

**HOMEOWNER DECISIONS TO RETROFIT TO REDUCE HURRICANE-  
INDUCED WIND AND FLOOD DAMAGE**

by

Zeinab Yahyazadeh Jasour

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Approved: \_\_\_\_\_  
Rachel A. Davidson, Ph.D.  
Professor in charge of thesis on behalf of the Advisory Committee

Approved: \_\_\_\_\_  
Harry W. Shenton III, Ph.D.  
Chair of the Department of Civil and Environmental Engineering

Approved: \_\_\_\_\_  
Babatunde A. Ogunnaike, Ph.D.  
Dean of the College of Engineering

Approved: \_\_\_\_\_  
Ann L. Ardis, Ph.D.  
Senior Vice Provost for Graduate and Professional Education

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## **ABSTRACT**

Even as new incentive programs emerge to encourage homeowners to strengthen their homes so as to reduce the risk of damage in extreme events, little is known about how homeowners make such decisions. In this paper, we combine revealed and stated preference survey data to develop separate mixed logit models for homeowner decisions about retrofits aimed at addressing four different types of hurricane damage—wind damage to the roof, openings (windows, doors), and roof-to-wall connection, and flood damage. Results provide evidence that offering a grant increases the likelihood of retrofitting, but offer no such evidence for incentives in the form of low interest loans or insurance premium reductions. The models also suggest that the probability of retrofitting varies by type, with the most interest in strengthening openings, and that homeowners are more likely to retrofit when they are closer to the coast, younger, in newer homes, or within a year of a hurricane experience.

## Chapter 1

### INTRODUCTION

#### 1.1 Retrofitting as an Effective Damage Reduction Method

While building codes have long been recognized as a critical mechanism for reducing the vulnerability of homes to damage from hurricanes and other extreme events, they typically apply only to new construction. For existing homes built before current codes were in place, retrofitting (i.e., strengthening) can be an effective way to reduce damage. Historically, however, household retrofits have not been widely implemented. Recognizing the risk associated with existing homes and the fact that homeowners have tended not to retrofit voluntarily, an increasing number of programs offer incentives to encourage homeowners to undertake those efforts (Rollins and Kinghorn 2013). The incentives come in different forms (e.g., grants, low interest loans, insurance premium reductions, and income tax deductions), address different hazards (wind, flood, earthquake), and offer different specific terms. In Florida, for example, the \$250 million My Safe Florida Home program, which operated from 2007 to 2009, offered homeowners a free vulnerability assessment and the possibility of a \$5000 grant to retrofit (Smith et al. 2016). Since 2011, North Carolina has offered insurance premium savings for those who install wind mitigation features according to the Insurance Institute for Business & Home Safety (IBHS) Fortified classifications ([disastersafety.org/fortified/](http://disastersafety.org/fortified/)) (NCJUA/NCIUA 2017). The Earthquake Brace + Bolt Program in California offers up to \$3000 to do certain earthquake retrofits on a house (CRMP 2017).

## **1.2 Research Motivation**

Despite the programs mentioned in previous section, little is known about how homeowners make retrofit decisions or the effect of monetary incentives on those decisions. While there is a significant and growing literature on protective action decision-making, it has primarily addressed activities associated with preparedness, recovery, insurance, and other types of mitigation, rather than decisions associated with structural retrofits (e.g., Bubeck et al. 2012, Lindell and Perry 2012, Lindell et al. 2009, Wang et al. 2017). Retrofits are different in character, typically requiring more time, money, and expertise to implement, and in some cases, affecting the appearance or value of the house.

In this study, we contribute to the empirical literature on homeowner retrofit decision-making through an analysis of survey data of homeowners in North Carolina about hurricane retrofits. Specifically, combining revealed and stated preference data, we develop separate mixed logit models for decisions about retrofits aimed at addressing four different types of hurricane damage—wind damage to the roof, wind damage to openings (windows, doors), wind damage to the roof-to-wall connection, and flood damage. In each case, we examine the effect of three possible types of monetary incentives—low interest loan, insurance premium reduction, and grant. Combining the two data types allows us to combine the strengths of each—investigation of incentives that do not yet exist in the real world through stated preference data and take-up rates of existing options through revealed preference data. The former allows for exploration of new possibilities, but relies on individuals' projections about what they might do in the future. The latter provides results that are often thought to be more reliable, but are necessarily limited to programs that have already been implemented. In particular, the study aims to develop statistical models

so they can be used to: (1) predict regional take-up rates for different retrofit types under different possible incentives; (2) better understand the effects of the different incentive types; and (3) and identify characteristics of homeowners more likely to undertake retrofits.

### **1.3 Organization of the Thesis**

The remainder of this thesis will provide lengthy, yet informative details on the process utilized to successfully understand the decisions being made by homeowners for different retrofit types under different possible incentives, during the hazards resulted from hurricanes. Chapter 2 is composed of background information that is necessary for understanding the logic and reasoning behind the homeowner retrofit decision making for predicted natural hazards. Following a review of the literature, we describe the data used in empirical model in Chapter 3 of this thesis. Chapter 4 describes the mixed logit model used in this study. Chapter 5 presents the conclusions and results drawn from the proposed model. Chapter 5 also includes a comparison of alternative model specifications and discussion of the final recommended models. We conclude with discussion of policy implications and a summary of the contributions and limitations. In addition, the designed questionnaire survey is provided in an individual Appendix.

## **Chapter 2**

### **BACKGROUND**

#### **2.1 Homeowner Retrofit Decision-Making**

Few papers have addressed homeowner decision-making related to whether or not to implement a structural retrofit that protects against damage from hurricanes or other extreme events. Of those that have, we find a mix of revealed preference (behavioral) studies and stated preference (perception) studies that can inform the current mixed approach. Further, the extant literature has addressed decisions for both wind and flood hazards that are also relevant to the current effort. In an early study, Peacock (2003) used revealed preference (RP) survey data to develop ordinal regressions that estimate the extent of hurricane shutter usage and envelope coverage as functions of household characteristics. Carson et al. (2013) utilized records of inspections, grant applications, and mitigation grants from the My Safe Florida Home (MSFH) program in Florida to investigate several hypotheses from the self-insurance theory in the economics literature. In a Heckman two-stage model that includes the probability of mitigating and the amount spent on mitigation, mitigation was treated as a binary variable with a value of one if the respondent undertook at least one of the wind damage reduction strategies allowed under the program. Petrolia et al. (2015) examined the wind mitigation decision in conjunction with the insurance purchase decision using RP survey data. They consider the following wind retrofits and code the response variable as number of mitigation activities from 0 to 5+: storm shutters, roof anchors, reinforced doors, wind-resistant glass, wind-resistant shingles, and

hurricane ties. One of the few studies to address incentives, Ge et al. (2011) examines the decision to install hurricane shutters and considers five possible incentives to encourage them—low interest loan, 5-year forgivable loan, reduction in homeowners insurance, property tax reduction, and home preparedness inspection program. They develop five separate logistic regression models, each using the response variable of likely to participate in the incentive program or not.

In addition to studies focused on mitigation for wind damage, several address mitigation for flood damage. Using survey data in Germany, Gorthmann and Reusswig (2006) develop logistic regression models of the decision to purchase flood mitigation devices (e.g., pumps) and the decision to undertake structural mitigation, such as elevating the heating equipment. Kreibich et al. (2005) and Thieken et al. (2006) analyze mitigation by households affected by the 2002 Elbe floods in Germany. Poussin et al. (2013, 2014) use RP and SP data from France to examine the number of flood mitigation measures in the house and the intent to do them in the future. While the previously mentioned studies use data only for households in floodprone areas, Osberghaus (2015) uses RP and SP data (analyzed separately) from across Germany to develop probit regressions for the decision to do (or intent to do) any of six flood mitigation measures—moving assets to higher floors; water barriers at basement openings; back flow flap; water-resistant exterior paint coat, interior paint coat, or floor. Like these previous studies, the research presented herein is one of the few that addresses structural retrofit measures. It extends that work by modeling and comparing the decisions to undertake different specific structural wind and flood retrofit strategies separately rather than creating a composite measure, such as the number of strategies; by comparing the effects of different monetary incentives on

those decisions; and by combining the strengths of RP and SP data using data from the U.S. Considering specific retrofit strategies separately is important because the costs, risk reduction benefits, and other attributes of strategies can differ greatly.

## **2.2 Factors Related to Retrofit Decision-making**

The covariates considered in this analysis were identified based on a broad review of the empirical literature. Importantly, however, it focuses on variables that can be matched to population-level data and thus used in a predictive mode to estimate take-up rates for a region (i.e., variables for which data are available at a regional scale). While psychological factors such as risk perception, may be important determinants of behavior, we do not include them in this analysis because they cannot be used to predict population-level behaviors. In this section, we discuss each covariate selected, in turn. Bubeck et al. (2012) and Poussin et al. (2014, supplementary material) provide more extensive summaries of the literature on factors that influence mitigation behavior. Wang et al. (2017) reviews it for the related decision of insurance purchase.

### **2.2.1 Incentives.**

Ge et al. (2011) used participation in an incentive program as the response variable rather than a covariate, but they do report that 31%, 60%, 69%, and 69% of responding households were likely to install shutters in response to a low-interest loan, 5-year forgivable loan, homeowner's insurance premium reduction, or property tax reduction, respectively. Poussin et al. (2014) found evidence that respondents who were "obliged to or received a strong incentive to do so" from a municipality or insurer undertook more mitigation measures. Hypotheses:(H<sub>1</sub>) Incentives are

associated with higher probability of retrofit, and (H<sub>2</sub>) a grant has a stronger effect than a low interest loan or premium reduction.

