Transferability of Hurricane Evacuation Choice Model: A Joint Model Estimation Combining Multiple Data Sources

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Abstract

Inferences on hurricane evacuation behavior are usually drawn through developing empirical models. These models are estimated using data that are specific to a given hurricane context. One important issue therefore is whether such models are applicable to different hurricane contexts. This paper investigates this transferability issue of evacuation choice models across different hurricanes. Initially, we estimate three separate models of the binary decision to evacuate or not, using datasets from three hurricanes (Andrew, Ivan, and Katrina) that occurred at different periods. Then a joint model is estimated combining these three evacuation data sources. When estimating the model jointly, the differences among the scale parameters of the datasets are specifically accounted for. The results from joint and separate models are then statistically tested to evaluate whether evacuation decision model parameters are transferable across different hurricane contexts. The result from the statistical test suggests that the parameters of the evacuation choice models are transferable over different hurricane contexts in similar regions, an important implication for policy makers and emergency preparedness agencies.

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Introduction

Hurricanes, one of the most costly natural disasters in the United States (U.S.), have increased in frequency and intensity in recent years. These hurricanes have particularly devastating consequences in coastal areas. For instance, the 2005 Atlantic hurricane season in the U.S. caused approximately 2,300 deaths and damages of over $130 billion (NHC 2006). The role of evacuation has been specifically realized after the 2005 hurricane season when citizens were trapped in floodwater in New Orleans (in Hurricane Katrina) and many evacuees were stuck in gridlock on the freeways during Hurricane Rita. At least a portion of the traffic during the Hurricane Rita evacuation was a result of shadow (or spontaneous) evacuation of people who did not need to evacuate; these people likely evacuated, at least in part, as a response to the severity of damage and loss of life caused by Hurricane Katrina. The magnitude of the shadow evacuation exceeded the expectations of the evacuation planners and managers. Clearly, these experiences show that there is a great deal of research to still be conducted to understand evacuation behavior at the household level. With such an understanding, better policies and evacuation strategies can be developed.

In order to gain better insights on evacuation behavior we therefore have to understand and address the complexity involved in the household-level decision-making process (Gladwin et al. 2007). One of the key outcomes of this process, from an evacuation planning perspective, is whether the household evacuates or not. Inferences about this evacuation decision are usually drawn using empirical models based on data gathered for a single, specific hurricane. The insights provided by these models, while applicable for the specific geographic area where the data was collected, have not been extended to other hurricanes within the area or a different geographic area. While evacuation behavior has been modeled separately using data from different hurricanes, one major question is whether the model parameters are transferable under a different future hurricane occurring in a similar geographical area or areas which share similar social, economic and built environment characteristics. To the best of our knowledge, no study previously investigated the transferability of these kinds of evacuation choice models' parameters from one hurricane to another hurricane context.

This paper investigates the transferability issues of the parameters of evacuation choice models across different hurricanes. Initially, we estimate three separate models of the decision to evacuate or not, using datasets from three hurricanes (Andrew, Ivan, and Katrina) that occurred in the same general geographic area between 1992 and 2005. Then, we estimate a joint model combining these three evacuation data sources. When estimating the model jointly, we allow for the differences among the scale parameters present in the dataset. Such a joint estimation enables us to evaluate the potential of transferring an evacuation choice model estimated for a particular hurricane context to another hurricane context. Thereby, the insights obtained can be generalized to a certain extent, which will provide valuable understanding of the determinants of evacuation decision making.

This paper is organized as follows. The next section presents a review of the literature on hurricane evacuation decision making behavior. The subsequent two sections describe the methodological framework and the empirical data used for model estimation. Then, we present and discuss the empirical results. The last section contains some concluding remarks along with some implications of our research.

Literature Review

A significant number of studies were devoted to understanding whether or not a household would evacuate under a hurricane threat. Research mainly focused on the characteristics of those who evacuate and those who do not (Baker 1979; Cross 1979; Baker 1991; Fischer et al. 1995; Dow and Cutter 1998; Drabek 1999; Hasan et al. 2011). A recent review by Dash and Gladwin (2007) on hurricane evacuation behavior concluded that factors such as age of the decision maker, presence of children or elderly persons in the household, gender, disability, race and ethnicity, income, previous experience, and geographic location, like proximity to highways and exit routes, play important roles in evacuation decision making. These factors can either encourage or restrain evacuation depending on the situation; for example, the presence of children in the household might influence parents to protect them from danger through evacuation, yet the presence of a disabled person may hinder their ability to take the essential steps for evacuation.

