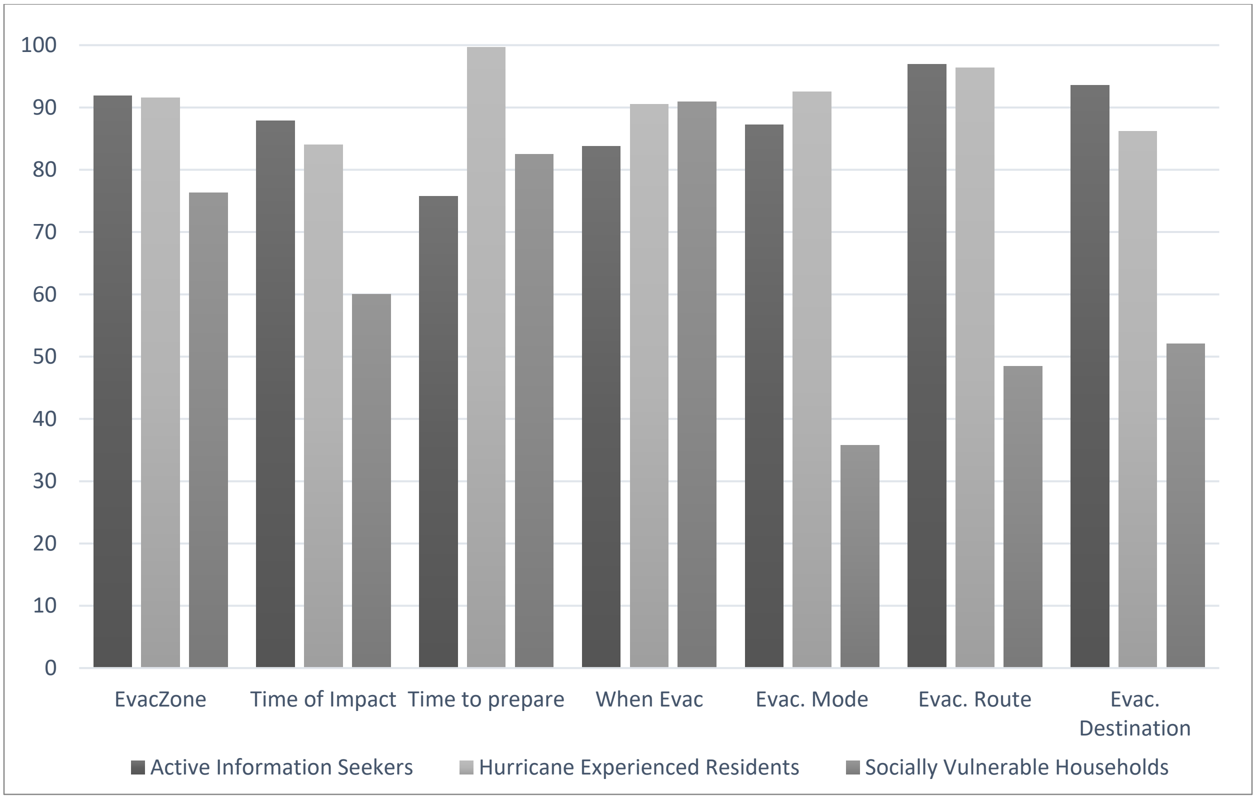

Figure 1. Certainties for Different Archetypes

HER have the highest average perceived certainty of 91.54%. HER have a negligibly lower perceived certainty of 0.4% than non-experienced residents for *evacuation mode*. HER, on average, have 37% higher perceived certainty compared to non-experienced residents. The most significant difference is in *time to prepare* perceived certainty where the certainty increase is 74% compared to residents who lived in this area less than a year and have households that cannot operate well under stress.

SVH's perceived certainty on evacuation *mode* and *evacuation route* have the lowest score of 35.78% and 48.46%. In generating the estimated certainty score, the maximum recorded six children was used. Although it is unlikely that many households have six children, 8.5% of households with children in the survey have more than four children. Not having access to a personal vehicle has the greatest effect on *mode* certainty. In our dataset, only a small number of respondents are carless. However, approximately 6% of households (about 34,000) in the Jacksonville area have no vehicle available (U.S. Census Bureau, 2017). For females, the *when to evacuate* certainty is 12.8% higher compared to males. For households with medical needs, their certainty is higher. In *time of impact*, *time to prepare*, and *when to evacuate*, SVH certainty is 9.88%, 7.93%, and 20.29% higher compared to households without a person who needs special medical attention.

Only two of SVH's certainties among all other archetypes have a lower than neutral (50%) score, consistent with the survey data in which all dependent variables' means are above neutral. HER has the highest average score of 90.98%, followed by 88.08% from AIS, and SVH has the lowest average of 64.3%.

7. Conclusion

This study investigated factors that affect households' certainties in Hurricane Matthew. Despite correlation among the certainty topics, the associated factors vary across models. Hurricane experience, factors indicating potential social vulnerability, household cohesion, evacuation notice, and close contacts (H1, 3.2, 4, 5, 7, 8) show significant relationships with multiple certainty topics. When significant, official evacuation notices and greater household cohesion are positively associated with certainty. Evacuation experience, any local information source, and relative decision sequence (H2, 3.1, 6, 9.1, 9.2, 9.3) are less transferable among certainty topics. Hurricane experience-related variables have mixed effects on certainty and showed non-significance with route certainty. Household characteristics and information sources have mixed effects on certainty and at least one factor from both groups was significant for every model.

7.1 Recommendations

The following recommendations are based on the archetypes:

Social media tools should reduce conflicting information for social media users. Social media has higher susceptibility to distortion and lower precision of dissemination compared to traditional information sources (Lindell et al., 2019). Frequent social media users should be aware of the potential to encounter comments which would decrease their certainty. Emergency managers and local officials should encourage residents to consult with their trusted close contacts when they are uncertain about their evacuation-related decisions, as the presence of close contacts increases certainty in all evacuation logistics.

Socially vulnerable households, on average, have about 18% less certainty compared to decision-makers with fewer constraints. Socially vulnerable households need more attention from emergency mangers to increase their certainty and compliance in evacuation. An education and information dissemination plan should be developed for these households about evacuation transportation that will be provided and their associated destinations. Social vulnerability does not always mean less certainty in evacuation. Women and households with medical needs have higher certainty.

Long-time residents with hurricane experience should be encouraged to share information with their family members. New comers should consult with their friends or find close contacts that could offer insights on hurricane evacuation. Possible education for evacuation logistics should also be considered as relative sequences (1. Departure time before mode, 2. Destination before mode, and 3. Mode before route) could increase certainty of *mode, when to evacuate, route*, and *destination* by 7.71%, 11.94%, 16.57%, and 30%.

7.2 Limitations and Future Direction

Our survey did not record the information channel through which an official evacuation notice was received, or the specific information obtained from different sources. Future surveys should include more detailed questions on these issues to investigate what type of information received from which information source increases/decreases household certainty.