### **2.2.2 Exposure/location/structural vulnerability factors**

Proximity to hazard can influence retrofit decisions by affecting risk perception and hazard experience (Ge et al. 2011). For wind retrofits, Peacock (2003), Ge et al. (2011), and Petrolia et al. (2015) found evidence that proximity to the coast was associated with increased mitigation. However, in Ge et al. (2011), the effect disappeared when risk perception and hazard intrusiveness were included; and in Peacock (2003), location in a coastal county was associated with increased mitigation, but being in the most at-risk areas of those counties, the evacuation zones, was not. For flood, none of the retrofit studies examined the effect of location, because either the sampled data was only from floodprone areas (e.g., Grothmann and Reusswig 2006, Poussin et al. 2014) or location was included as one of many bundled into control variables (Osberghaus 2015).

Some studies have used home age as a proxy for structural vulnerability and hypothesized that older homes are likely to be more vulnerable, have greater benefits associated with mitigation and therefore, are more likely to be associated with mitigation activities. Carson et al. (2013) and Grace et al. (2004) found older homes more likely to be mitigated and have catastrophe insurance, respectively. Peacock (2003) found a positive relationship between years in residence (which is strongly correlated to home age) and mitigation. On the other hand, Petrolia et al. (2015) report evidence that older homes are associated with less wind mitigation. They hypothesize that may be because newer homes are built to codes that require more mitigation features (which applies if considering the presence of certain features of a home, not a

deliberate act to install those features), or that home age and home value tend to be negatively related, and homeowners may be willing to spend less on mitigation for less valuable homes. In that case, home age is essentially an indicator of asset value, not vulnerability. Hypotheses: Shorter distance to coastline (H<sub>3</sub>) and location in a floodplain (H<sub>4</sub>) are associated with higher probability of retrofit. The relationship between home age and probability of retrofitting is unclear.

### **2.2.3 Hazard experience factors.**

Peacock (2003), Petrolia et al. (2015), Kreibich et al. (2005), Gorthmann and Reusswig (2006), and Osberghaus (2015) find evidence that prior hazard experience is associated with increased mitigation. Ge et al. (2011) found evidence for the decision to accept a low-interest loan, but not the other incentives. In reviewing flood mitigation decisions, Bubeck et al. (2012) report strong evidence of a positive relationship between experience and flood mitigation across multiple studies as well. In Poussin et al. (2014), however, flood experience is positively related to implementation of non-structural measures (avoidance and emergency preparedness), but not structural measures. In addition to the type of mitigation measure (structural vs. non-structural), the specific nature of the experience—number and recentness of events, and severity and nature of the overall impact of the event and of the impact to the homeowner personally—may affect how important experience is in influencing protective action. Hypotheses: More hurricane experiences (H<sub>5</sub>) and less time since the last hurricane experience (H<sub>6</sub>) are associated with higher probability of retrofitting.

#### **2.2.4 Socio-demographic factors.**

Income is often shown to be positively related to mitigation efforts, especially those with substantial upfront cost, such as the structural retrofits considered in this analysis. Indeed, Peacock (2003), Grothmann and Reusswig (2006), Osberghaus (2015), and Ge et al. (2011) all report evidence that higher income is associated with more mitigation. In Petrolia et al. (2015) and Poussin et al. (2014), however, income was not a significant predictor of mitigation.

Other socio-demographic characteristics can facilitate our understanding of social vulnerability to hazards and allow identification of populations most and least likely to adopt mitigation measures for use in targeting policies and programs (Peacock 2003, Ge et al. 2011). Demographic factors may affect risk perception or access to resources required for mitigation (Ge et al. 2011). Those with less formal education may have less access to resources and information about mitigation. Older homeowners may be less inclined to mitigate since they will likely have less time to enjoy the benefits of a strengthened home and may be more likely to be on a fixed income and not as willing to take on financial risk (Ge et al. 2011). Previous findings on the role of socio-demographic variables are somewhat mixed (Poussin et al. 2014). Age was positively related to mitigation in Poussin et al. (2014), Osberghaus (2015), and Grothmann and Reusswig (2006); negatively related in Ge et al. (2011); and insignificant in Peacock (2003). There is little evidence that gender, marital status, race, or education are significant. Hypotheses: (H<sub>7</sub>) Higher income is associated with higher probability of retrofitting. The relationships between other homeowner characteristics (age, gender, marital status, education, and race) and probability of retrofitting are unclear.

## **Chapter 3**

### **DATA**

#### **3.1 Survey Overview**

Data reported here are taken from a telephone survey carried out in Fall 2012 through Spring 2013 at the University of Delaware, Disaster Research Center (DRC). The survey was designed to obtain household-level information about homeowners' hurricane mitigation decisions. It included questions about the respondent's house, hazard event experience, past insurance and retrofit decisions, hypothetical future retrofit decisions, and socio-demographic characteristics. The study area was the eastern half of North Carolina, including Raleigh. The sample included 50% listed household numbers, 25% random digit dial landline numbers, and 25% random digit dial cellphone numbers. Telephone numbers were purchased from a third party provider, Genesys. Business and disconnected numbers were removed, and screening questions ensured the house was single-family or duplex and the respondent was the homeowner who makes retrofit decisions. A computer-assisted telephone interviewing (CATI) interview protocol was used to conduct the survey, which required 27 minutes on average to administer. Each phone number was called up to ten times. An incentive was offered to participants who completed the survey in that they were entered into a drawing with a 1 in 100 chance of winning an iPad. The dataset includes 303 respondents after removing the ineligible respondents, resulting in a 19.5% cooperation rate. There were 303 RP observations and 226 to 320 SP observations

depending on the model (226 for roof, 273 for roof-to-wall, 319 for openings, and 261 for flood) (Table 3.1).

Table 3.1 Number of observations for each choice for each response variable

Damage type	Retrofit alternative	Revealed preference <sup>a</sup>	Stated preference	
Roof	Shingles later	89	132	
	Shingles now	---	21	
	Adhesive	10	12	
	None	204	61	
	Total	303	226	
Wind	Shutters	20	42	
	Openings	Impact resistant	73	54
		None	210	223
	Total	303	319	
Roof-to-wall	Straps	47	60	
	None	256	213	
	Total	303	273	
Flood	Appliances	7	20	
	Insulation/siding	41	29	
	Elevation	87	8	
	None	168	204	
	Total	303	261	

<sup>a</sup> Values are after all coding adjustments have been implemented as described in section 3.2.

We compared the sample distribution for each variable to the distribution for all homeowners in the eastern half of North Carolina to ensure that the sample is reasonably representative of the population. The sample is slightly older (mean age is 59.3 for sample vs. 53 for population), more likely to be in flood plain area (mean is 0.12 for sample and 0.03 for population), and very slightly farther from coastline (mean is 104 km for sample vs. 94 km for population). Since the population distribution of income was not available for homeowners, based on an estimate using

the income distribution for the population and national rates of homeownership by income bracket, the sample is likely somewhat higher income than the population.

### **3.2 Response Variables**

Four analyses were conducted, one each to address four types of damage: (1) wind damage to the roof, (2) wind damage to the openings (i.e., windows and doors), (3) wind damage to the roof-to-wall connection, and (4) flood damage. For each analysis, a response variable was defined to represent a homeowner's choice to do nothing or choose among one to three possible retrofit strategies (Table 3.1). The wind retrofit options were defined to be compatible with those recommended in the Insurance Institute for Business and Home Safety (IBHS) Fortified Home program (<https://disastersafety.org/fortified/>). The flood retrofit options were adopted from Taggart and van de Lindt (2009). Both revealed preference and stated preference data were collected for each response variable. The two methods of uncovering homeowner preferences offer complementary strengths, and combining them in an analysis can allow us to take advantage of those complementarities. Revealed preference data reflect actual choices and thus have high reliability and face validity, but they are not available for incentive conditions that do not exist (Louviere et al. 2000). Survey questions representing a stated preference approach fill this gap.

To collect the revealed preference data, one question was asked for wind and one for flood, and respondents were asked if their house had each possible feature that would mitigate the damage. For wind damage, for example, they were asked: "To the best of your knowledge, does your home have any of the following features that protect against wind damage?" They then answered yes, no, or don't know for each of the following: (1) High wind shingles and synthetic water barrier on

the roof, (2) spray adhesive applied to the underside of the roof in the attic, (3) hurricane straps to improve the connection between roof and walls, (4) hurricane shutters, (5) impact resistant windows and doors. For each feature with a Yes response, the respondent was then asked, “For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.” Similarly, for flood damage, they were asked “To the best of your knowledge, does your home have any of the following features that protect against flood damage?” They then answered yes, no, or don’t know for each of the following: (1) elevated electrical outlets and appliances, (2) water-resistant insulation and siding, (3) is your entire house elevated. The same question then followed to determine if features were there due to deliberate action or not.

For the stated preference data, one question was presented for each of the four damage types and respondents were asked which, if any, of the strengthening strategies they were most likely to do in the next couple years. A brief introduction explained that for each specific strengthening activity, a rough estimate of the cost for an average-sized home would be provided, but “while actual costs can vary significantly depending on the home, contractor, and other factors these should give some sense of the expense involved.” For wind damage to the roof, the choices were: (1) Wait until you have to redo your roof anyway and at that time use high wind shingles and a special water barrier underneath, which would add about \$400 extra to your roofing bill, (2) reroof now with high wind shingles and a special water barrier underneath, which would cost about \$8000, (3) apply a special foam adhesive on the

underside of the roof in the attic, which would cost about \$2000, (4) none of those. For wind damage to openings, the choices were: (1) Install permanent hurricane shutters on all windows and exterior doors, and reinforce any garage doors which would cost about \$7,000, (2) install impact resistant windows and exterior doors everywhere, and reinforce any garage doors which would cost about \$15,000, (3) neither. For wind damage to the roof-to-wall connection, the choices were: (1) add metal hurricane straps for about \$2000, (2) do not. For flood damage, the choices were: (1) Elevate electrical switches, outlets, and appliances to keep them above any flood water that entered your home, which would cost about \$2000, (2) install water-resistant insulation and siding to protect those items from damage, which would cost about \$10,000, (3) Elevate your entire home on piles, which could cost about \$52,000 if you have a basement or \$144,000 if you do not have a basement, (4) none of those.