Evacuation behavior is usually inferred by building statistical models (Perry 1994; Gladwin and Peacock 1997; Whitehead et al. 2000; Gladwin et al. 2001; Lindell et al. 2005; Fu and Wilmot 2004; Fu and Wilmot 2006; Solis et al. 2009; Hasan et al. 2011). These models include a diverse set of behavioral aspects for understanding the evacuation decision making process. Gladwin and Peacock (1997), for example, focused on the influence of contextual indicators on evacuation behavior. They found that variables influencing evacuation include being in an evacuation zone (positive effect) and demographic factors, such as household size, presence of either elders (negative effect) or children (positive effect), and living in a single-family dwelling unit (negative effect). However, specific measurements representing risk perception are not incorporated in their models.

Whitehead et al. (2000), on the other hand, considered storm intensity, by presenting hypothetical storm scenarios to respondents, in addition to objective and subjective risk variables. Their findings suggest that storm intensity is the most important determinant for households' evacuation decision. Regarding objective risk factors, households receiving a mandatory evacuation order instead of a voluntary order and households living in mobile homes are more likely to evacuate. On the other hand, subjective risk factors, such as perceived risk from flooding, are more important than risk from wind when making evacuation decisions. Influences of objective and subjective risk variables are measured through the coefficients of a logistic regression model.

Using correlation analysis, Lindell et al. (2005) found that evacuation decisions tended to be strongly correlated with geographic characteristics (e.g. proximity to the coast, proximity to inland waterways), utilization of information from peers and local authorities, social cues (e.g. official evacuation recommendations, observations of peers evacuating, and official watches and warnings), and demographic characteristics (e.g. younger, female, and respondents with children at home). On the other hand, personal hurricane experience and previous experience of unnecessary evacuations were not significantly correlated with evacuation decisions. However, it is noteworthy to mention that such correlation-based analysis measures the influence of the variables on the evacuation decision separately instead of their combined effects.

In spite of significant research efforts on evacuation behavior as indicated by the above review, no studies specifically investigate the transferability of evacuation choice models over different hurricanes. However, there are studies that qualitatively compare aggregate evacuation behavior under different hurricanes. Baker (1991) made the first attempt in this regard by comparing twelve different hurricane evacuation studies over the period of 1961-89. This study compared the correlation between aggregate evacuation rate and different candidate factors. The study concluded that variations in evacuations can be consistently explained by a set of explanatory variables. These variables include risk level of an area, actions by public authorities, housing type, prior risk perception, and storm-specific threat factors (Baker 1991).

In general, the transferability of a model is defined as "the application of a model formulated and estimated in one context to another context" (Koppelman et al. 1985). While building any model a researcher or practitioner is usually concerned with whether the estimated parameters of the model are spatially or temporally transferable. The transferability of a model, estimated at a particular context, is warranted if the modeler wants to extract useful information about the behavior in the application context using the same model. This transferability issue has been widely studied in the past by many researchers particularly within the travel demand modeling community where primary attention was devoted to trip generation and mode choice models (Koppelman et al. 1985; Atherton and Ben-Akiva 1976; Koppelman and Wilmot 1982; Supernak 1983). Trip generation is directly analogous to the decision to evacuate or not. Transferability can be considered at four different levels of the model development framework (Hansen 1981; Bekhor and Prato 2009): (i) broad behavioral postulates (*e.g.* utility maximization), (ii) mathematical model classes, (iii) model specifications, and (iv) model parameters. In this paper we particularly address the transferability of model parameters.

However, such transferability issues have not been extensively considered in the context of the evacuation decision making problem. This paper begins to fill this gap in our knowledge by studying the transferability evacuation decision models over different evacuation choice contexts.

Methodology

The initial presentation in this section discusses the utility framework for household decision making under hurricane risk. The question of whether to evacuate or stay at home due to the threat of a hurricane involves a decision between these two possible choices. These types of mutually exclusive and collectively exhaustive choices have often been modeled through logit models, which offer a rigorous analytical framework for modeling such discrete choices. In the context of hurricane evacuation, for a given household n, the utilities for the two evacuation choices of whether or not to evacuate (denoted by U_{in} and U_{jn} respectively) are defined as in equation (1):

$$\begin{aligned} U_{in} &= V_{in} + \varepsilon_{in} = \boldsymbol{\beta_i}'\boldsymbol{X_{in}} + \varepsilon_{in} \\ U_{jn} &= V_{jn} + \varepsilon_{jn} = \boldsymbol{\beta_j}'\boldsymbol{X_{jn}} + \varepsilon_{jn} \end{aligned} \tag{1}$$