Certainties from this survey were obtained months after Hurricane Matthew. Compared to specific topics (e.g., number of vehicles used during evacuation) certainties are vulnerable to retrospective error as respondents might fail to recall every certainty topic accurately after a hurricane event (Lindell et al., 2019). Future studies investigating certainty should deploy surveys more rapidly. Certainty of evacuation decision (specifically evacuate or stay) should be asked as well since in this survey this certainty topic was not included.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the study as follows: study conception and design: J. Shen, P. Murray-Tuite; data preparation: J. Shen; analysis and interpretation of results: J. Shen, P. Murray-Tuite, S. Lee, Y. Ge; draft manuscript preparation: J. Shen, D. Marasco, P. Murray-Tuite, S. Lee, Y. Ge, S. Ukkusuri. All authors reviewed the results and approved the final version of the manuscript.

DATA AVAILABILITY

The data is proprietary and can be made available to reviewers to replicate the results.

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CHAPTER FOUR

Perceived Certainty's Effect on Households' Evacuation Decisions

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Abstract

The evacuate/stay decision affects the overall demand estimation process. In this study, perceived certainty of evacuation destination was added as a contextual factor into evacuation decision modeling. Using data from a survey conducted after Hurricane Matthew, a two stage model was developed to investigate how the effects of variables that influence perceived certainty are reflected in evacuate/stay decision predictions. The first stage is a linear regression model for evacuation destination perceived certainty. The second is a binary probit model for the respondent's choice to evacuate or stay. This two stage model also addresses endogeneity through a control function approach. The uncorrected model was found to have a downward bias of the perceived certainty of evacuation destination. With endogeneity bias corrected, unbiased estimators for the evacuation decision model were obtained. Non-demographic variables in stage 1 included a household's social network size and frequency of checking national TV. A sensitivity analysis revealed an approximately 10% change in the evacuation rates when the values of either of these two variables changed from the mean minus 1 standard deviation to the mean plus 1 standard deviation. When similarly varied, the variable representing receiving an evacuation notice (present in Stage 2) had a larger effect with a change of more than 40% in the evacuation rate, confirming its importance in promoting evacuation as a protective action.

Keywords:

Evacuation; Perceived Certainty; Probit Model; Two-stage model; Endogeneity bias

1. Introduction

Hurricanes and how to respond to them involve considerable uncertainty, particularly several days before landfall, posing decision-making challenges for both emergency managers and the public. This study focuses on the public's perspective, particularly the link between certainty and evacuate/stay decision-making, which may be influenced by the information received, among many other factors. The specific research question addressed in this study is: how do variables affect the evacuate/stay decision through perceived certainty? Perceived certainty types examined in this study pertain to: evacuation destination, evacuation mode, evacuation route, and departure timing. Determining which certainty has the most significant impact on the evacuate/stay decision, if any, could provide a deeper understanding of evacuation decisions and help emergency managers to allocate their resources and communication better.

While numerous studies have identified factors associated with the decision to evacuate from a hurricane or stay (see for example Thompson et al., 2017; Huang et al., 2016; Murray-Tuite and Wolshon, 2013; and references therein), some fundamental questions remain. One of these is how to influence certainty and how certainty manifests in evacuate/stay decision outcomes. Lindell and Perry (2012) proposed the Protective Action Decision Model (PADM) to describe the process of how people arrive at a decision outcome (e.g., evacuate/stay). The framework represents a repetitive process; a protective action will not be implemented until uncertainty has been resolved and reduction in certainty at any stage transition can result in harmful delays or even sequence reset (Lindell, Perry, 2012). PADM offers a theoretical base for studies to incorporate contextual factors (such as perceived risk and certainty) into evacuation decision modeling efforts to better mimic the human decision process. This study uses concepts outlined in PADM by adopting the concept of a two-stage approach to model certainty and the effects on protective action selection.

Similar to perceived risk (Mileti and Beck, 1975; Huang et al., 2012, 2017) , perceived certainty as an evacuation determinant lends itself well to the conceptualization of multi-stage modeling, as there are variables (such as information sources and evacuation experiences) that would logically influence people's perceived certainty instead of the final decision outcome. Few researchers have modeled perceived certainty and investigated how variables in certainty models affect evacuation decisions. Previous efforts from our research project explored modeling of different perceived certainties or used perceived certainty as an explanatory variable in choice models in single model contexts (Alawadi et al., 2020). This study starts to connect evacuation decisions with perceived certainty using an evacuate/stay model. To accommodate the continuous – discrete modeling transformation, this study adopts the sequential model framework with a control function approach which involves similar procedures to two-stage modeling (Petrin and Train, 2010).

The rest of the paper is divided into five sections. Section 2 presents existing literature related to the evacuate-stay decision, the role of certainty, and the modeling approach. Section 3 describes the dataset and the methods that were used to refine the data for statistical analysis. Section 4 includes the modeling methodology. Section 5 presents and discusses the results and a sensitivity analysis. Section 6 summarizes the findings of the paper and offer suggestions for future research.

2. Background and Literature Review

The question of who evacuates and who stays can be informed by the PADM (Lindell, Perry, 2012, Lindell et al., 2018). From the PADM's theoretical framework, three items can initiate the intention to evacuate: environmental cues, social cues and warnings. People are engaged with these three components passively (observing various cues) and actively (accessing warning information). Based on receivers' characteristics, sources, and channels, information elements change receivers' beliefs and then behaviors (Lindell et al., 2018). Accordingly, higher perceived certainty about the hurricane or evacuation logistics could pave the way for a smoother evacuation decision process. The question of *how* certainty is influenced by other factors and how this influence manifests in an evacuate/stay decision remains unanswered. PADM suggests the decision-making process has multiple stages and is repetitive. Motivated by the concept of a multi-stage process in the theoretical framework, we conducted a review of literature on evacuation decisions and literature on how to link perceived certainty with choice as a contextual factor.

Dash and Gladwin (2007) highlighted the need for future research to concentrate on what factors people consider as they make their decisions and how these factors would impact their decisions throughout the decision-making process. Huang et al. (2016) also pointed out (1) there is a need to develop more complex models with stages and (2) predictors with mixed effects and non-significance in evacuate/stay decisions could affect the decision through contextual factors. Some examples of multi-stage modeling approaches can be found in (Mileti, Beck, 1975, Huang Shih-Kai et al., 2012, Huang Shih-Kai, Lindell Michael & Prater Carla, 2017). Huang et al.'s (2012) work focused on household evacuation decisions and departure timing for Hurricane Ike. An abbreviated form of PADM was tested which hypothesized female gender, warning messages, hurricane experience, environmental and social cues would affect expected personal impact first and then perceived evacuation impediments along with personal impact would affect the evacuation decision and departure time (Huang et al. 2012). A similar mediation framework was tested in Huang et al. (2017)'s work for Hurricanes Katrina and Rita. Personal characteristics and environmental and social cues were found to determine expected evacuation impediments, expected wind impacts, and expected storm threat. Expected wind impacts and evacuation impediments affect the evacuation decision (Huang et al. 2017). Mileti and Beck (1975) explained evacuation behavior symbolically employing the two-stage modeling concept. Evacuation was hypothesized as a function of warning content, communication mode, situational context, and warning belief; warning belief was hypothesized as a function of warning content, communication mode, perceived warning certainty, and warning confirmation (Mileti and Beck, 1975).