Each respondent was asked the stated preference questions twice, and each time they were asked to assume one of four hypothetical incentive conditions: (1) No incentive, (2) grant that does not need repayment, (3) low interest loan, or (4) insurance premium reduction. The selection and order of incentive conditions were randomized across respondents. For each wind damage type, if the respondent indicated in the revealed preference questions that his house had a mitigation feature, then the corresponding question was not asked as a stated preference question because it did not make sense to ask if the homeowner would be adding a feature that the house already had. For flood damage, if the respondent indicated in the RP question that the entire house had been elevated already, then the corresponding SP question was omitted. Complete survey questions are available in Appendix A.

The revealed preference questions required a few special coding notes to fit the final choice sets (Table 3.1). Assuming a homeowner would know if he had undertaken a deliberate retrofit, we coded Don't know responses as No. Observations in which a homeowner indicated his house had a retrofit feature but it was not because of a deliberate action were coded as No as well because indicating the feature was not important to them suggests they likely would not have done the retrofit given the chance. To merge the RP and SP choice sets, the Shingles response in the RP question was coded as Shingles Later, assuming houses that have the high-wind shingles installed them as part of construction or regular, periodic roof replacements rather than stand-alone roof retrofits. When a respondent said he had done both roof retrofits deliberately (14 times), we coded it as Shingles because there is not a reason to do both, so there was likely a misunderstanding and since shingles are more obvious, we assumed that is what was done. Similarly, when both Shutters and Impact resistant were indicated (10 times), we coded it as Shutters. Finally, when a respondent said he had deliberately done multiple flood retrofits (57 times), we coded it as the more expensive one. In each case, we explored other reasonable assumptions (e.g., removing the Both responses for openings), but none affected the results enough to change the conclusions. Table 3.1 summarizes the data after these coding notes were implemented.

### **3.3 Covariates**

Candidate covariates were selected to: (1) incorporate concepts that are most likely to predict the retrofit decision based on the literature, as discussed above, (2) concentrate on those that can be used in predictive mode (i.e., those that data can be collected for a region), (3) restrict the total number to prevent overspecification

(Babyak 2004, Harrell 2015, Hutcheson 2011), and (4) avoid including multiple covariates that were highly correlated. Tables 3.2 and 3.3 present the descriptive statistics for the continuous and categorical covariates, respectively.

Table 3.2 Descriptive statistics for continuous covariates

Variable	Hypothesized effect <sup>a</sup>	Num. respondents	Mean	Standard deviation
$x_{dist}$ Distance to coastline, km	Negative	257	104.0	69.06
$x_{hage}$ Home age, yrs	Unclear	307	31.9	27.38
$x_{inc}$ Income, <sup>b</sup> \$/yr	Positive	223	101,334	72,112
$x_{age}$ Age, yrs	Unclear	272	59.3	13.43

<sup>a</sup>Positive means increase in variable is associated with an increase in probability of doing a retrofit

<sup>b</sup>Income was asked as an interval variable but was coded as a continuous variable with the values in parentheses for each interval: less than \$15k (\$7.5k), \$15k-\$35k (\$25k), \$35k-\$50k (\$42.5k), \$50k-\$75k (\$62.5k), \$75k-\$100k (\$87.5k), \$100k-\$150k (\$125k), \$150k-\$250k (\$200k), more than \$250k (\$300k).

Table 3.3 Number of respondents associated each level for categorical covariates

Variable <sup>a</sup>	Hypothesized effect <sup>b</sup>	Levels	Num. respondents
$x_{num1}$ , $x_{num2}$ Num. hurricane experiences	Positive	2 Three or more experiences	201
		1 One or two experiences	62
		0 No experiences	18
$x_{time1}$ , $x_{time2}$ Time since last hurricane experience	Negative	2 Five or more years	115
		1 Two to four years	112
		0 One year or less	35
$x_{fp}$ Location in floodplain	Positive	1 In floodplain	30
		0 Not	226
$x_{exp}$ Hurricane experience	Positive	1 Yes	263
		0 No	18
$x_{mg1}$ , $x_{mg2}$ Marital status/gender	Unclear	2 Married	207
		1 Single male	22
		0 Single female	48
$x_{rac}$ Race	Unclear	1 White	224
		0 Other	51
$x_{edu}$ Education	Unclear	1 At least 4-year college degree	160
		0 Other	118

<sup>a</sup>For the three-level categorical variables (i.e., *Num. hurricane experiences*, *Time since last hurricane experience*, and *Marital status/gender*), *Level=0* corresponds to  $x_1=0$  and  $x_2=0$ ; *Level=1* corresponds to  $x_1=1$  and  $x_2=0$ ; and *Level=2* corresponds to  $x_1=0$  and  $x_2=1$ .

<sup>b</sup>Positive means increase in variable is associated with an increase in probability of doing a retrofit

*Location in a floodplain* ( $x_{fp}$ ) and straight-line nearest *Distance to coastline, km* ( $x_{dist}$ ) were computed in a geographic information system (GIS) based on the address or nearest cross-streets provided. In the survey, respondents were asked “How many hurricane events have you personally experienced?” which provided *Number of hurricanes experienced* ( $x_{num}$ ). If they answered more than zero to that question, they were asked for the year of their last hurricane experience to get *Time since last hurricane* ( $x_{time}$ ). *Number of hurricanes experienced* ( $x_{num}$ ) was coded as categorical (Table 3.3) to reflect the idea that there is a big difference between having at least one experience vs. none, and that each additional experience is not equally important. Similarly, *Time since last hurricane* ( $x_{time}$ ) is categorical with the idea that an extra year since the hurricane experience is not equally important if it has been one to two years, vs. 14 to 15 years. Since the *Time since last hurricane* ( $x_{time}$ ) only applies to responses with a positive number of hurricanes experienced, we defined the binary *Hurricane experience* ( $x_{exp}$ ) variable as one when  $x_{num} > 0$  and zero otherwise so that  $x_{exp} * x_{time}$  could be used in the models.

### **3.4 Imputation**

The data for the 303 respondents had missing values in a patchwork, not monotone pattern. Using the common methods of listwise or pairwise deletion to handle the missing data results in discarding a large number of observations and producing coefficient estimates that are potentially biased (Harrell 2015). Therefore, we used multiple imputation to address the missing data instead. In multiple imputation, for each missing value,  $m$  new values are imputed, which results in  $m$  complete datasets. The datasets are analyzed separately and then the results combined to create one final pooled result (van Buuren 2012). Unlike single imputation, multiple

imputation accounts for the uncertainty around the imputed data. We used the package `{mice}` in R for imputation, which uses the multiple imputation using chain equations (MICE) algorithm (van Buuren and Groothuis-Oudshoorn 2011, van Buuren 2012). We generated  $m=7$  imputed datasets, consistent with approximate guidelines in van Buuren (2012) and Harrell (2015). As recommended in Hurrell (2015) and Moons (2006), and White et al. (2011), we used all variables as predictors, and the algorithm was set for 30 iterations. The classification and regression trees (CART) method was used for *Number of hurricane experiences*, *Home age*, *Distance to coastline*, and *Time since last hurricane* since it provided the best results for those variables. Otherwise, default settings were used, i.e., logistic regression for binary variables and predictive mean matching for other variables. To ensure they are adequately similar, we compared the distributions of the observed and imputed data using kernel densities for continuous variables, and frequency tables for categorical variables. Results suggest that in terms of distributions of variables, the imputed datasets match the observed data. Results from imputed datasets were combined using Rubin's rules (van Buuren 2012, White et al. 2011, Miles 2015).

## Chapter 4

### MIXED LOGIT MODEL

The analyses in this study require discrete choice models, since each describes a choice between two or more discrete alternatives—a specified retrofit alternative or doing nothing. Specifically we employ mixed logit models (also known as random parameters logit models) using the unified framework described in Hensher et al. (2008) because it is implemented in NLOGIT software and is able to capture three issues relevant to this situation: (1) Inter-alternative error structure, (2) RP-SP scale difference, and (3) unobserved heterogeneity effects. First, the simpler multinomial logit (MNL) model assumes error terms are identically and independently distributed (IID) across alternatives with an extreme value type I distribution. As a result, the MNL model has the independence of irrelevant alternatives (IIA) property. We suspect the IID assumption may not hold in this case because of the difference between the *No retrofit* alternative on the one hand, and the different retrofit type alternatives on the other. Instead, we want to allow correlation across the error terms of the retrofit alternatives. Second, we are combining RP and SP data in this analysis and since the RP and SP choice settings are quite different, there is no reason to believe that the variance of the unobserved factors in the two settings will be the same. As a result, it is necessary to allow the scale for the RP responses to differ from the scale for the SP responses. Third, we have panel data, with each respondent providing answers to up to three questions, an RP and an SP with each of two different incentive conditions. As a result, we want to allow that there may be some correlation among

responses of a single individual across multiple questions. These unobserved heterogeneity effects also lead indirectly to non-IID error structures across alternatives and thus violation of the IIA property (Bhat and Castelar 2002). Note we omit the fourth issue Hensher et al. (2008) discuss, state dependence, since respondents were only asked SP questions if they indicated in the RP response that the corresponding retrofit had not already been done. Bhat and Castelar (2002) explain the four issues as well.