where V_{in} and V_{jn} are the deterministic parts of the utility terms, $\boldsymbol{\beta_i}$ and $\boldsymbol{\beta_j}$ are vectors of estimable parameters, $\boldsymbol{X_{in}}$ and $\boldsymbol{X_{jn}}$ are vectors of the factors (covariates) that determine the utility of evacuation and non-evacuation decisions, respectively, for household n, and ε_{in} and ε_{jn} are random terms. If the random terms ε_{in} and ε_{jn} are assumed as independent and identically Gumbel (or Type I extreme value) distributed then the standard binary logit form for the evacuation decision choices is as in equation (2):

$$P_n(i) = P\left(U_{in} \geq U_{jn}\right) = \frac{e^{\mu \boldsymbol{\beta}_i' \boldsymbol{X_{in}}}}{e^{\mu \boldsymbol{\beta}_i' \boldsymbol{X_{in}}} + e^{\mu \boldsymbol{\beta}_j' \boldsymbol{X_{jn}}}} \tag{2}$$

where $P_n(i)$ is the probability of household n evacuating and μ is a positive scale parameter. For the case of linear-in-parameters utility specifications (such as Equation (1)) the scale parameter μ cannot be distinguished from model parameters $\boldsymbol{\beta}$ (Ben-Akiva and Lerman 1985). For convenience in the model estimation process it is generally assumed that $\mu = 1$.

In order to address the transferability issue specific to our problem, consider an evacuation decision model, E estimated using two separate household-level datasets $D1$ and $D2$ representing two hurricane contexts $H1$ and $H2$ respectively. For both of these hurricane contexts each household n has to make a decision out of two choices of whether to evacuate or not. The underlying decision making protocol (*i.e.* utility maximization) and the associated mathematical model class (*i.e.* binary logit) are also assumed to be consistent across the contexts $H1$ and $H2$. The transferability issue of model E will be then whether model parameters estimated using data from $H1$ are transferable to $H2$, and vice versa. This transferability of model parameters can be examined by a set of tests ranging from informal parameter comparisons to formal likelihood ratio tests such as:

i. Informal parameter comparison done by computing the ratios of the parameters of models estimated using each single dataset (Louviere et al. 2000). This analysis identifies potential parameters that are likely to be equal despite the presence of different scale parameters of datasets.

ii. The calculation of model equality test statistic based on a joint estimation of a model using the combined data sources (Koppelman and Wilmot 1982; Ben-Akiva and Morikawa 1990).

The later test is considered as a formal test of transferability and discussed in detail in the following sub-section.

Model Equality Test Statistic

Equality of model parameters (estimated for different contexts) for an evacuation decision making model is established when similar parameter estimates are obtained from models estimated for different contexts. To measure the differences in model parameter estimates we define here a test statistic that utilizes a joint model estimation approach using a combination of multiple data sources (Koppelman and Wilmot 1982; Ben-Akiva and Morikawa 1990). Although our application is based on comparisons among three different hurricane contexts and the model parameters estimated using these datasets, for clarity we define the transferability problem and the associated test statistic for two different contexts first.

Consider again an evacuation decision making model E (as shown in Equation (2)) estimated for two hurricane contexts $H1$ and $H2$. Since model E is estimated assuming the distribution of the random terms (*i.e.* extreme value type I), it has an embedded scale parameter (μ) which is inversely related to the variance of the random terms. The vector of model parameters estimated using a given source of data is $\mu\boldsymbol{\beta}$ (Ben-Akiva and Lerman 1985). Since, as previously mentioned, μ cannot be separately identified from model parameters $\boldsymbol{\beta}$, μ is usually normalized to a constant (e.g. unity). Similarly, the estimated parameters of model E for contexts $H1$ and $H2$ would correspond to the terms $\mu_{H1}\beta_{H1}$and $\mu_{H2}\beta_{H2}$ respectively where μ_{H1} and μ_{H2} are the corresponding scale parameters of $H1$ and $H2$ respectively. Thus model E estimated for the contexts $H1$ and $H2$ may result in different parameter estimates due to differences in scale parameters (*i.e.* μ_{H1} and μ_{H2}) or model parameters (*i.e.* $\beta_{H1}$and β_{H2}) or both. Therefore, without considering these scale parameters it is not possible to directly compare the estimated model parameters from $H1$ and $H2$.