The theoretical background discussed above and the research question suggest two-stage modeling[1] as an appropriate approach. Support is also available from a statistical modeling aspect. Both discrete and continuous models have an important assumption that explanatory variables are exogenous to the outcome variable (Train, 2009). When the exogenous assumption is violated with an endogenous variable, the estimated coefficients suffers endogeneity bias (Gretz, Malshe, 2019). Endogeneity bias refers to the correlation between the error term and explanatory variable that causes the estimated parameters to be inconsistent (Wooldridge, 2015). Endogeneity bias has many causes: omitted variables, measurement error, and simultaneous causality (Zaefarian et al., 2017, Train, 2009, Wooldridge, 2010). In our study, using perceived certainty as a novel predictor for the evacuate/stay decision is subject to endogeneity bias; unobserved factors that affect certainty may also impact evacuation decisions. As mentioned by Train (2009), in many situations explanatory variables of interest are endogenous. Consistent parameters of variables cannot be obtained until endogeneity bias, which is highly likely to present, is addressed.

The two-stage modeling concept originates from two-stage Least Squares (2SLS), which is an extension of Ordinary Least Squares (OLS). The concept of two-stage modeling is to resolve the endogenous bias in estimated parameters by correcting the exogenous assumption. The variation of endogenous variable(s) is explained using instruments, and the re-estimated

[1] Note that researchers from different disciplines have been using different terminologies (two-stage, multiple-stage, mediation analysis) under the concept of examining how variable (X) affects decision outcome (Z) via another variable (Y) (Huang, Lindell & Prater, 2016, MacKinnon, Fairchild & Fritz, 2007, Walker et al., 2011). We use the terminology of two-stage modeling in this study.

endogenous variable(s) will be appropriately exogenous to the outcome variable (Wooldridge, 2015). Caution is needed when applying the two-stage concept since linear projection will not carry through nonlinear functions (Wooldridge, 2010).

The evacuation decision was kept as a binary variable (evacuate/stay) in the above three relevant evacuation decision studies that employed two-stage modeling concepts (Mileti, Beck, 1975, Huang Shih-Kai et al., 2012, Huang Shih-Kai, Lindell Michael & Prater Carla, 2017). Two approaches were used to analyze the binary outcome variable. Huang et al. (2012, 2017) in both their studies used regression analysis in all stages while Mileti and Beck (1975) transformed all variables into binary form. The first approach maintains the linear format for regression, however this caused resulting models to be difficult to interpret particularly in predicting households' choices. When the defined outcome is 0 or 1, linear regression models transform the expected value into a continuous variable. The second approach simplifies the modeling framework with only binary variables; models produced are linear probability functions and coefficients have straightforward probabilistic interpretations. The disadvantage of dichotomization of continuous variables is the significant reduction in variation. The structure of our models has perceived certainty in the first stage estimated using an ordinary least squares (OLS) model, and the second stage has a binary evacuate/stay outcome that is estimated using discrete choice to retain the variation in perceived certainty.

Readers interested in a detailed discussion of methodologies for solving endogeneity bias in a continuous-discrete modeling structure can refer to (Wooldridge, 2010, Train, 2009, Guevara, 2015, Petrin, Train, 2010). We selected the control function approach to properly estimate predictors' parameters in the evacuation decision model. This method was first introduced by Heckman and Robb (1985) and improved by Rivers and Vuong (1988). This research employs the control function method presented by Wooldridge (2015). Control functions gained popularity due to the relative simplicity and flexibility compared to other methods to solve for endogeneity (Wooldridge, 2015).

The variables used in the models in this study are informed by prior literature as well as some factors unique to this study. Baker reviewed fifteen studies about twelve hurricanes that took place from 1961 – 1990 (Baker, 1991). The key finding was that over those three decades, most variations in evacuation rate could be explained through five variables: risk level of the area, action taken by authorities, housing, prior perception of personal risk, and storm specific factors. Many individual-differences variables including demographics were found to have inconsistent and weak relations with hurricane evacuation (Baker, 1991). In 2007, Dash and Gladwin (2007) conducted a review on evacuation behavior; they noticed the trend of researchers focusing on the evacuation decision-making processes. Historically used factors, including age, presence of children, gender, disability, and income, were argued to be influencing contextual factors like risk and affect the evacuate or stay decision. Dash and Gladwin (2007) argued that the direct use of the factors rather than as contextual factors was the reason for the inconsistent impacts.

Three later review papers were selected to understand the research trends. Murray-Tuite and Wolshon (2013) and Thompson, Garfin, and Silver (2017) both reviewed evacuation with different focuses. The former reviewed evacuation modeling across disaster types while the latter focused solely on hurricane response. Both reviews have similar findings on socio-demographics' effects on evacuation decisions: only a few variables have consistent likelihood effects when modeled or examined directly with evacuation decisions, and the moderating effects of these variables still remained unanswered (Murray-Tuite, Wolshon, 2013, Thompson, Garfin & Silver, 2017). The third review is from Huang et al. (2016). This review paper revisited Baker's (1991) research findings and raised the research question of whether information sources would have a consistent, significant effect in predicting evacuation behavior among 49 hurricane studies (Huang et al. 2016). While the results remained consistent with Baker's (1991) previous conclusion for socio-demographic factors, they found that information sources show small effect sizes and low consistency across studies (Huang et al. 2016). They argued the reason the reliance on information sources would vary is because of the characteristics of the hurricane.

To consider the possibility of factors influencing the context as well as the decision directly, we examine socio-demographics both for perceived certainty and the evacuation decision. Information sources and related variables are also included to understand how information is utilized by household decision makers. Our study also includes certainty as a more unique factor. Previous research has found having an adaptive plan increases the likelihood of evacuation (Burnside et al. 2007, Dash and Gladwin 2007, Perry 1981), and an absence of a plan for safe routes for an exit or destination could hinder evacuation response (Perry 1981). The fact that planning has been identified as influential in the evacuate-stay decision makes a few types of perceived certainty (evacuation destination, mode, and route) good candidates for inclusion in the model of the evacuation decision.

3. Data

Data for this study came from a survey conducted after Hurricane Matthew (2016). A mail survey was distributed to 5,000 households in the Jacksonville Metropolitan area in 2017. The survey was designed to capture households' evacuation related decisions, information sources, social network characteristics, family characterization, certainty levels, and socio-demographic characteristics. The dataset contained 498 responses; however, not all responses were complete, leading to different numbers of observations for each variable.

Table 1 includes a description of the unweighted sample and variables tested in this study. The evacuation decision question in the original survey allowed five categories of response depending on who (if any) from the household evacuated. Because this study concerns only the actions and perceptions of the respondent, the categories that contained affirmative replies about whether or not the respondent himself/herself evacuated are coded as "yes" (1). Any responses that did not include the evacuation of the respondent are coded as "no" (0). This changes the variable into a binary response variable. Overall, the unweighted evacuation rate among the entire sample is 49%.