With these ideas in mind, the formulation is as given in Hensher et al. (2008), with  $\varphi_i = 0$  to omit state dependence. Each household decision-maker is assumed to choose the single alternative that provides the highest utility from among a finite set of alternatives. The utility,  $U_{ijt}$ , that an individual  $i$  assigns to an alternative  $j$  on choice occasion  $t$  may be written:

$$U_{ijt} = \alpha_{ji} + \beta_i^T x_{jit} + \sum_{m=1}^M d_{jm} \theta_m E_{im} \quad (4.1)$$

where  $\alpha_{ji}$  are alternative-specific constants (ASCs);  $x_{jit}$  is a vector of observed covariates relating to individual  $i$ , alternative  $j$ , and choice occasion  $t$ ;  $\beta_i$  is the corresponding coefficient vector for individual  $i$ ; and the last term represents error components used to capture influences related to alternatives. A choice occasion  $t$  may be the RP choice occasion or one of the SP choice occasions. The alternative-specific constants and variable coefficients can be random parameters, specified as:

$$\alpha_{ji} = \alpha_j + \sigma_j v_{ji} \quad (4.2 \text{ a})$$

$$\beta_{ki} = \beta_k + \sigma_k v_{ik} \quad (4.2 \text{ b})$$

where  $\alpha_j$  and  $\beta_k$  are the population means for the  $j^{\text{th}}$  alternative-specific constant and  $k^{\text{th}}$  coefficient, respectively;  $v_{ji}$  and  $v_{ik}$  are the individual-specific heterogeneity with mean zero and standard deviation one; and  $\sigma_j$  and  $\sigma_k$  are the standard deviations of the distributions around  $\alpha_j$  and  $\beta_k$ , respectively. In all models in this paper, we use the *No retrofit* alternative as the reference level, and thus ASCs are only estimated for the other alternatives. The last term in Equation 4.1 adds error components to create what amounts to a random effects model. Alternatives are divided into  $M$  groups sharing common unobserved components (in this case, we group retrofit alternatives separately from the *No retrofit* alternative). Covariance is introduced among the alternatives in group  $M$ , and heteroscedasticity across the groups of alternatives. Specifically, in the last term of Equation 4.1,  $E_{im} \sim N[0,1]$  for  $m = 1, \dots, M$ ;  $\theta_m$  is the standard deviation associated with the effect for group  $m$ ; and  $d_{jm}$  are binary variables that are one if random term  $E_{im}$  appears in the utility function for alternative  $j$  and zero otherwise.

With these utility functions, the probability individual  $i$  chooses alternative  $j$  in choice occasion  $t$  is:

$$P(y_{it} = j) = \frac{\exp(U_{ijt})}{\sum_{q=1}^{J_i} \exp(U_{iqt})} \quad (4.3)$$

It can also be written in vector form, substituting the utility equation in, and simplifying the notation by including the alternative-specific constants in  $\beta_i$  and the corresponding alternative-specific dummy variables in  $x_{jit}$  to obtain:

$$P(y_{it} = j | v_i, E_i) = \frac{\exp[(\beta + \Gamma\Omega v_i)x_{jit} + \sum_{m=1}^M d_{jm}\theta_m E_{im}]}{\sum_{q=1}^{J_i} \exp((\beta + \Gamma\Omega v_i)x_{qit} + \sum_{m=1}^M d_{qm}\theta_m E_{im})} \quad (4.4)$$

where  $v_i$  is a vector of independent random variables with mean zero and variance one,  $\mathbf{\Omega}$  is a diagonal matrix of standard deviations, and  $\mathbf{\Gamma}$  is a lower triangular matrix that allows correlation across parameters. In all models in this analysis, we assume random parameters are uncorrelated, so  $\mathbf{\Gamma} = \mathbf{I}$ . These conditional choice probabilities are functions of the unobserved individual-specific random terms, so the unconditional choice probabilities are computed by integrating over the random terms to obtain Equation 4.5. The integral has to be solved by simulation as described in Hensher et al. (2008) and Train (2009).

$$P(y_{it} = j) = \int_{v_i} \int_{E_i} P(y_{it} = j | v_i, E_i) f(v_i, E_i) dE_i dv_i \quad (4.5)$$

To accommodate the scale difference between the RP and the SP choice occasions, the scale parameter for the RP dataset is normalized to one, and the scale parameter for the SP data set relative to RP is specified as:

$$\lambda_{qt} = [(1 - \kappa_{qt,RP}) \times \lambda] + \kappa_{qt,RP} \quad (4.6)$$

where  $\kappa_{qt,RP}$  is a dummy variable that is one if choice occasion  $t$  for individual  $q$  corresponds to an RP choice and zero otherwise; and  $\lambda$ , the SP scale relative to RP, is estimated. In NLOGIT, which was used in this study,  $\lambda$  is estimated by introducing a set of ASCs into the SP data that have zero mean and free variance (Hensher et al. 2008, Hensher et al. 2015). Then according to the extreme value I distribution,  $\lambda$  is inversely proportional to  $\sigma$ , the estimated standard deviation of the ASC of an alternative:  $\lambda = (\pi/\sqrt{6})$ ,  $\sigma = 1.28255/\sigma$ . For each model, we used NLOGIT 5 to solve each imputed dataset and then we pooled the results manually in Excel (Greene 2012).

## **Chapter 5**

### **RESULTS AND CONCLUSION**

#### **5.1 Comparison of Model Specifications**

Four different versions of the models were fitted to examine the effect of addressing the three issues mentioned in the Mixed Logit Model section—unobserved heterogeneity effects, scale difference, and inter-alternative error structure—and chose a best formulation. Table 5.1 summarizes the results for the wind damage to openings models. A similar process was used for each of the other three damage types. We begin with the simplest model and gradually add complexity.

Table 5.1 Comparison of alternative model formulations for wind damage to openings retrofit decision

Attribute	Model 1		Model 2		Model 3		Model 4	
	Multinomial		Panel data		Panel and SP-RP scale		Panel, SP-RP scale, inter-alternative error	
	Parameter <sup>a</sup>	p-value	Parameter <sup>a</sup>	p-value	Parameter <sup>a</sup>	p-value	Parameter <sup>a</sup>	p-value
<b>Alternative specific constants</b>								
Shutters – RP	-1.497 <sup>‡</sup>	0.037	-2.729*	0.006	0.222	0.663	-1.924	0.209
Impact resistant– RP	-0.202	0.770	-1.434	0.138	1.517*	0.001	-0.629	0.680
Shutters – SP	-1.459 <sup>‡</sup>	0.048	-5.379*	0.001				
Impact resistant– SP	-1.208 <sup>†</sup>	0.099	-4.145*	0.002				
<b>Covariates</b>								
Grant, $x_g$	2.033*	0.000	3.162*	0.000	2.248*	0.000	4.115*	0.000
Premium reduction, $x_{pr}$	0.460	0.271	0.952	0.128	-0.013	0.981	1.038	0.204
Low interest loan, $x_{loan}$	0.399	0.358	0.639	0.319	-0.262	0.654	0.628	0.486
Location in floodplain, $x_{fp}$	0.526	0.128	0.758 <sup>†</sup>	0.072	0.621	0.152	2.296	0.173
Distance to coastline, $x_{dist}$	-0.008*	0.000	-0.009*	0.000	-0.011*	0.000	-0.033*	0.008
Home age, $x_{hage}$	-0.001	0.901	0.002	0.733	-0.001	0.917	0.006	0.751
Num. hurricane experiences 1, $x_{num1}$	0.366	0.482	1.056	0.146	0.057	0.927	1.914	0.435
Num. hurricane experiences 2, $x_{num2}$	0.127	0.786	0.732	0.270	-0.275	0.622	0.920	0.666
Time since last hurricane 1, $x_{time1}$	-0.692 <sup>‡</sup>	0.036	-0.918 <sup>‡</sup>	0.022	-0.858 <sup>‡</sup>	0.037	-3.181 <sup>‡</sup>	0.057
Time since last hurricane 2, $x_{time2}$	-0.052	0.878	-0.063	0.879	0.136	0.749	0.025	0.986
Age, $x_{age}$	0.003	0.691	0.014	0.181	-0.008	0.337	0.018	0.562
Income, $x_{inc}$	0.003 <sup>†</sup>	0.054	0.003	0.216	0.002	0.479	0.006	0.410
Marital status/Gender 1, $x_{mg1}$	-0.627	0.201	-0.627	0.289	-0.968	0.110	-2.440	0.269
Marital status/Gender 2, $x_{mg2}$	-0.005	0.986	0.247	0.502	-0.133	0.696	0.664	0.610
Race, $x_{race}$	-0.479 <sup>†</sup>	0.075	-0.483	0.140	-0.517	0.116	-1.307	0.263
Education, $x_{educ}$	-0.136	0.531	-0.199	0.459	-0.338	0.212	-0.808	0.364
<b>Random parameter st. dev., <math>\sigma_j</math></b>								
Shutters - SP			3.369*	0.000				
Impact resistant - SP			2.520*	0.000				
No retrofit - SP								
<b>SP-RP Scale Parameter, <math>\lambda</math></b>								
Shutters					1.328	0.138	0.939	0.139
Impact resistant					0.870*	0.004	0.613 <sup>‡</sup>	0.019
No retrofit					0.596*	0.000	1.457	0.663