We hypothesize that the underlying decision making protocol (*i.e.* choice process between the options to evacuate or not) in hurricane contexts $H1$ and $H2$ is similar. Then the joint estimation (Ben-Akiva and Morikawa 1990) of E from combining data sources $D1$ and $D2$ (datasets representing the contexts $H1$ and $H2$ respectively) provides us information about the differences between the scale parameters. Using this joint estimation, a test statistic can be computed to measure the model parameter equality. This test statistic uses the log-likelihood from the estimation of the two separate models and the log-likelihood from the joint estimation with the combined data source. The model equality of test statistics (METS) is given by equation (3) (Koppelman and Wilmot 1982; Washington et al. 2003)

$$METS = -2[LL(\beta_{D1\cup D2}) - LL(\beta_{D1}) - LL(\beta_{D2})] \quad (3)$$

where $LL(\beta_{D1\cup D2})$ is the log-likelihood at convergence of the model estimated using the combination of the datasets $D1$ and $D2$ (*i.e.* log-likelihood at convergence from the joint estimation), $LL(\beta_{D1})$ is the log-likelihood at convergence of the model estimated using dataset $D1$, and $LL(\beta_{D2})$ is the log-likelihood at convergence of the model estimated using dataset $D2$. The test statistic is χ^2 distributed with $(K_{D1} + K_{D2} - K_{D1\cup D2})$ degrees of freedom, where K_{D1} and K_{D2} are the numbers of estimated parameters of models estimated using dataset $D1$ and $D2$ respectively and $K_{D1\cup D2}$ is the number of parameters of the restricted model. The null hypothesis of equal parameter estimates is rejected when METS exceeds the critical value of χ^2 with $K_{D1} +$

$K_{D2} - K_{D1 \cup D2}$ degrees of freedom. The joint model estimation process follows the approach proposed for modeling the combination of revealed and stated preference data (Ben-Akiva and Morikawa 1990; Hensher et al. 1999).

Data Description

Three datasets from surveys of households that experienced Hurricanes Andrew, Katrina, and Ivan are used to understand the transferability issues of the model. This section briefly describes these hurricanes and the corresponding datasets. Table 1 summarizes the statistics of selected variables for all three datasets and Figure 1 shows the percentage of people who evacuated and did not evacuate from each dataset.

Hurricane Andrew

Hurricane Andrew was a Category 4 hurricane when it passed through southern Florida on August 24, 1992. Evacuations were ordered for about 1.1 million people of Dade County, Broward County, Palm Beach County, and St. Lucie County in Florida. After passing Florida, Hurricane Andrew reached the central Louisiana coast on August 26th with Category 3 status. Approximately 1.25 million people evacuated from parishes in south-eastern and south-central Louisiana (NHC 2010). However, the survey corresponding to Hurricane Andrew captured only 954 residents living in Miami-Dade County (Florida); the sample was drawn from areas that were evacuation zones at the time of Hurricane Andrew and areas immediately adjacent to these zones (Gladwin et al. 2001). The survey asked about respondents' thoughts while making the decision whether or not to evacuate, characteristics of the evacuation, motivations for their decisions, and socio-economic characteristics of the household.

Hurricane Ivan

Hurricane Ivan made landfall as a Category 3 hurricane just west of Gulf Shores, Alabama on September 16, 2004 (NHC 2010; Stewart 2004). Hurricane warnings and evacuation orders for Hurricane Ivan varied from region to region. For example, a mandatory evacuation was ordered on September 10th in the Florida Keys. However, on September 11th, Ivan shifted westward from the Keys and Florida's southern coastline. On September 14th, a hurricane watch was issued for the northwestern panhandle of Florida; this hurricane watch soon became a hurricane warning for the area. The Alabama coastline was included in the September 14th warning area. A mandatory evacuation was ordered for Gulf Shores, Orange Beach, and Fort Morgan, Alabama. A mandatory evacuation was also ordered for the 78 miles of coastline of Mississippi. The New Orleans area of Louisiana was included in the warning on September 14th and 1.4 million residents were urged to leave. Overall, about 600,000 citizens of New Orleans tried to evacuate during that period (Morrow and Gladwin 2005). The Hurricane Ivan survey included a random sample of the counties and parishes in the area adjacent to the path of the hurricane in Alabama, Florida, Louisiana, and Mississippi (Morrow and Gladwin 2005). The survey included questions on evacuation decisions and behaviour, home mitigation and/or preparation, household circumstances, and economic impacts, as well as household information needs.

Hurricane Katrina

Hurricane Katrina made landfall as a tropical storm near the Miami-Dade/Broward county line during the evening of August 25th, 2005. Katrina moved to the eastern Gulf of Mexico where it reached Category 5 status on August 28th. It made its first landfall near Buras–Louisiana on August 29th and then a second landfall near the Louisiana/Mississippi border as a Category 3 hurricane. Katrina brought hurricane conditions to south-eastern Louisiana, southern Mississippi, and south-western Alabama. Storm surge due to Katrina caused total destruction of many infrastructures along the Mississippi coast, south-eastern Louisiana, and southeast of New Orleans (NHC 2010). The Hurricane Katrina survey was from a study that originally intended to discover the influence of previous hurricane experience on evacuation. Thus, the Katrina survey was a panel survey of 811 households who were previously interviewed in the above mentioned Hurricane Ivan survey. The households were re-interviewed with questions related to hurricane knowledge, attitudes, behaviour, and future intent.