Respondents were asked to identify the timeframe and frequency of accessing different information sources. A set of indictor variables was created to denote whether each source was used before or during the evacuation decision. Quantitative frequency variables recording how many times per day respondents consulted the source were interacted with the indicator variable.

The survey contained several questions that were answered with Likert-type scale values. For example, the certainty questions (1, not certain at all; 5, very certain) and concerns about household members getting injured (1, not concerned; 5, very concerned). Because these answers were quantitative measures with numerical intensity and intervals, they were transformed into continuous variables (1→ 0; 2→25; 3→50; 4→75; 5→100). Variables 14, 15, and 16 in Table 2 present the perceived certainty of respondents' evacuation logistics including evacuation route, departure timing, mode, and destination.

Individuals who were older and/or female and with higher education levels were overrepresented, relative to Census 2017 (published in 2018) estimates. A rake weighting procedure was used to reduce the sample bias. In this study, similar to Alawadi et al. (2020) who used the same survey data, the variables used to weight the responses were gender (female or male), education (college educated or not college educated), and age group (18 through 45, 45 through 59, and 60+) (Table 2). These variables were chosen because they provide weights that improve the demographic profile of the data set when compared to the population. The reference demographic information for Jacksonville is courtesy of the American Community Survey (2017). The marital status (married or not married) and income (six levels) variables were used as references for bias reduction testing. After weighting, the bias for income and marital status reduced from 6% to 1.7% and 23% to 15% with an average improvement of 6.1% (Table 2). The detailed comparison for each level of these two variables are available from the authors upon request.

Table 1. Description of Unweighted selected variables tested in the model

Variables	Number of Observations	Min	Max	Mean	Standard Deviation
1.Evacuation Decision: 1 if evacuated for hurricane Matthew, 0 if stayed	439	0	1	0.49	0.5
2.Male Gender	477	0	1	0.40	0.4
3.Age	472	20	92	58.3	14.7
4.Household Size	481	0	8	2.23	1.2
5.Medical Needs: Dummy variable: 1 if there is anyone with medical needs in the household, 0 otherwise	472	0	1	0.18	0.39
6.Years Lived in Current Community	428	0	63	14.36	12.5
7.Income	436	7500	100000	67169.7	31135.5
8.Previously Stayed: Dummy variable: 1 if respondent did not evacuate and stayed during a hurricane event, 0 otherwise	470	0	1	0.42	0.4
9.Hurricane Experience: Dummy variable: 1 if respondent has any hurricane experience, 0 otherwise	470	0	1	0.82	0.3
10.Network Size: Continuous variable: records size of respondent's close contact network, up to 5 close contacts	350	1	5	2.63	1.4

11.Frequency of Checking National Television Daily Before or During Decision Making	477	0	100	6.22	8.6
12.Frequency of Checking Social Media Daily Before or During Decision Making	476	0	100	2.70	9.9
13.Received Evacuation Notice (Mandatory or Voluntary) During Hurricane Matthew	414	0	1	0.62	0.4
14.Certainty of Evacuation Route: Percentage of perceived certainty level of evacuation route. From 0 (not certain at all) to 100 (very certain)	426	0	100	74.64	33.5
15.Certainty of Departure Time: Percentage of perceived certainty level for evacuation timing	442	0	100	74.43	30.3
16.Certainty of Evacuation Destination: Percentage of perceived certainty level of evacuation destination	428	0	100	71.14	36.4
17. Certainty of Evacuation Mode: Percentage of perceived certainty level of evacuation mode	425	0	100	84.58	28.5
18.Infosharing: Percentage of how well the statement 'My family members always share information with each other' describes respondent's household. From 0 (not at all) to 100 (very well)	427	0	100	82.08	22.5
19.Injury Concern: Percentage of concern over a household member getting injured. From 0 (not concern at all) to 100 (very concerned)	429	0	100	31.7	32.0

Table 2: Bias of demographics in sample data compared to ACS Census Data for Jacksonville Area

Attribute	Bias	Bias Reduction After Weighting
Age group	0.19	-
Education level	0.42	-
Gender	0.08	-
Income (annual)	0.06	-0.08
Marital status	0.23	-0.043

4. Methodology

The two stages of the model were (1) certainty and (2) evacuate/stay. The first was modeled using linear regression with weighting, which can be found in many textbooks. Certainty is modeled using equation (1) (Washington et al., 2020):

$$Y_i = \beta_0 + \beta X_i + \epsilon_i \tag{1}$$

The second stage uses a probit model with weighting. The rest of this section first introduces the probit model and then presents the proposed correction for endogeneity in a two-stage setting. The approach follows procedure 15.1 from Wooldridge (2010, section 15.7.2) and Wooldridge (2015). The often-used logit model assumes a Gumbel distribution for the residual (Washington et al., 2020) while OLS assumes a normal distribution for residual. The control function approach requires the residual from the first stage (OLS) to enter the second stage as an extra variable and having different distributions for residuals complicates the analysis. For this research, the probit model which assumes a normal distribution for the residual was employed instead of the logit model for the convenience of analysis.

4.1 Probit Model

The probit model can be written using a latent variable y_i^* and the equation can be expressed as in equation (2) (Wooldridge, 2010, Section 13.2):

$$y_i^* = \theta x_i + e_i \tag{2}$$

Where y_i^* is the latent variable that was not directly observed (e.g., utility), x_i represent explanatory variables, e_i is the error term which is independent of x_i and e_i ~ Normal (0,1). For a binary outcome, the observed outcome is y_i and the relationship between the latent variable y_i^* is shown in equation (3) (Wooldridge, 2010).

$$y_i = \begin{cases} 1 & if y_i^* > 0 \\ 0 & if y_i^* \leq 0 \end{cases} \tag{3}$$

Equation (3) can be simplified as $y_i = 1[y_i^* > 0]$. Given x_i, the distribution of y_i can be obtained with a simple expression shown in equation (4) (Wooldridge, 2010):

$$\mathrm{P}(y_i = 1 \mid x_i) = \mathrm{P}(y_i^* > 0 \mid x_i) = \Phi(\theta x_i) \tag{4}$$

Where Φ is the cumulative distribution function for a standard normal (0,1).