<sup>a</sup>The symbols <sup>†</sup>, <sup>‡</sup>, \* indicate significance levels of 0.1, 0.05, and 0.01, respectively

5.1 Comparison of alternative model formulations for wind damage to openings retrofit decision

Attribute	Model 1		Model 2		Model 3		Model 4	
	Multinomial		Panel data		Panel and SP-RP scale		Panel, SP-RP scale, inter-alternative error	
	Parameter <sup>a</sup>	p-value	Parameter <sup>a</sup>	p-value	Parameter <sup>a</sup>	p-value	Parameter <sup>a</sup>	p-value
<b>Error components, <math>\sigma_m</math></b>								
Retrofit alternatives (RP and SP)							4.914	0.502
No retrofit (RP and SP)							5.102	0.486
Sample size	622		622		622		622	
k (all parameters)	20		22		21		23	
McFadden pseudo R <sup>2</sup>	0.050		0.611		0.605		0.613	

<sup>a</sup>The symbols †, ‡, \* indicate significance levels of 0.1, 0.05, and 0.01, respectively

Model 1 is a base case that ignores the three issues described above. Neglecting the fact that the data set is a panel (unobserved heterogeneity), Model 1 treats every observation as independent despite the fact that up to three responses are associated with the same person. Ignoring the scale difference means that the error variance is the same for RP and SP choice situations. The model also omits the last term in Equation 4.1, thus not specifying inter-alternative error correlations. Model 2 acknowledges the fact that the data are panel data. The alternative-specific constants (ASCs) for SP are treated as random variables. Comparing Models 1 and 2 suggests that it is important to recognize the properties of panel data. The standard deviations associated with the ASCs,  $\sigma_j$ , are highly significant (3.369 and 2.520 with  $p < 0.0001$ ), suggesting there is considerable individual-level heterogeneity in intrinsic preferences for the different alternatives. The models' goodness-of-fit, as evaluated based on the McFadden's pseudo- $R^2$ , also suggest Model 2 is preferred to Model 1 ( $R^2_{Model1} = 0.05$ ,  $R^2_{Model2} = 0.61$ ). The McFadden's pseudo- $R^2$ , also called the likelihood ratio index,  $0 < \rho < 1$ , is defined as  $\rho = 1 - (LL(\hat{\beta})/LL(0))$ , where  $LL(\hat{\beta})$  is the log-likelihood value at the estimated parameters and  $LL(0)$  is the log-likelihood with alternative specific constants only (Hensher et al. 2015). In Model 2, note also that the SP ASCs are substantially lower than the corresponding RP ASCs, which suggests that people understate their tendency to retrofit in the stated preference relative to what the revealed preference responses indicate. (Since NLOGIT uses SP ASCs to compute the SP-RP scale parameter, the comparison is not available for Models 3 or 4.)

In Model 3, we retain the panel data and add the scale difference, which is commonly accounted for when combining RP and SP data. The scale of SP relative to RP is highly significant for the alternatives *Impact resistant* and *None*. In both cases

they are less than one ( $\lambda_{ImpactResistant} = 0.870$  and  $\lambda_{None} = 0.596$ ), meaning that the error variance in the SP choice context is higher than in the RP choice context, perhaps because of the limited set of attributes in the SP questions. Finally, in Model 4, the inter-alternative error structure is included. Specifically, two groups of alternatives are defined ( $M=2$ )—all alternatives that are associated with undertaking a retrofit in one group, and *None* in the other group—with the idea that the error terms of the retrofit alternatives may be correlated. The results of Model 4 suggest that the covariance among alternatives in each group,  $\sigma_m^2$ , are not significant. We cannot reject the hypothesis that there is equal variance in the retrofit alternatives and in the *None* alternative. Based on this comparison across the four models, and similar analyses for the other damage types, we proceed with models of the form of Model 3, which accounts for panel data and an SP-to-RP scale factor.

## 5.2 Results for Each Damage Type

Table 5.2 summarizes the results of the retrofit decision model for each of the four damage types. The models McFadden's pseudo- $R^2$  are 0.57, 0.60, 0.71, and 0.58, for wind damage to roof, wind damage to openings, wind damage to roof-to-wall connections, and flood, respectively, indicating very good fits for all models. For comparison, the panel models for the transportation models in Baht and Castelar (2002) are 0.53. In all except the roof-to-wall model, the SP-to-RP scale parameter,  $\lambda$ , is significant for at least one alternative. In all cases, they are less than one, indicating that the error variance in the SP choice context is greater than in the RP choice context and that it is important to account for that difference.

Table 5.2 Final models for each retrofit decision

Attribute	Roof			Openings			Roof-to-wall			Flood		
	ASC <sup>a</sup>	Parameter <sup>b</sup>	p-value	ASC <sup>a</sup>	Parameter <sup>b</sup>	p-value	ASC <sup>a</sup>	Parameter <sup>b</sup>	p-value	ASC <sup>a</sup>	Parameter <sup>b</sup>	p-value
<b>Alternative specific constants</b>	SHL	-0.006	0.991	SH	0.222	0.663	ST	0.560	0.349	AP	-0.545	0.310
	AD	-2.192**	0.000	IR	1.517**	0.001				IN	1.222**	0.003
	SHN	0.004	0.989							EL	1.975**	0.000
<b>Covariates</b>												
Grant, $x_g$		1.136 <sup>†</sup>	0.097		2.248*	0.000		2.365*	0.001		-0.589	0.258
Premium reduction, $x_{pr}$		0.307	0.620		-0.013	0.981		0.292	0.665		-0.063	0.887
Low interest loan, $x_{loan}$		-0.511	0.408		-0.262	0.654		-0.323	0.649		-0.514	0.286
Location in floodplain, $x_{fp}$		-0.144	0.718		0.621	0.152		0.565	0.241		0.511	0.213
Distance to coastline, $x_{dist}$		-0.005 <sup>‡</sup>	0.011		-0.011*	0.000		-0.015*	0.000		-0.006*	0.003
Home age, $x_{hage}$		0.001	0.906		-0.001	0.917		-0.029*	0.004		-0.010 <sup>‡</sup>	0.033
Num. hurricane experiences 1, $x_{num1}$		0.203	0.753		0.057	0.927		-0.550	0.511		-0.254	0.642
Num. hurricane experiences 2, $x_{num2}$		0.658	0.261		-0.275	0.622		-0.877	0.267		-0.227	0.654
Time since last hurricane 1, $x_{time1}$		-0.619	0.278		-0.858 <sup>‡</sup>	0.037		-0.327	0.537		-0.747 <sup>‡</sup>	0.051
Time since last hurricane 2, $x_{time2}$		-0.312	0.514		0.136	0.749		0.856	0.117		-0.406	0.308
Age, $x_{age}$		-0.017 <sup>‡</sup>	0.049		-0.008	0.337		-0.001	0.920		-0.012 <sup>†</sup>	0.080
Income, $x_{inc}$		0.004 <sup>†</sup>	0.085		0.002	0.479		0.002	0.465		0.001	0.666
Marital status/Gender 1, $x_{mg1}$		0.564	0.282		-0.968	0.110		-1.011	0.264		-0.716	0.197
Marital status/Gender 2, $x_{mg2}$		0.664 <sup>†</sup>	0.051		-0.133	0.696		-0.299	0.497		-0.109	0.722
Race, $x_{race}$		-0.318	0.343		-0.517	0.116		0.420	0.435		-0.368	0.206
Education, $x_{educ}$		-0.289	0.553		-0.338	0.212		-0.034	0.924		-0.019	0.938
<b>SP-RP Scale Parameter, <math>\lambda</math></b>	SHL	0.221*	0.000	SH	1.328	0.138	ST	0.755	0.387	AP	0.843*	0.000
	AD	34.795	0.947	IR	0.870*	0.004	No	0.756	0.395	IN	0.725*	0.000
	No	1.057	0.150	No	0.596*	0.000				EL	113.2	0.984
										No	3.258	0.702
Sample size		529			622			576			564	
k (all parameters)		22			22			19			23	
McFadden pseudo R <sup>2</sup>		0.568			0.605			0.710			0.579	

<sup>a</sup>SHL= Shingles later; SHN= Shingles now; AD= Adhesive; No=No retrofit; SH= Shutters; IR= Impact resistant; ST= Straps; AP= Appliances; IN= Insulation/siding; EL= Elevation.

<sup>b</sup>The symbols <sup>†</sup>, <sup>‡</sup>, \* indicate significance levels of 0.1, 0.05, and 0.01, respectively

Table 5.3 Marginal effects for covariates that are statistically significant at  $\alpha = 0.1$

Attribute	Roof			Openings		Roof-to-wall	Flood		
	Shingles later	Shingles now	Adhesive	Shutters	Impact resistant	Straps	Appliances	Insulation/siding	Elevation
Grant	0.016	0.037	0.037	0.129	0.120	0.115			
Distance to coastline, $x_{dist}$	0.000	-0.060	-0.015	-0.050	-0.142	-0.105	-0.011	-0.058	-0.100
Home age, $x_{hage}$						-0.096	-0.007	-0.034	-0.057
Time since last hurricane 1, $x_{time1}$				-0.019	-0.052		-0.006	-0.032	-0.054
Income, $x_{inc}$	0.083	0.039	0.015						
Age, $x_{age}$	-0.199	-0.103	-0.034				-0.018	-0.088	-0.146
Marital status/Gender 2, $x_{mg2}$	0.114	0.052	0.020						

### 5.3 Incentives

One of the key aims of the analysis was to determine how effective various monetary incentives might be in encouraging retrofit. For all the wind damage models, the coefficient of grant is significant and positive (Table 5.2), indicating that offering a grant is associated with increased probability of undertaking a retrofit. The coefficients of premium reduction and low interest loan, however, are not significant in any case. These results agree with hypothesis  $H_2$ , but only partially with  $H_1$ . Since coefficients of mixed logit models are difficult to interpret directly, direct marginal effects were also computed for covariates that are statistically significant at  $\alpha = 0.1$  (Table 5.3). A direct marginal effect is the effect of a unit change in a variable for alternative  $j$  on the probability of choosing that alternative  $j$ . Since the marginal effect varies by observation, we compute them for each observation, then take a weighted average, with weights defined as the choice probabilities. Hensher et al. (2015) recommends this probability weighted sample enumeration (PWSE) method. The results suggest that introducing a grant would lead to a substantial increase of approximately 0.12 in the probability of undertaking a retrofit of openings or a roof-to-wall retrofit (hurricane straps) (Table 5.3). The effect would be smaller (0.02 to 0.04) for roof retrofits.