Table 2 presents a Census based profile of the counties/parishes from which the samples were drawn for the datasets. The statistics shown in the table are related to the socio-demographic variables in Tables 1 and 3, and other characteristics that may have an intuitive impact on the transferability of the models are included as well. As shown in Table 2, the Hurricane Andrew dataset was drawn from a single, highly populated, coastal county in Florida, while the Hurricane Ivan sample was drawn from both coastal and inland counties in four neighboring states. The populations of the counties in the Hurricane Ivan dataset ranged between 3 and 21.5% of the single county in the Hurricane Andrew dataset. The percentage of owner occupied housing units of counties in the Ivan dataset ranged between 46.5% and 81.9% with a sample weighted average of approximately 71.6%, while the corresponding value for

Miami-Dade County (Hurricane Andrew) was 57.8%. The generally lower rate in Miami-Dade County is not surprising as a more densely populated area implies a greater number of rental properties. The percentage of mobile homes in Miami-Dade (1.8%) was substantially lower than the other counties (weighted average 14.5%), except for Orleans Parish (0.3%). In terms of percentages of families with at least one of their own children under 18 years old, the values for Miami-Dade and the sample weighted average of the other counties were fairly similar. However, examination of the number of children in Table 1 and the difference in ages associated with a "child" designation suggests a greater number of children in the Hurricane Andrew dataset. Thus, among the variables captured by the surveys, mobile home residence, home ownership, and number of children may show some differences across the models, and basic locations (due to the above as well as inherent differences) may exert some influence on the transferability of the models. These issues are explored below.

Empirical Results

In this section we report model estimates from single and combined data sources and the transferability test statistics calculated from our model estimation results. Our analysis provides insights into the differences among utility parameter estimates. We also discuss the potential transferability of evacuation decision making models.

Table 3 presents the estimation results from single data sources and the combined data source. The estimation of the models is performed with Biogeme (Bierlaire 2003; Bierlaire 2008). For estimation purposes we specify the utility functions for evacuation and non-evacuation alternatives. Since we do not have any variable that is different across these two alternatives our utility definition for the non-evacuation alternative includes only a constant term while the utility for the evacuation alternative includes the remaining variables.

We include several variables that are only available to specific datasets in the utility specification for the combined model. For example, the Ivan dataset is based on the survey of households from Florida, Alabama, Louisiana, and Mississippi. Therefore, keeping the indicator variable for Florida households as the base, we include indicator variables for Alabama, Louisiana, and Mississippi households specific to the Ivan dataset in our combined model. Similarly, keeping the indicator variable for the households from Mississippi as the base, we include indicator variables for Alabama and Louisiana households specific to the Katrina dataset in our combined model. The indicator variables for mandatory work requirement and previous hurricane experience are only available for the Ivan and Katrina datasets. However, since the Katrina dataset consists of a portion people who were interviewed in Ivan survey, all the respondents for the Katrina dataset had a previous hurricane experience. Therefore, the coefficient for previous hurricane experience specific to Katrina is not identifiable.

Parameter estimates across different hurricane contexts suggest similar household evacuation behavior (see Table 3). Households with a greater number of persons prefer not to evacuate. Families that own their houses are less likely to evacuate compared to the families that do not own their houses. However, the estimated parameter from the Katrina dataset does not indicate similar behavior; this fact can be ignored as the parameter is not statistically significant. Households that have window protection measures (e.g. putting storm shutters, metal panels, or Plywood sheets on windows) are less likely to evacuate compared to the households that do not have any protection measures. Households that live in mobile houses are also more likely to evacuate compared to the households that live in other types of houses. The number of children positively influences the evacuation of households. Households receiving evacuation notice are also more likely to evacuate. Previous hurricane experience is found to negatively impact the evacuation; however this influence can be estimated only for the Ivan dataset. Similarly, a mandatory work requirement negatively influences evacuation. In general, except the house ownership variable, all other variables have consistent signs across different hurricane contexts.