4.2 Probit Model with a Continuous Endogenous Variable

This section introduces the procedure to estimate the probit model with a continuous endogenous variable based on Section 4.1. This model is applicable when there is endogeneity bias because of unobserved attributes, measurement error, or an endogenous variable and outcome variable being determined jointly (Wooldridge, 2010). The probit model can be written as:

$$y_1^* = z_1\delta_1 + \alpha_1 y_2 + u_1 \tag{5}$$

$$y_2 = z\delta_2 + v_2 \tag{6}$$

$$y_1 = 1[y_1^* > 0] \tag{7}$$

Where y_2 is the endogenous variable and y_1 is the observed outcome variable. z_1 and z both include an intercept and represent exogenous variables. Both error terms (u_1, v_2) have a standard bivariate normal distribution with a mean of zero and are independent of z. Equations (5) and (7) together are the structural equations (Wooldridge, 2010). Equation (6) is a reduced form of y_2; the endogeneity issue appears when error terms (u_1, v_2) are correlated. Under the assumption that (u_1, v_2) are jointly normal, u_1 can be regressed on v_2(Wooldridge, 2015). The equation can be written as in equation (8) (Wooldridge, 2015):

$$u_1 = bv_2 + e, \tag{8}$$

e being normally distributed as well. Equation (5) can be rewritten as:

$$y_1^* = z_1\delta_1 + \alpha_1 y_2 + bv_2 + e \tag{9}$$

Where, $e \mid z, y_2, v_2 \sim$ Normal($0,1$-ρ^2), where $\rho = Corr(v_2, u_1)$

To obtain consistent estimation of parameters in the probit model, a scaled calculation is needed using the scale coefficient ρ^2. Consistent estimation means that as the number of data points available increases to infinity, the probability of the estimator being randomly close to the true parameter converges to 1 (Amemiya, 1985). When the assumption of the error term e_i in equation (2) not being correlated with any independent variable in the equation is violated, the estimated parameters will not be consistent (Wooldridge, 2010). Equation (10) represents the overall transformation of the probit model (Rivers, Vuong, 1988, Wooldridge, 2015):

$$P(y_1 = 1|z, y_2) = P(y_1 = 1|z_1, y_2, v_2) = \Phi[\frac{z_1\delta_1 + \alpha_1 y_2 + \rho v_2}{\sqrt{(1-\rho^2)}}] \quad (10)$$

The whole process can be written as ((Wooldridge, 2010) Procedure 15. 1) Run least square regression y_2 on z and record the error term v_2, 2) Run a probit model for y_1 on z_1, y_2, v_2, 3) Scale coefficients of the variables using ρ^2 to get consistent coefficients. The null hypothesis of y_2 being exogenous can be easily tested using *t* statistics of v_2 (Wooldridge, 2010).

4.3 Model Building Process

The probit model was estimated using NLogit software (Version 6.0) and the OLS model was estimated using IBM SPSS Statistics 25. A correlation matrix for variables tested in the OLS model and probit model is presented in Table 3.

The model building process started with the base probit model, investigating certainty variables' relationship with the evacuation decision. From Table 3, variables representing certainty about evacuation destination, evacuation mode, and evacuation route (variable 14, 16, 17) all have a significant relationship with the evacuation decision and these certainty variables are highly correlated with each other (0.60-0.78). To avoid multicollinearity, only one certainty variable was permitted in the probit model at a time, resulting in three separate probit models. The probit models were built by adding variables one at a time using a manual forward stepwise-based approach (the entering order was based on the variable's p-value with respect to the outcome variable from low to high). Any entering variable was evaluated in terms of its significance in the multi-variable context, and the resulting model's McFadden Pseudo R^2 compared to the previous model. The final base probit model (Table 5, base model) contained certainty of evacuation destination as this variable was consistently significant when more independent variables entered the probit model.

The certainty of evacuation destination was estimated using a subset of variables from Table 2. The subset included all variables that were not included in the probit model and can be referred to as instruments, the assumption being that they only affect the outcome variable (evacuate decision) through evacuation destination certainty (Greenland, 2000). This assumption ruled out the use of the same variables in both stages (Greenland, 2000), so all variables that were already in the probit model were prohibited from the search. A manual forward stepwise-based method was employed for this stage as well. The significance level for each variable was kept at 0.05 at both stages (Table 4 and 5 base model), strongly correlated variables (0.4 or greater in the correlation matrix, Table 3) were not included in the same model. After finalizing both models, the procedure mentioned in section 4.2 was employed to test for endogeneity in having evacuation destination certainty in the probit evacuation decision model.

Table 3. Correlation Matrix

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Evacuated	1	-.14	0.09	-0.07	-0.01	-.11*	0.06	-.22**	-.21**	0.07	0.09	0.06	.54**	.21**	-0.03	.23**	.24**	-0.01	.27**
2. Male Gender		1	0.02	0.02	-0.01	-0.03	.18**	.13**	.09*	-.12*	-0.06	0.01	-0.01	-0.07	-0.03	-0.04	-.09*	-0.03	-0.09
3.Age			1	-.37**	.15**	.40**	-.21**	0.02	-0.06	-0.01	-0.04	-.23**	0.04	0.07	0.01	0.05	0.02	-0.05	0.02
4.HHsize				1	-0.02	-.12**	.23**	-0.05	-0.01	-0.02	0.06	0.09	-0.03	-0.01	-0.01	-0.03	-0.01	0.04	0.05
5.Medicalneeds					1	0.09	-.09*	0.06	0.03	0.09	0.05	-0.03	-.12*	-0.08	-0.05	-.12*	-0.06	-0.01	0.06
6.Years in Community						1	-.24**	.13**	-.09*	-0.02	-0.01	-.10*	-0.08	0.01	0.01	0.03	-.11*	0.01	-0.01
7.Income							1	-0.01	-0.08	-0.01	-0.01	0.01	.13*	0.08	.09*	0.01	.14**	0.05	-0.04
8.PreviouslyStayed								1	.41**	-0.01	0.01	-0.05	-0.03	-0.03	0.01	-0.05	-.13**	0.05	-0.06
9.Hurricane Experience									1	-0.07	-0.03	0.08	-.19**	-.10*	-0.04	-0.09	-0.09	0.07	0.01
10.Network Size										1	-0.01	.12*	0.01	0.05	0.01	0.10	0.09	-0.07	.10*
11.freqnatv_bd[1]											1	.09*	.11*	0.04	0.05	0.05	0.05	-0.02	.13**
12.freqsomedia_bd[2]												1	0.06	-0.03	0.02	0.01	0.01	-0.05	0.04
13.Evacuation Notice													1	0.06	0.06	0.05	.15**	-0.02	.22**
14.Route Certainty														1	.48**	.78**	.68**	0.05	0.02
15.Departure Time Certainty															1	.49**	.51**	.17**	-0.04
16.Destination Certainty																1	.60**	0.01	0.04
17.Mode Certainty																	1	0.09	0.04
18.Infosharing																		1	-0.02
19.InjuryConcern																			1

Note: Freqsomedia_bd[1] : Frequency of Checking National Television Daily Before or During Decision Making, ** p < .05, * p <.1

5. Results and Discussion

The first step of the control function approach is to estimate the perceived certainty functions to find the residuals entering the control functions in the probit model. The perceived certainty of evacuation destination is regressed against instrumental variables listed in Table 4.

Table 4. Linear Regression of Perceived Certainty of Evacuation Destination

Variable	Coefficient	Standard Error
Constant	61.96***	8.50
Male Gender	-9.13**	3.89
Income	0.17E-3**	0.59E-4
Household Size	-5.45**	1.70
Network Size	5.26***	1.48
Frequency of Checking National Television Daily Before or During Decision Making	.80***	.18
Model Statistics		
Observations	318	
Adjusted R^2	0.17	
F	12.431***	

Note: *** p < .001, ** p < .05

Residuals from the regression then entered the probit model. Table 5 provides the estimated parameters. The first model was the base probit model that did not correct for the correlation between perceived certainty and the residual in the probit model. The second model applied the control function by including the error from the perceived certainty of evacuation destination.