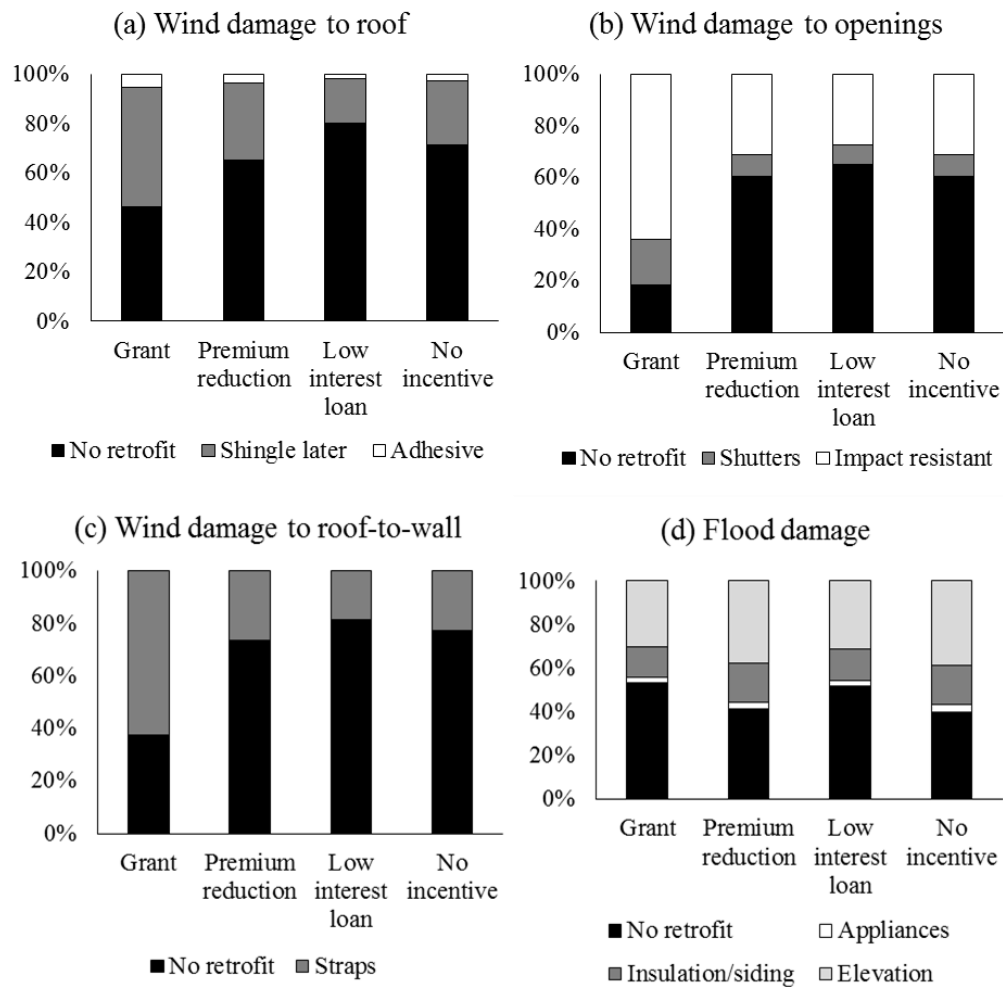


Figure 5.1 Probability of choosing each alternative under each incentive condition, for (a) wind damage to roof, (b) wind damage to openings, (c) wind damage to roof-to-wall connections, and (d) flood

Figure 5.1 provides another way to examine the effect of different incentives on retrofit decisions. It shows the percentage of homeowners choosing each alternative under each incentive condition. To generate these results, using the sample data, we set the incentive to a specified condition (e.g., grant) and then computed the choice probability for each alternative (e.g., for wind damage to roof, *Shingles later*, *Adhesive*, *None*). In the wind damage models, the percentage of individuals who do no retrofit is lowest for grant, higher for premium reduction, and highest for low interest loan. For the flood model, none of the incentives has a statistically significant effect on the retrofit rate.

#### **5.4 Covariates**

In addition to examining the role of incentives, we are interested in determining if there are any characteristics of the household that are particularly associated with an increased probability of retrofit. Such information may be relevant in determining how to target retrofit incentive programs.

Location in floodplain (xfp) and Distance to coastline (xdist) were used to indicate exposure to the hazard in all four models. Consistent with findings of Peacock (2003), Ge et al. (2011), and Petrolia et al. (2015) and our hypothesis H3, there is a positive association between proximity to the coast and likelihood of undertaking retrofit activities. The coefficients for Distance to coastline (xdist) are negative and highly significant for every model (Table 5.2). The marginal effects for xdist indicate that on average, for every one km increase in distance from the coastline, the probability a homeowner will elevate their appliances and outlets to reduce flood damage decreases by 0.011, for example (Table 5.3). Location in floodplain (xfp), however, is not significant in any of the models, contrary to hypothesis H4. Unlike

findings in Carson et al. (2013), the results indicate a negative relationship between home age and undertaking retrofits in the case of roof-to-wall and flood damage, and the results are statistically significant (Tables 5.2 and 5.3).

*Number of hurricane experiences* ( $x_{num1}$ ,  $x_{num2}$ ) and *Time since last hurricane* ( $x_{time1}$ ,  $x_{time2}$ ) were used to represent the relationship between hazard experience and retrofit. There was no evidence of a relationship between the number of hurricane experiences and probability of retrofitting (Hypothesis  $H_5$ ). Consistent with our hypothesis  $H_6$ , however, the results suggest that being one year or less since the last hurricane experience was associated with a significant positive effect on the decision to do flood and opening retrofits.

As hypothesized in  $H_7$  and consistent with the findings of Peacock (2003), Grothmann and Reusswig (2006), Osberghaus (2015), and Ge et al. (2011), higher income is associated with an increased probability of undertaking roof retrofits, with marginal effects between 0.015 to 0.083 for different retrofit choices (Table 5.2). Contrary to the findings of Poussin et al. (2014), Osberghaus (2015), Grothmann, and Reusswig (2006) but consistent with Ge et al. (2011), there is a significant negative effect of age on the decision to do flood and roof mitigation. Among other socio-demographic factors, there is evidence that being married has a positive effect on the decision to do roof strengthening, and that younger homeowners are 0.02 to 0.15 and 0.03 to 0.20 more likely to undertake flood and roof retrofits, with marginal effects of -0.02 to -0.20, depending on the retrofit choice.

Overall, the results show that *Grant* ( $x_g$ ) is consistently significant across the wind damage type models, and *Distance to the coastline* ( $x_{dist}$ ) is consistently significant across all four models (Table 5.3). On the other hand, *Premium reduction*,

*Low interest loan, Location in floodplain, Number of hurricane experiences, Race,* and *Education* were not statistically significant in any model. The effects of the other covariates vary by model.

## **5.5 Conclusions**

In this paper, we combine revealed and stated preference data to develop separate mixed logit models for homeowner decisions about retrofits aimed at addressing four different types of hurricane damage. We examine the effects of three possible types of monetary incentives and household attributes on the probability of undertaking a retrofit. With programs being introduced across the country that offer monetary incentives to encourage homeowners to retrofit their homes, the results offer multiple policy implications. First, the results suggest there is some interest among homeowners in retrofit incentives, but the evidence only supports that for grants that do not have to be repaid. The lack of evidence that a loan or premium reduction effectively motivate behavior suggests that grant programs might be the best way to spend limited government funds to encourage widespread retrofitting. Second, the results vary across retrofit types, with more interest in retrofitting openings than the other types examined. This suggests there may be other attributes of the retrofits that affect the decisions beyond cost, such as, perceived effectiveness at reducing damage, ease of implementation, or effect on the aesthetics of the house or resale value. This is important to consider for a couple reasons. If given a choice of how to spend a grant, the type of retrofit a homeowner decides to do may not be based solely on upfront cost and effectiveness at reducing future damage. If a certain type of retrofit is specified in a retrofit incentive program, take-up rates may not be the same across types. Third, the results associated with the other covariates suggest possible ways to target a retrofit

incentive program so as to maximize take-up rates. The results offer strong evidence that homeowners closer to the coastline are more likely to undertake retrofits, and some evidence that younger homeowners and homeowners in newer homes are more likely to undertake retrofits. Although the effect of prior experience is complex, depending on the number, recentness, and nature of prior hurricane experiences, the results also indicate that programs might be most effective if they target homeowners within a year of a hurricane experience.

As with any empirical study, it is important to remember that lack of evidence does not mean a relationship does not exist, just that the sample of data analyzed did not demonstrate it. Future work that expands the sample size could be useful in examining the issue further. In particular, it would be valuable to examine the roles of different attributes of retrofits in determining their appeal, how the specifications of a grant program (e.g., amount) affect its influence, and how prior experience affects homeowner retrofit decisions.