The first step to test the transferability of a model consists of computing the ratios of the parameters estimated with each single dataset. This analysis reveals that the common variables show some differences in their estimated parameters. Particularly, even after considering the differences in the scale parameters of the datasets, household size and the indicator variable for households with window protection measures have different parameters (from the model estimated on the Ivan dataset) than the corresponding parameters from the models based on the other two datasets (*i.e.* Andrew and Katrina). Therefore, we defined two combined models for our analysis. Combined model-1 assumes that all the common variables (including household size and the indicator variable for window protection measures) have equal parameters across the three datasets. On the other hand, combined model-2 assumes all common variables except the two variables have equal parameters across datasets. However, this comparative analysis is not conclusive as there is no formal statistical test to conclude the equality of model parameters. In order to draw valid conclusions on the equality of the model parameters we calculate the model equality test statistic using the combined estimation process. The combined models are estimated restricting the parameters of the common variables to be equal according to the specifications mentioned above.

The combined estimation shows that the Ivan and Katrina datasets have more noise as the variances of their random terms are higher (scale parameter is inversely proportional to variance of random terms) than that of the Andrew dataset. This result could be due to the heterogeneity of locations and socio-demographic characteristics among the counties. Also notice that parameter estimates from the combined model are very close to the parameter estimates obtained from the model for the Andrew dataset. This is quite reasonable as in both cases the scale parameter for Andrew is restricted to one. To compare the parameters of the combined model with those from the other two models (*i.e.* separate models estimated using the Ivan or Katrina datasets), their individual scale parameters have to be considered.

The model equality test statistic using the log-likelihoods from combined model-1 and models using single datasets is calculated as (see Equation (3)):

$\mathrm{METS} = -2[-2240.208 + 457.93 + 1485.404 + 281.163] = 31.422$ with $df = 11$

Since $\chi^2_{11,0\,.01} = 24.725$, we reject the null hypothesis that the parameters across different hurricane contexts are equal. Next we compute the same test statistic using the log-likelihoods from combined model-2 and models using single datasets as:

$\mathrm{METS} = -2[-2228.788 + 457.93 + 1485.404 + 281.163] = 8.582$ with $df = 9$

However, in this case, since $\chi^2_{9,0\,.01} = 21.67$ we cannot reject the null-hypothesis of equal parameters for the specific subset of variables across different hurricane contexts.

This statistical test fails to reject the hypothesis of model transferability across different hurricane datasets. Notice that although we have used parameters for household size and the indicator variable for household window protection measures specific to Hurricane Ivan, these parameters have similar estimates across the other two datasets (*i.e.* Andrew and Katrina) given that the difference in the scale parameters is considered. This suggests that, for Hurricane Ivan, these two variables have either statistically insignificant or different influence on evacuation choice. When these facts are accounted for, the equality of model-2 parameters across different hurricane contexts is established.

This finding suggests that except for the region-specific indicator variables, the constant terms, and a few specific variables (household size and window protection strategies), evacuation decision making models have equal parameters across the three different hurricane contexts. Thus, the conclusions from our statistical test support a reasonable validity of evacuation choice model transferability across different hurricane contexts given the constant terms can be found for these contexts.

Summary and Conclusions

This paper compared evacuation decision making models estimated for three different hurricane contexts (Hurricanes Andrew, Ivan and Katrina). The hurricanes were classified as categories 3 and 4, indicating a relatively high threat. The survey samples were different in many aspects, including diversity of geographic locations, socio-demographic characteristics, and prevalence of mobile homes in the source counties/parishes. This diversity provided an excellent background on which to test the potential of transferring the parameter estimates for household evacuation decision making models. A formal statistical test was used to evaluate the equality of model parameters. The test statistic was based on a joint model estimation combining the datasets from three hurricane contexts. Combined models estimated for the three hurricane contexts also revealed the scale parameters specific to each hurricane context. This scale parameter allows us to compare model parameters across different hurricane contexts. The model equality test adopted in this study concluded that the parameters of the evacuation choice models can be transferred across different contexts and that the factors involved in the decision to evacuate or not transcend many potential differences among populations. However, one has to interpret the validity of these results within the same geographical area and under the usual assumptions of econometric models. The region-specific variables and constants have to be updated before transferring such kinds of models.

This study has implications related to the application of an evacuation decision making model estimated using a particular dataset to a different hurricane context. Although this study only examined three hurricanes, the results are promising, and additional hurricane datasets will be tested in the future. Model application is warranted to understand evacuation behavior as well as to determine evacuation demand for a future hurricane. However to this date (to the best of our knowledge), no one rigorously investigated whether the model developed for a particular region and a specific hurricane would reasonably reflect behavior for a different hurricane context in a different region (Wilmot and Mei 2004). As mentioned before, Baker (1991) found consistent patterns of a resident's decision of whether or not to evacuate through comparisons of the correlation between explanatory variables and aggregate evacuation behavior (*i.e.* evacuation rate of an area). Our findings, following a rigorous modeling approach, support similar consistent evacuation behavior patterns across different hurricanes. Our study also provides estimates of model parameters transferable to other hurricane contexts which provide a stronger basis for developing specific strategies for emergency preparedness.