Table 5. Probit Model of Evacuation Choice: Control Function Approach

	1.Base Model		2. Corrected Model	
Variable	Coefficient	S.E.	Coefficient	S.E.
Constant	-2.77***	.358	-4.47***	.65
Injury Concern	.011***	.004	.013***	.004
Certainty of Evacuation Destination	.024***	.003	.046***	.007
Received an Evacuation Notice	2.13***	.251	2.15***	.27
Previously Stayed	-.93***	.256	-.93***	.008
Years lived in Community	-0.03***	0.008	-0.03***	.267
Residual of Evacuation Destination	-	-	-.02***	.007
Number of Observations	318		318	
Log Likelihood at Convergence	-140.1		-135.7	
Adjusted McFadden Pseudo R-Squared	0.39		0.42	

Note: *** p < .001, ** p < .05, * p <.1

Without the endogeneity correction, the base coefficient for perceived certainty of evacuation destination is 0.024. The second model shows that there is an endogeneity issue when including certainty of evacuation destination into the probit model since the residual is significant. Model 2 is the final model for evacuate or stay and based on the t-statistics for the residual, the null hypothesis of evacuation destination certainty being exogenous is rejected. The uncorrected model gives a false sense of precision by assuming that perceived certainty is independent of unobserved factors when in fact evacuation destination certainty is related to these factors (Petrin, Train, 2010). Inclusion of the control function adjusts the coefficients for the perceived certainty variable to 0.046. The next process is to re-scale the coefficients from the final model. The correlation between the residual of OLS and the residual of the probit model is -0.21, indicating a moderate correlation. Following Equation (9) and (10), the rescaled model can be written as:

$$y_1 = \Phi[(-4.57 + 0.013 * (\text{Injury Concern}) + 0.048 * (\text{Certainty of Evacution Destination}) + 2.20 * (\text{Recevied Evacuation Notice}) - 0.95 * (\text{Previously Stayed}) - 0.03 * (\text{Years Lived in Community}) - 0.02 * (\text{Residual of Evacuation Destination})] \quad (11)$$

The probit model's residual was e ~ Normal (0, 0.96). Overall, there was not a significant change in coefficients when rescaling. The coefficient for certainty of evacuation destination was underestimated in the original probit model, the new coefficient was almost two times higher than the originally estimated parameter (from 0.024 to 0.047).

5.1 Discussion

The first stage regression model explained 17% of variance in the data. Female gender had a positive effect on perceived certainty of evacuation destination. Bateman and Edwards (2002) found women more likely to plan for evacuation; it made sense that their evacuation destination certainty would be higher as a result of planning in advance. Income was a positive predictor for perceived certainty of evacuation destination; higher income households may have greater access to resources that could help them identify a destination to which to evacuate. Both information channel-related variables: frequency of checking national TV before or during decision making and size of the respondent's close contact network increased perceived certainty of evacuation destination. Television was recognized as the primary information channel during Hurricane Isaac and Hurricane Sandy (Lindell et al., 2018). Our result indicated that more frequent checking of national TV was associated with greater certainty about evacuation destination. Close contacts living at the destination selected played an important role; 63 percent of evacuees in our survey stayed with family/friends after evacuating. More close contacts in one's network implies more evacuation destination options. Larger household size had a negative impact on destination certainty, as decision-makers might have concerns about peers' ability to accommodate the whole household. Smith and McCarty (2009) also found that household size negatively impacted the decision of staying at a peer's home. For households with larger size, the multiplicity of opinions on where to evacuate could make the decision maker hesitate to decide, and their certainty decreases.

For the evacuate or stay decision, the probit model had an adjusted McFadden Pseudo R-squared of 0.42. Concern about injury to oneself or one's family members was a positive predictor for evacuation, as expected. Perceived certainty of evacuation destination was a positive predictor for evacuation. A *lack* of certainty about evacuation destination might make a person more hesitant to evacuate, especially if that person lacks resources (money, connections, etc.) to find alternative places to stay. Receiving an evacuation notice was a positive predictor of evacuation, consistent with established literature (e.g., Huang et al. 2016; Murray-Tuite and Wolshon 2013 and references therein). Having stayed during a previous hurricane approach was a negative predictor for evacuation. This was consistent with previous studies that have shown that people tend to repeat their earlier evacuation decisions (Dow and Cutter 1998; Murray-Tuite et al., 2012). Longer years of residence was associated with lower likelihood of evacuation.

Among the complete observations, the evacuation rate was 53.1% (169/318), higher than the raw rate in Table 1, which included some incomplete responses. Our model's estimated evacuation rate was 46.5% (148/318), the uncorrected estimated evacuation rate was 44.6% (142/318). The correction for endogeneity improved the accuracy of the model.

5.2 Sensitivity Analysis

To align with the purpose of this study, a sensitivity analysis was conducted to investigate how the choice to evacuate or stay would change based on the change in non-demographic predictors in both stages. Twelve scenarios were created by changing values of a specific variable in Table 6 (all other variables took their observed values). Each value assigned in a scenario was calculated using the variable's observed mean and mean ± the standard deviation from Table 2. Calculated values were adjusted to the max/min if they exceeded the max/min. Figure 1 shows the variation in evacuation rates for each scenario, the baseline evacuation rate is based on the estimated evacuation rate using sample data directly. Figure 1 presents the resultant variation in evacuation probability.

Table 6. Sensitivity Analysis Table

Scenario	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Variable	Social Network Size			Frequency of Checking National TV			Received Evacuation Notices			Injury Concern		
Assigned Value	1.20	2.60	5.00[1]	0[1]	6.22	14.82	0.22	0.62	1.00[1]	0[1]	31.70	63.70
Mean of Predicted Certainty of Evacuation Destination	69.02	76.44	88.87	69.42	76.33	83.24	71.14					

[1]Note: Calculated value exceeded observed maximum or minimum and used observed max/min instead.