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## Appendix

### QUESTIONNAIRE SURVEY

#### A.1 Introduction

The survey questions used in this study is a part of a larger survey carried out at the University of Delaware, Disaster Research Center (DRC). The following outlines a set of selective survey questions used to acquire the data for this study.

#### A.2 Screening Questions

1. To begin I have a few questions about how I reached you. Am I speaking to you on a cell phone or a landline phone located in your home?

- 1) Cell phone (*Go to Question 2*)
- 2) Regular, landline phone, or voice over IP (*Go to Question 3*)
- 88 Don't know (*Go to Question 3*)
- 99 Refused (*Go to Question 3*)

*Ask if Question 1 = Cell phone*

2. If you are doing something that requires your full attention, I can call you back at a later time at this number or on a landline phone. Can you talk now?

- 1) Go on
- 2) Call back [**Schedule Appointment**]

3. I need to confirm that you are at least 18 years old. Are you?

- 1) Respondent is adult
- 2) Respondent is not adult
- 99) Refused

*Ask if Question 3= Respondent is not adult*

4. Is there an adult over age 18 who I can speak with?

- 1) Yes
- 2) No (*Go to Ineligible*)
- 3) Not available [**Schedule Appointment**]
- 99) Refused

5. Next I need to confirm that you own one or more homes in the eastern half of North Carolina, that is, from the Raleigh Durham area to the coast?

- 1) Owns
- 2) Other [Specify: \_\_\_\_\_] (*Go to Ineligible*)
- 88) Don't know (*Go to Ineligible*)
- 99) Refused (*Go to Ineligible*)

If you own more than one home in the eastern half of North Carolina, then for the rest of the survey, I would like you to consider only the home closest to the coast as you answer questions.

**Home Type:**

6. Which of the following best describes that home?

- 1) Single family home
- 2) A manufactured home or trailer
- 3) A duplex or any two-family home
- 4) A townhouse, apartment, or condominium with 3 or more units (*Go to Ineligible*)
- 5) Some other kind of structure (*Go to Ineligible*)
- 88) Don't know (*Go to Ineligible*)
- 99) Refused (*Go to Ineligible*)

7. Today I am only looking to speak with people who make decisions related to property insurance and home repairs or improvements for their homes. Are you one of those people?

- 1) Yes (*Go to Background Question*)
- 2) No
- 88) Don't know (*Go to Ineligible*)

99) Refused (*Go to Ineligible*)

*Ask if Question7 = No*

8. Would it be possible for me to speak with one of the people who make those decisions?

1) Yes

2) No [**Try to Schedule Appointment**]/ (*Go to Ineligible*)

99) Refused (*Go to Ineligible*)

### **A.3 Background Questions**

#### **Home Age:**

To the best of your knowledge what year was your home built?

Note: Answer in year (yyyy)

1) \_\_\_\_\_(1700-2013)

#### **A.3.1 Wind**

Ask if **Home Type** does not = 2

#### **Windretrofit1:**

To the best of your knowledge, does your home have any of the following features that protect against *wind* damage?

High wind Shingles and Synthetic water barrier on the roof? (Only answer yes if respondent has both.)

1) Yes

2) No

88) Don't know

99) Refused

*Ask if Windretrofit1 = Yes*

#### **Didselfwind1:**

For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**Windretrofit2:**

Does your home have Spray Adhesive applied to the underside of the roof in the attic?

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

*Ask if Windretrofit2= Yes*

**Didselfwind2:**

Was this feature a deliberate action you took or not?

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-----

For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**Windretrofit3:**

Does your home have Hurricane Straps to improve connection between roof and wall?

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

*Ask if Windretrofit3= Yes*

**Didselfwind3:**

Was this feature a deliberate action you took or not?

-----

-----

For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**Windretrofit4:**

Does your home have Hurricane Shutters?

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

*Ask if Windretrofit4= Yes*

**Didselfwind4:**

Was this feature a deliberate action you took or not?

-----

-----

For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**Windretrofit5:**

Does your home have Impact Resistant windows and doors?

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

*Ask if Windretrofit5= Yes*

**Didselfwind5:**

Was this feature a deliberate action you took or not?

-----

-----

For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**A.3.2 Flood**

**Floodretrofit1:**

To the best of your knowledge, does your home have any of the following features that protect against *flood* damage?

Elevated electrical and appliances?

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

*Ask if Floodretrofit1= Yes*

**Didselfflood1:**

Was this feature a deliberate action you took or not?

-----

-----

For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**Floodretrofit2:**

Does your home have both Water-Resistant Insulation and Siding?  
(Interviewer: only answer yes if the respondent has both)

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

*Ask if Floodretrofit2 = Yes*

**Didselflood2:**

Was this feature a deliberate action you took or not?

-----

-----

For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**Floodretrofit3:**

Is your entire house elevated?

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

*Ask if Floodretrofit3= Yes*

**Didselflood3:**

Was this feature a deliberate action you took or not?

-----

-----

For the feature you just mentioned your home having, I would like to know if the house has that feature because of a deliberate action you took or not. A deliberate action could be that you installed that feature, you hired someone to do it, or you considered that an important feature when you bought the house.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**A.4 Risk Perception and Hazard Experience Questions**

**1. Number of Hurricane Experience:**

How many hurricane events have you personally experienced?

- 1) \_\_\_\_\_(0-200)

**2. Time since Last Hurricane:**

What year was your last hurricane experience? (YYYY)

Note: if the answer is the name of a hurricane, input year from the hurricane list

- 1) \_\_\_\_\_(1900-2013)

**A.5 Protective Action Questions**

## **A.5.1 Wind**

### **Wind Incentive 1**

Hypothetical condition randomly assigned to respondents to keep in mind for the following questions.

0. No incentive
1. Grant that does not need repayment
2. Premium reduction
3. Low interest loan

### **Wind Retrofit Intro.**

I want to ask now about the possibility that you would strengthen your house to reduce the chance that a hurricane would cause *Wind-Related* damage. For each specific strengthening activity I mention, I will also indicate a rough estimate of the cost for an average-sized home. While actual costs can vary significantly depending on the home, contractor, and other factors these should give you some sense of the expense involved.

*If Home Type=2 or Windretrofit 1 or 2 is Yes, skip this question*

### **May Roof retrofit:**

I'm going to describe three ways you can strengthen your Roof against hurricane wind damage and improve its ability to keep water out. Which one, if any, are you most likely to do in the next couple years?

***(Read 1-4; say number out loud; repeat if necessary)***

- 1) Wait until you have to redo your roof anyway and at that time use high wind shingles and a special water barrier underneath, which would *add* about \$400 extra to your roofing bill
- 2) Reroof *now* with high wind shingles and a special water barrier underneath, which would cost about \$8000
- 3) Apply a special foam adhesive on the underside of the roof in the attic, which would cost about \$2000
- 4) None of those
- 88) Don't know
- 99) Refused

*If Home Type=2 or Windretrofit 4 or 5 is Yes, skip this question*

**May Opening retrofit:**

Another option to protect your home against hurricane wind damage is to strengthen the windows, exterior doors, and garage doors. I am going to describe two ways you could do that. Which one, if any, are you most likely to do in the next couple years?

*(Read choices 1-3; say number out loud; repeat if necessary)*

- 1) Install permanent hurricane shutters on all windows and exterior doors, and reinforce any garage doors which would cost about \$7,000.
- 2) Install impact resistant windows and exterior doors everywhere, and reinforce any garage and exterior doors everywhere, reinforce any garage doors which would cost about \$15,000.
- 3) Neither
- 88) Don't know
- 99) Refused.

*If Home Type=2 or Windretrofit 3 is Yes, skip this question*

**May Strap retrofit:**

Finally, the connection between your roof and walls can be another weak area. Are you likely to add metal hurricane straps to strengthen that connection in the next couple years? This would cost about \$2000.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

**Wind Incentive 2**

Hypothetical condition randomly assigned to respondents to keep in mind for the following questions.

0. No incentive
1. Grant that does not need repayment
2. Premium reduction
3. Low interest loan

**Wind Retrofit Intro.2**

If you will bear with me, I am going to ask you those same questions about strengthening your house again, but this time I want you to imagine ....

*If Home Type=2 or Windretrofit 1 or 2 is Yes, skip this question*

**May Roof retrofit:**

I'm going to describe three ways you can strengthen your ROOF against hurricane wind damage and improve its ability to keep water out. Which one, if any, are you most likely to do in the next couple years?

*(Read 1-4; say number out loud; repeat if necessary)*

- 1) Wait until you have to redo your roof anyway and at that time use high wind shingles and a special water barrier underneath, which would *add* about \$400 extra to your roofing bill
- 2) Reroof *now* with high wind shingles and a special water barrier underneath, which would cost about \$8000
- 3) Apply a special foam adhesive on the underside of the roof in the attic, which would cost about \$2000
- 4) None of those
- 88) Don't know
- 99) Refused

*If Home Type=2 or Windretrofit 4 or 5 is Yes, skip this question*

**May Opening retrofit:**

Another option to protect your home against hurricane wind damage is to strengthen the windows, exterior doors, and garage doors. I am going to describe two ways you could do that. Which one, if any, are you most likely to do in the next couple years?

*(Read choices 1-3; say number out loud; repeat if necessary)*

- 1) Install permanent hurricane shutters on all windows and exterior doors, and reinforce any garage doors which would cost about \$7,000.
- 2) Install impact resistant windows and exterior doors everywhere, and reinforce any garage and exterior doors everywhere, reinforce any garage doors which would cost about \$15,000.
- 3) Neither
- 88) Don't know
- 99) Refused.