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Table 1: Summary Statistics of Some Selected Variables

Variables	Percent of Households		
	Andrew	**Ivan**	**Katrina**
Total observations	954	3200	811
Evacuated (percent)	33.8	45.1	62.4
Household Location			
Alabama (percent)	-	12.5	24.2
Florida (percent)	100	40.6	-
Louisiana (percent)	-	28.1	45.3
Mississippi (percent)	-	18.8	30.6
Housing Type			
Mobile home (percent)	1.6	6.8	3.1
Notice received	39.2	45.6	72.7
Received recommended notice (percent)	-	23.5	26.8
Received mandatory notice (percent)	-	19.3	43.0
*Number of Children**			
None (percent)	60.4	53.3	58.1
1 – 2 (percent)	31.8	24.4	22.1
3 or more (percent)	7.9	6.2	6.5
Hazard actions			
Knew and live in an evacuation zone (percent)	60.7	44.3	44.8
Households with protection strategies before the hurricane	71.3	66.2	52.4

Variables	Percent of Households		
	Andrew	Ivan	Katrina
(percent)			

* Children under 13 years old for Andrew and under 18 years old for Ivan and Katrina

** Ranges were approximated to the best common data

Note: Percentages do not add up to 100 due to missing data or omission of some categories from the table.

Table 2: Census Based Profiles of Sampled Counties

County / Parish	Coastal / Inland	Number of Interviews *	Population +	Owner occupied housing units+	Mobile Homes (% of total housing units) +	Households with at least one child under 18+,#	Average HH size+	Average family size+
			Hurricane Andrew					
Miami-Dade County, FL	Coastal	954	2,253,362	57.8%	1.8%	33.8%	2.84	3.35
			Hurricanes Ivan and Katrina					
Alabama								
Baldwin	Coastal	200	140,415	79.5%	17.7%	31.5%	2.50	2.94
Mobile	Coastal	200	399,843	68.8%	9.3%	34.4%	2.61	3.13
Louisiana								
Jefferson	Mostly Inland	200	455,466	63.9%	1.9%	31.9%	2.56	3.13
Orleans	Coastal	200	484,674	46.5%	0.3%	29.2%	2.48	3.23
Plaquemines	Coastal	100	26,757	78.9%	31.5%	39.5%	2.89	3.30
St. Bernard	Coastal	100	67,229	74.6%	7.9%	33.7%	2.64	3.12
St. Charles	Inland	100	48,072	81.4%	11.0%	43.4%	2.90	3.27
St. John	Inland	100	43,044	81.0%	12.6%	43.0%	2.89	3.38
St. Tammany	Mostly Inland	100	191,268	80.5%	11.4%	39.3%	2.73	3.15
Mississippi								
Hancock	Coastal	200	42,967	79.6%	18.8%	31.5%	2.52	2.99
Harrison	Coastal	200	189,601	62.7%	12.4%	33.5%	2.55	3.07

County / Parish	**Coastal / Inland**	**Number of Interviews ***	**Population +**	**Owner occupied housing units+**	**Mobile Homes (% of total housing units) +**	**Households with at least one child under 18+,#**	**Average HH size+**	**Average family size+**
Jackson	Coastal	200	131,420	74.6%	12.7%	37.0%	2.72	3.14
Florida								
Bay	Coastal	150	148,217	68.6%	16.5%	30.6%	2.43	2.92
Escambia	Coastal	200	294,410	67.3%	9.6%	29.9%	2.45	2.98
Franklin	Coastal	100	11,057	79.2%	20.2%	24.8%	2.28	2.77
Gulf	Coastal	100	13,332	81.0%	25.4%	28.4%	2.42	2.87
Monroe	Coastal	200	79,589	62.4%	19.0%	20.8%	2.23	2.73
Okaloosa	Coastal	150	170,498	66.4%	8.1%	33.1%	2.49	2.94
Santa Rosa	Coastal	150	117,743	80.4%	17.5%	36.5%	2.63	3.00
Walton	Coastal	100	40,601	79.0%	22.1%	26.4%	2.35	2.83
Liberty	Inland	150 total	7,021	81.8%	46.5%	34.2%	2.51	3.00
Calhoun	Inland		13,017	80.2%	38.3%	32.5%	2.53	3.02
Holmes	Inland		18,564	81.5%	33.9%	30.9%	2.43	2.92
Washington	Inland		20,973	81.9%	37.2%	30.3%	2.46	2.93
Jackson	Inland		46,755	77.9%	32.1%	30.9%	2.44	2.95

* Morrow and Gladwin (2005)

+ U.S. Census, Census 2000 data.