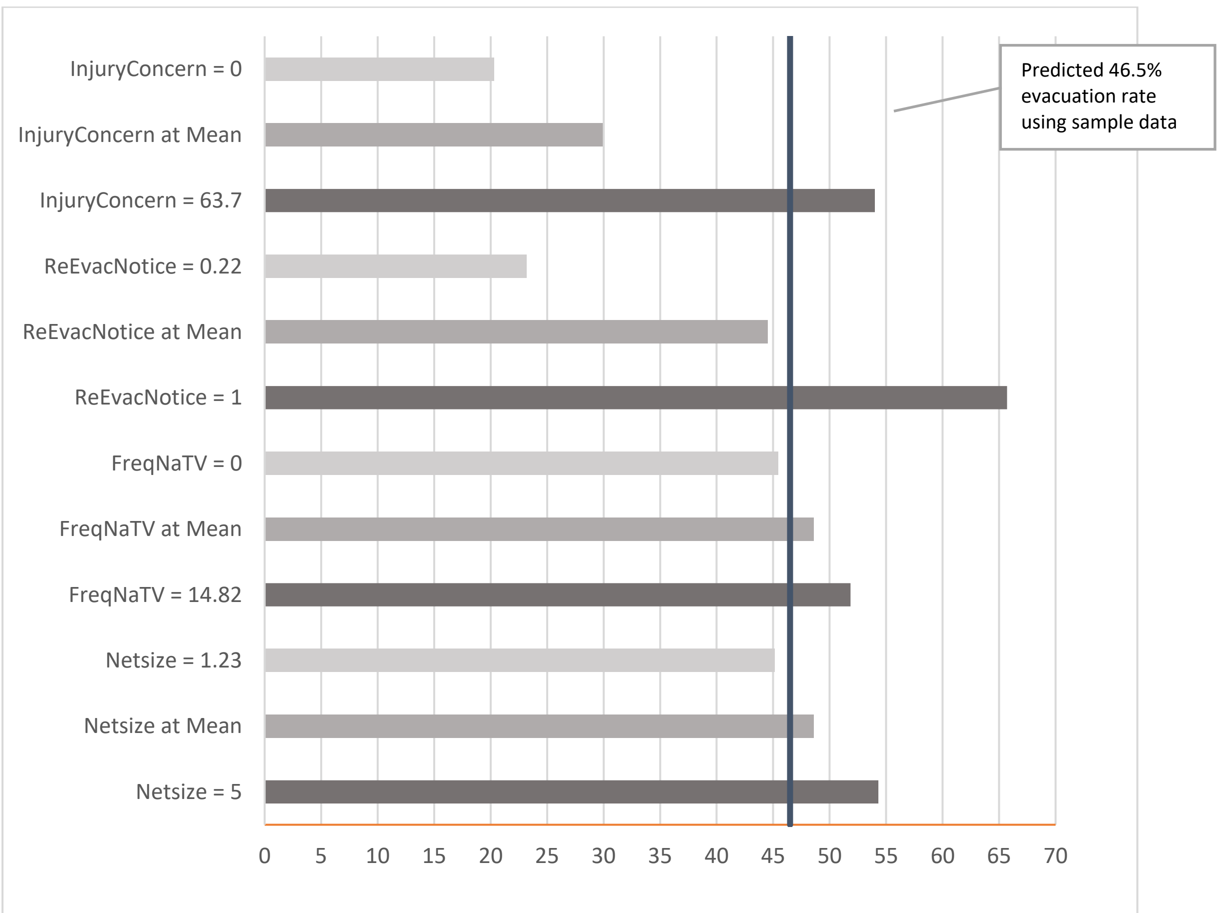

Figure 1. Evacuation Rates from Sensitivity Analysis

When a household's social network size was reduced by the standard deviation from the mean value and equaled 1.23, the estimated evacuation rate was 45.14%, and when the network size increased to 5, the estimated evacuation rate was 54.32% with a 9.18% increase. The frequency of checking national TV daily had the least changes in evacuation rate among the four variables. When the frequency of checking national TV daily was zero, the evacuation rate was 45.45%, and when the variable was 14.82 (mean + 1 standard deviation), the evacuation rate was 51.85%. This result was expected as people have multiple ways to get access to hurricane information. The two information source-related variables (network size and frequency of checking national TV daily) did not show much impact on evacuation rate compared to injury concern and receiving an evacuation notice. This made sense because the information source-related variables were not in the second stage model, their impact on the evacuation decision was not direct but through the certainty of evacuation destination. Additionally, their effects on evacuation destination certainty were both less than the observed standard deviation of evacuation destination certainty (36.4).

The highest evacuation rate (65.7%) occurred when all residents received an evacuation notice. The range of evacuation notice scenarios (22% to 100% of residents receiving the notice) showed the most disparities in the sensitivity analysis, the evacuation rate went from 23.18% to 65.7%. This finding was consistent with literature that found evacuation notice to promote the evacuation decision and be one of the few consistent predictors (Baker, 1991; Baker, 2000; Huang et al., 2016). The lowest evacuation rate was found when concern for injuries was low (InjuryConcern =1). When no resident perceived any risk (injury concern), the evacuation rate was the lowest at 20.3% and when residents perceive above average (63.7%) risk, the evacuation rate was 54%. Injury concern could be extended into risk perception; previous research found people less likely to evacuate when they did not believe they were at risk (Mileti and Beck, 1975).

6. Conclusions and Future Directions

In this study, perceived certainty was investigated for two reasons. Firstly, certainty is not yet well understood, both in terms of what influences it and what influence it exerts over evacuation decisions. Secondly, certainty can potentially fit into the households' evacuation decision making. Lindell and Perry (2012) recognize certainty as an important component of the PADM model (a theoretical framework that helps to investigate human decision making for evacuation). Uncertainty can cause a decision stage to delay or reset, as people need to conduct further information searches to reinforce their belief (Lindell and Perry, 2012). With the same logic, variables like information channels and social characteristics along with other factors were thought to influence people's certainty level and then their decision.

Perceived certainty of evacuation destination was linked to the evacuate/stay decision through a control function approach. The evacuate-stay decision was researched in the context of perceived certainty, demographic factors, and other variables to both further verify well-studied variable effects (such as evacuation notice being a strong predictor of deciding to evacuate) and to gain insight into new relationships. Based on a binary probit model, residents who previously stayed during a hurricane event and/or lived in the community for a longer period of time were less likely to evacuate. Individuals with higher injury concern (perceived risk), higher certainty of evacuation destination, and/or received an evacuation notice were more likely to evacuate. Predictors for certainty of evacuation destination were also found using linear regression. Male gender and larger household sizes had negative effects on evacuation destination certainty. Higher household income, larger social network size, and more frequent checking of national TV daily had positive effects on evacuation decision certainty.

From the sensitivity analysis, utilizing the models developed, there are multiple ways to increase the evacuation rate. Evacuation notice was the most influential variable in the sensitivity analysis. The challenges of evacuation notices include effective dissemination and ensuring the residents believe there is a potential threat (Baker 1991, Lindell et al., 2019). Although it is impossible to employ the traditional yet effective door-to-door notification for all hurricane notices (Lindell et al., 2019), emergency managers could seek better information dissemination strategies in the age of multi-medias and the internet. Another way to raise evacuation compliance is to influence targeted areas' residents perceived risk, as the increase in injury concern for household members also shown drastic increase in evacuation rate. Public education of the hazards as well as messages highlighting the potential for injuries could influence this perception.

Future research should investigate the transferability of this research and test the consistency of the findings. The concept of two-stage modeling could be tested for other hurricane evacuation logistics and provide researchers with more understanding about how residents reach to their final decisions. As the PADM suggests, the protective action decision is an iterative and dynamic process (Lindell and Perry, 2012), having two or more stages to represent residents' decision processes could be enhanced with dynamic modeling to better represent the real-world process.

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Data Availability

The data is proprietary and can be made available to reviewers to replicate the results.