*If Home Type=2 or Windretrofit 3 is Yes, skip this question*

**May Strap retrofit:**

Finally, the connection between your roof and walls can be another weak area. Are you likely to add metal hurricane straps to strengthen that connection in the next couple years? This would cost about \$2000.

- 1) Yes
- 2) No
- 88) Don't know
- 99) Refused

## **A.5.2 Flood**

### **Flood Incentive 1**

Hypothetical condition randomly assigned to respondents to keep in mind for the following questions.

0. No incentive
1. Grant that does not need repayment
2. Premium reduction
3. Low interest loan

### **Flood Retrofit Intro.**

I want to ask now about the possibility that you would strengthen your house to reduce the chance that a hurricane would cause *Flood-Related* damage. As we did before, for each specific strengthening activity I mention, I will also indicate a rough estimate of the cost for an average-sized home...

*If Floodretrofit3 = Yes, skip this part questions.*

*If Floodretrofit2=Yes, and Floodretrofit1 not= Yes, and Floodretrofit3 not=Yes, then go to May Flood retrofit1.*

*If Floodretrofit1=Yes, and Floodretrofit2 not= Yes, and Floodretrofit3 not=Yes, then go to May Flood retrofit2.*

*If Floodretrofit1 not=Yes, and Floodretrofit2 not= Yes, and Floodretrofit3 not=Yes, then go to May Flood retrofit3.*

*If Floodretrofit1=Yes, and Floodretrofit2 = Yes, and Floodretrofit3 not=Yes, then go to May Flood retrofit4.*

### **May Flood retrofit1:**

I'm going to describe three options you might choose when it comes to reducing hurricane-related flood damage. Which are you most likely to do in the next couple years?

***(Read choices 1-3; say number out loud; repeat if necessary)***

- 1) Elevate electrical switches, outlets, and appliances to keep them above any flood water that entered your home, which would cost about \$2000
- 2) Elevate your entire home on piles, which could cost about \$52,000 if you have a basement or \$144,000 if you do not have a basement
- 3) Do none of those
- 88) Don't know
- 99) Refused

**May Flood retrofit2:**

I am going to describe three options you might choose when it comes to reducing hurricane-related flood damage. Which are you most likely to do in the next couple years?

***(Read choices 1-3; say number out loud; repeat if necessary)***

- 1) Install water-resistant insulation and siding to protect those items from damage, which would cost about \$10,000
- 2) Elevate your entire home on piles, which could cost about \$52,000 if you have a basement or \$144,000 if you do not have a basement
- 3) Do none of those
- 88) Don't know
- 99) Refused

**May Flood retrofit3:**

I am going to describe four options you might choose when it comes to reducing hurricane-related flood damage. Which are you most likely to do in the next couple years?

***(Read choices 1-4; say number out loud; repeat if necessary)***

- 1) Elevate electrical switches, outlets, and appliances to keep them above any flood water that entered your home, which would cost about \$2000
- 2) Install water-resistant insulation and siding to protect those items from damage, which would cost about \$10,000
- 3) Elevate your entire home on piles, which could cost about \$52,000 if you have a basement or \$144,000 if you do not have a basement
- 4) Do none of those

- 88) Don't know
- 99) Refused

**May Flood retrofit4:**

I am going to describe two options you might choose when it comes to reducing hurricane-related flood damage. Which are you most likely to do in the next couple years?

*(Read choices 1-2; say number out loud; repeat if necessary)*

- 1) Elevate your entire home on piles, which could cost about \$52,000 *if you have a basement or \$144,000 if you do not have a basement.*
- 2) Do none of those
- 88) Don't know
- 99) Refused

**Flood Incentive 2**

Hypothetical condition randomly assigned to respondents to keep in mind for the following questions.

- 0. No incentive
- 1. Grant that does not need repayment
- 2. Premium reduction
- 3. Low interest loan

**Flood Retrofit Intro.2**

If you will bear with me, I am going to ask you that same question about strengthening your house against flood one last time. This time I want you to imagine ....

*If Floodretrofit3 = Yes, skip this part questions.*

*If Floodretrofit2=Yes, and Floodretrofit1 not= Yes, and Floodretrofit3 not=Yes, then go to May Flood retrofit1.*

*If Floodretrofit1=Yes, and Floodretrofit2 not= Yes, and Floodretrofit3 not=Yes, then go to May Flood retrofit2.*

*If Floodretrofit1 not=Yes, and Floodretrofit2 not= Yes, and Floodretrofit3 not=Yes, then go to May Flood retrofit3.*

*If Floodretrofit1=Yes, and Floodretrofit2 = Yes, and Floodretrofit3 not=Yes, then go to May Flood retrofit4.*

**May Flood retrofit1:**

I'm going to describe three options you might choose when it comes to reducing hurricane-related flood damage. Which are you most likely to do in the next couple years?

***(Read choices 1-3; say number out loud; repeat if necessary)***

- 1) Elevate electrical switches, outlets, and appliances to keep them above any flood water that entered your home, which would cost about \$2000
- 2) Elevate your entire home on piles, which could cost about \$52,000 if you have a basement or \$144,000 if you do not have a basement
- 3) Do none of those
- 88) Don't know
- 99) Refused

**May Flood retrofit2:**

I am going to describe three options you might choose when it comes to reducing hurricane-related flood damage. Which are you most likely to do in the next couple years?

***(Read choices 1-3; say number out loud; repeat if necessary)***

- 1) Install water-resistant insulation and siding to protect those items from damage, which would cost about \$10,000
- 2) Elevate your entire home on piles, which could cost about \$52,000 if you have a basement or \$144,000 if you do not have a basement
- 3) Do none of those
- 88) Don't know
- 99) Refused

**May Flood retrofit3:**

I am going to describe four options you might choose when it comes to reducing hurricane-related flood damage. Which are you most likely to do in the next couple years?

***(Read choices 1-4; say number out loud; repeat if necessary)***

- 1) Elevate electrical switches, outlets, and appliances to keep them above any flood water that entered your home, which would cost about \$2000
- 2) Install water-resistant insulation and siding to protect those items from damage, which would cost about \$10,000
- 3) Elevate your entire home on piles, which could cost about \$52,000 if you have a basement or \$144,000 if you do not have a basement
- 4) Do none of those

- 88) Don't know
- 99) Refused

**May Flood retrofit4:**

I am going to describe two options you might choose when it comes to reducing hurricane-related flood damage. Which are you most likely to do in the next couple years?

*(Read choices 1-2; say number out loud; repeat if necessary)*

- 1) Elevate your entire home on piles, which could cost about \$52,000 *if you have a basement or \$144,000 if you do not have a basement.*
- 2) Do none of those
- 88) Don't know
- 99) Refused

**A.6 Socio-Demographics Questions**

**1. Age:**

In what year were you born? (YYYY)

- 1) \_\_\_\_\_(1890-2013)

**2. Marital Status:**

Are you currently married, widowed, divorced, separated, or have you never been married?

- 1) Married
- 2) Widowed
- 3) Divorced
- 4) Separated
- 5) Never Married
- 99) Refused

**3. Education:**

What is the highest level of education you have completed?

- 1) Elementary school only
- 2) Some high school, did not finish

- 3) Completed high school
- 4) Some college but didn't finish
- 5) 2 Year college degree /A.A./A.S.
- 6) 4 Year college degree /B.A./B.S.
- 7) Some graduate work
- 8) Completed masters or professional degree
- 9) Advanced graduate work or Ph.D.
- 88) Don't know
- 99) Refused

**4. Income:**

I am going to read a list of income ranges. Please stop me when I read the range that best describes your annual household income from all sources. This is before taxes and other deductions.

*[Read categories until respondent says yes]*

- |                                 |                         |
|---------------------------------|-------------------------|
| 1) Less than 15 thousand        | [\$0 -\$14,999]         |
| 2) 15 to 35 thousand            | [\$15,000 - \$34,999]   |
| 3) 35 to 50 thousand            | [\$35,000 - \$49,999]   |
| 4) 50 to 75 thousand            | [\$50,000 - \$74,999]   |
| 5) 75 to 100 thousand           | [\$75,000 - \$99,999]   |
| 6) 100 thousand to 150 thousand | [\$100,000 - \$149,999] |
| 7) 150 thousand to 250 thousand | [\$150,000 - \$250,000] |
| 8) Over 250 thousand            | [\$250,000 +]           |
| 88) Don't Know                  |                         |
| 99) Refused                     |                         |

**5. Race:**

I am going to read a list of racial categories. Would you tell me what category best describes you?

- 1) White
- 2) African American / Black
- 3) Asian [including South Asia]
- 4) American Indian [Native America; includes Eskimo, Aleut]
- 5) Pacific Islander
- 6) Multi-Racial

**6. Gender:**

What is your gender?

- 1) Male
- 2) Female

- 3) Other
- 99) Refused

**7. Address:**

As I mentioned at the beginning, as a thank you for participating, one out of every hundred people who complete the survey will win a new iPad. Would you provide your mailing address so that we can mail you the prize if you win?

- 1) Number
- 2) Street
- 3) City
- 4) State
- 5) Zip
- 6) Not sure/Don't know
- 7) Refused

**8. Location:**

Ask if Question 7 = 8 or 9

Would you be willing to provide a zip code and the nearest cross street/intersection to your home? That information will help us determine the likelihood that a hurricane will affect your location.

- 1) Zip
- 2) Cross street
- 3) Enter response \_\_\_\_\_
- 4) Not sure/Don't know
- 5) Refused