percent of family households

Table 3: Model Estimation Results for Single Datasets and Combined Datasets

Variable Description	ANDREW Coeff. (t-stat.)		IVAN Coeff. (t-stat.)		KATRINA Coeff. (t-stat.)		Combined Model 1 Coeff. (t-stat.)		Combined Model 2 Coeff. (t-stat.)	
Alabama Indicator Variable (1 if HH is from Alabama, 0 otherwise; defined specific to Ivan)			0.76	(5.31)			1.03	(4.80)	0.941	(4.74)
Louisiana Indicator Variable (1 if HH is from Louisiana, 0 otherwise; defined specific to Ivan)			0.999	(8.86)			1.41	(6.74)	1.24	(6.49)
Mississippi indicator variable (1 if HH is from Louisiana, 0 otherwise; defined specific to Ivan)			1.01	(8.09)			1.4	(6.51)	1.25	(6.31)
Alabama Indicator Variable (1 if HH is from Alabama, 0 otherwise; defined specific to Katrina)					-1.67	(-6.23)	-2.62	(-4.09)	-2.87	(-4.01)
Louisiana indicator variable (1 if HH is from Louisiana, 0 otherwise, defined specific to Katrina)					1.41	(5.80)	2.18	(3.81)	2.41	(3.76)
Constant (defined for the outcome of not evacuating and specific to Andrew)	-0.0985	(-0.42)					0.615	(3.63)	0.0474	(0.22)
Constant (defined for the outcome of not evacuating and specific to Ivan)			0.959	(4.57)			0.848	(3.71)	1.17	(4.65)

Variable Description	ANDREW Coeff. (t-stat.)	IVAN Coeff. (t-stat.)	KATRINA Coeff. (t-stat.)	Combined Model 1 Coeff. (t-stat.)	Combined Model 2 Coeff. (t-stat.)
Constant (defined for the outcome of not evacuating and specific to Katrina)			0.646 (1.07)	-0.187 (-0.60)	-0.79 (-2.18)
Household Size	-0.229 (-3.68)	-0.0294 (-0.66)	-0.148 (-1.25)	-0.147 (-3.35)	-0.208 (-4.05)
Household Size (defined specific to Ivan)					-0.0552 (-1.11)
Household Ownership	-0.329 (-1.92)	-0.247 (-1.64)	0.643 (1.35)	-0.356 (-2.77)	-0.295 (-2.36)
Indicator Variable for HHs with Window Protection Measures before the Hurricane	-1.2 (-6.72)	-0.276 (-3.04)	-0.484 (-2.09)	-0.647 (-5.80)	-1.14 (-6.75)
Indicator Variable for HHs with Window Protection Measures before the Hurricane (defined specific to Ivan)					-0.335 (-2.90)
Indicator variable Mobile House (1 if HH lived in a mobile home, 0 otherwise)	2.06 (2.45)	1.11 (5.61)	2.11 (1.51)	1.54 (5.46)	1.44 (5.42)
Number of children	0.206 (2.17)	0.127 (2.12)	0.243 (1.64)	0.216 (3.55)	0.19 (3.28)
Indicator Variable for Evacuation Notice (1 if the HH received an evacuation notice, 0 otherwise)	1.77 (10.74)	1.52 (16.69)	1.28 (5.22)	1.94 (12.95)	1.85 (11.98)
Indicator Variable for Previous Hurricane Experience (1 if		-0.266 (-2.34)		-0.344 (-2.22)	-0.327 (-2.29)

Variable Description	ANDREW Coeff. (t-stat.)	IVAN Coeff. (t-stat.)	KATRINA Coeff. (t-stat.)	Combined Model 1 Coeff. (t-stat.)	Combined Model 2 Coeff. (t-stat.)
HH has experienced a major hurricane before, 0 otherwise)					
Indicator Variable for Mandatory Work Requirement (1 if someone in the HH had to work during the evacuation period, 0 otherwise)		-0.276 (-2.86)	-0.0203 (-0.08)	-0.298 (-2.41)	-0.313 (-2.69)
Scale Parameter Andrew				1.000 Fixed	1.000 Fixed
Scale Parameter Ivan				0.743 (-3.54)	0.813 (-2.28)
Scale Parameter Katrina				0.643 (-2.90)	0.589 (-3.51)
Number of Estimated Parameters	7	12	10	18	20
Number of Observations	892	2568	589	4049	4049
Log-likelihood at Zero	-618.287	-1780.002	-408.264	-2806.553	-2806.553
Log-likelihood at Convergence	-457.93	-1485.404	-281.163	-2240.208	-2228.788
Adjusted Rho-bar Squared	0.248	0.159	0.287	0.195	0.199