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CHAPTER FIVE

CONCLUSIONS

This thesis utilized survey data obtained from residents in the Jacksonville Metropolitan area who experienced Hurricane Matthew in 2016 to analyze perceived certainty of households and their evacuation decision. Motivation for analyzing perceived certainty was found in the PADM (Lindell and Perry, 2012) and motivation for a multi-stage modeling effort was found in previous evacuation decision studies (Huang et al., 2012; Mileti & Beck, 1975).

The first part of the research studied perceived certainty. Seven perceived certainty topics: whether one lives in an evacuation zone, time of hurricane impact, evacuation preparation time needed, when to evacuate, evacuation destination, evacuation travel mode, and evacuation route were regressed against various information sources and channel/medium factors, socio-demographic factors, intra-household communication factors, and relative decision sequences. Results showed that significant explanatory variables vary across the seven different perceived certainty topics. Hypotheses tested in the first part were:

- H1: *Hurricane* experience is positively related to the perceived certainty of time of hurricane impact and whether a respondent lives in an evacuation zone.
- H2: Hurricane *evacuation* experience is positively related to perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

- H3.1: Socio-demographic factors potentially indicating higher social vulnerability (older age, larger households, female, medical needs) are positively related to perceived certainty topics of time of hurricane impact and whether a respondent lives in an evacuation zone.
- H3.2: Socio-demographic factors potentially indicating higher social vulnerability (older age, larger households, female, medical needs) are negatively related to perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.
- H4: Frequent household discussion is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.
- H5: A household's ability to make decisions under stressful situations is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.
- H6: Using local information sources (local TV, radio, or print media) before or during the evacuation decision process is positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.

- H7: Evacuation notices are positively related to perceived certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, and evacuation route.
- H8: More frequent contacts within the social network before or during decision-making processes is positively related to certainty topics of time of hurricane impact, whether a respondent lives in an evacuation zone, perceived certainty of time to prepare for evacuation, when to evacuate, evacuation mode, evacuation route, and evacuation destination.
- H9.1: Making the evacuation departure time decision before the mode decision is negatively related with certainty of when to evacuate and travel mode.
- H9.2: Making the evacuation destination decision before the mode decision is positively related with certainty of destination and travel mode.
- H9.3: Making the evacuation mode decision before the route decision is positively related with certainty of travel mode and route.

Hypotheses for hurricane experience (H1) and evacuation notices (H7) were fully supported and aligned with previous findings of relevant studies. Hypotheses about socio-demographic factors indicating higher social vulnerability (H3.1, H3.2), familial discussion (H4, H5), close contacts (H8), and evacuation decision sequence (H9.1, H9.2, H9.3) were partially supported (significant but with mixed effects on dependent variables) based on the modeling results. Finally, hypotheses about evacuation experience (H2) and usage of local information sources (H6) were rejected. The disparities in hypothesis support showed that perceived certainty for households in hurricane evacuation is more complicated than anticipated since most hypotheses were built based on previous evacuation decision studies. Archetypes were built based on the modeling result. Hurricane experienced residents had the greatest perceived certainty (average of 91% for all certainty topics), followed by active information seekers (average of 88%) and then socially vulnerable households (average of 64.3%).

Recommendations based on the findings in Chapter 3 are the following:

- Social media tools should be developed to reduce conflicting information for social media users. Frequent social media users should be aware of the potential to encounter content which would decrease their certainty;
- Emergency managers and local officials should encourage residents to consult with their trusted close contacts when they are uncertain about their evacuation-related decisions;
- An education and information dissemination plan should be developed for socially vulnerable households about evacuation transportation that will be provided and their associated destinations; and
- Long-time residents with hurricane experience are encouraged to share information with their family members.

The second part of the research added perceived certainty as a mediator in the evacuate/stay decision. To solve for endogeneity bias that is likely to be caused by unobserved factors, this thesis adopted the control function approach. The original model developed in part one contained a decision sequence variable which eliminated non-evacuees. To be consistent with the evacuate/stay choice, the perceived certainty of evacuation destination was re-estimated without these variables. A linear model of perceived certainty was constructed in the first stage and a probit model (which assumes a normal distribution for the error term) was constructed in the second stage. Compared to the un-corrected model, the parameter for certainty of evacuation destination was almost two times higher than the originally estimated parameter. A sensitivity analysis was conducted to investigate how the evacuate/stay decision would change based on the change in predictors in both stages. Twelve scenarios were created by changing values of one variable at a time. Each value assigned in a scenario was calculated using the variable's observed mean and mean ± the standard deviation. The highest evacuation rate (65.7%) occurred when all residents received the evacuation notice. The range of evacuation notice scenarios (22% to 100% of residents receiving the notice) showed the most disparities in the sensitivity analysis - the evacuation rate went from 23.18% to 65.7%. This finding was consistent with literature that found evacuation notice to promote the evacuation decision and be one of the few consistent predictors (Baker, 1991, Baker, 2000, Huang, Lindell & Prater, 2016). Evacuation notice was the most influential variable in the sensitivity analysis. Another way to raise evacuation compliance is to influence targeted areas' residents' perceived risk, as the increase in injury concern for household members also showed a substantial increase in the evacuation rate. Public education of the hazards as well as messages highlighting the potential for injuries could influence this perception.

This thesis firstly revisited hypotheses towards evacuation decision from previous literature, modified and tested these hypotheses with respect to different certainty topics. These models provide valuable insights of how emergency managers and decision makers could influence residents' certainty in a hurricane event. The addition of perceived certainty as a mediator in the evacuation modeling process utilized variable pools identified in the thesis's first part. The resulting two-stage model linked behavioral models with the certainty model. As the PADM suggests, the protective action decision is an iterative and dynamic process (Lindell and Perry, 2012). This thesis also contributes to the multi-stage modeling efforts in hurricane evacuation decision literature.

5.1 Future Directions

The entire thesis was built based on survey data. The quality of the data largely dominated the predictive power of the statistical models. Since the survey consisted of over 60 questions and many detailed sub-level questions, missing data was a potential limitation. This imposed challenges when analyzing the dataset where adding some variables to the model required a tradeoff of either losing sample size or increasing the predictive power of the model.

The transferability of this research remains unknown since no evacuation studies, to the knowledge of the author, modeled different topics of perceived certainty of households before. Future studies can re-test the hypotheses in this thesis in the context of a different location or a different disaster.

The control function approach to resolve the endogenous bias that this thesis adopted in Chapter 4 has the potential to be applied in future multi-stage modeling. The control function is a flexible method that allows continuous/binary/multi-level response, and the model can go from fixed parameters to random parameters. Disaster researchers, when testing out mediator effects or adding novel variables into their models, should be cautious of the potential endogenous bias.

The general framework of various factors affecting perceived certainty first and then households' decisions could be tested for evacuation logistic decisions like accommodation choices, evacuation destinations, and evacuation modes. Similar to the evacuation decision (evacuate/stay) these logistic decisions have multiple levels and can be modeled using binomial (2 levels) or multinomial (more than 2 levels) logit models. By using a control function as a statistically valid method, future research can test whether variables hypothesized are endogenous or not. The research team could project the work presented here and test it at a population level. The change of evacuation compliance rate from manipulating perceived certainty of households could be an interesting research topic.

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