Modeling Risk Attitudes in Evacuation Departure Choices

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The decision of whether and when to evacuate can be characterized as decision making under risk. Presently, most models assume linear utility functions through which it is impossible to disentangle factors that influence risk attitudes and other factors that affect decision making under risk. There is a need to disentangle and study factors that affect risk attitudes from factors that affect an evacuee's preparation time. The aim in doing so is to provide planners and practitioners with an ability to measure a person's risk attitude and develop appropriate strategies that could motivate people to evacuate. This study is expected to connect the theory of risk developed in economic theory with behavior under threat. The paper uses the Hurricane Andrew response data in conjunction with time-dependent data on the probability of a hurricane strike and the category of the hurricane data to develop a model for evacuation departure choice. A constant relative risk aversion specification is used to model risk attitudes. The process of an evacuation is abstracted as an individual being given a choice between two lotteries: either to stay or leave. The results show that the model is able to predict the total number of evacuees and the time varying evacuation rates with reasonable accuracy. Factors such as time of day, length of time spent in a region, and whether a mandatory evacuation order was issued affected risk attitudes. The presence of children affected the amount of time spent preparing if the family decided to stay.

The risk of being harmed by an impending disaster is the main motivation for evacuating. Therefore, the decision to evacuate or not and when to evacuate can be characterized as decision making under risk. Modeling individual risk attitude has been widely studied in economic theory, and the concept is relevant to evacuation behavior. Despite this, risk attitudes have not been accurately modeled in the evacuation behavior literature. Various utility models have been proposed in economic theory to measure an individual's risk attitude. Kahneman received the Nobel Prize in Economic Sciences in 2002 for the work he did in collaboration with Tversky on prospect theory to model individual behavior under risk (*1*). Since then, models such as the rank dependent utility theory have been proposed by Quiggin (*2*). Risk attitudes of individuals are related to the curvature in the utility function. The constant relative risk aversion model is the most commonly used to explain individual behavior under risk and was first proposed by Friedman and Savage in 1948 (*3*).

Previous literature characterizes the behavior of evacuees as a rational behavior in which their decisions are based on certain environmental and demographic factors (*4–8*). Alsnih et al. summarized the research on evacuation demand, illustrating a general model for evacuation behavior, as well as the response curves (*4*). In a series of works Fu and Wilmot (*5, 6*) and Fu et al. (*7*) developed a sequential logit model to estimate the evacuation departure time choice by using evacuation data from South Carolina during Hurricane Floyd and used this model to successfully predict evacuation departure time choice behavior for Hurricane Andrew in southwest Louisiana. Recently Hassan et al. (*8*) extended the sequential logit model (*9, 10*) to a mixed logit model that is able to control for the heterogeneous responses of households. In addition, Lindell and Perry developed a rational framework called the protective action decision model, which took into account three major predecision processes: reception, attention, and comprehension of exposure (*11*). According to the model, these predecisions are influenced by threat perceptions, protective action perceptions, and stakeholder perceptions. In general, people collectively act rationally during evacuation and their decision to evacuate depends on factors such as direct perception of threat (*12, 13*), demographics (*9, 14*), and issuance of an evacuation notice (*10, 12, 15*).

Almost all models assume linear utility functions through which it is impossible to separately identify factors that influence risk attitudes from other factors that affect decision making. In fact, evacuation behavior models presented as sequential logit (*5–7*) and mixed logit models (*8*) have the risk attitudes embedded in the linear utility specifications. This paper presents a new framework to model evacuation departure time choice while controlling for risk attitudes. This study is expected to connect the theory of risk developed in economic theory with behavior under threat. This connection would provide planners and practitioners with an ability to measure a person's risk attitude and develop appropriate strategies that would motivate people to evacuate. The following sections of this paper outline the methodology, describe the data, present the results gained from the analysis, and summarize the overall conclusions, contributions, and future applications of this work.

METHODOLOGY

It is recognized that evacuation decision making is a decision process under risk. In this study risk is defined by the probability of a hurricane striking. Data are routinely collected and maintained by the National Oceanic and Atmospheric Administration (NOAA) (*16*). Utility is usually defined over consequences [e.g., Clemen and Reilly (*17*)]. In the case of hurricanes, the consequences are dependent on time spent

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preparing and gathering knowledge about the path and strength of the hurricane to make appropriate choices. Therefore, it can be argued that an individual making a decision to evacuate or not defines his or her utility over time. In recognition that time is an important consideration in decision making, an individual's utility to stay or leave is defined over time.

The process of an evacuation can be abstracted as an individual being given a choice between two lotteries at every time step. Consider an individual making a choice between two lotteries of the form shown below:

Lottery A:

$2.00 with probability 0.9
$3.00 with probability 0.1

Lottery B:

$0.25 with probability 0.9
$6.00 with probability 0.1

An individual's decision to choose a certain lottery reveals his or her risk attitude. For example, a risk-averse individual would choose Lottery A, and a risk seeker would choose Lottery B.

Under the threat of a hurricane an individual makes a decision in each time interval either to stay or leave.

Lottery "Leave":

$U_{\text{hit}}^{\text{leave}}$ with probability P_{hit} of a hurricane hit
$U_{\text{miss}}^{\text{leave}}$ with probability $1 - P_{\text{hit}}$ of a miss

Lottery "Stay":

$U_{\text{hit}}^{\text{stay}}$ with probability P_{hit} of a hurricane hit
$U_{\text{miss}}^{\text{stay}}$ with probability $1 - P_{\text{hit}}$ of a miss

It is assumed that individuals have a constant relative risk attitude, and it has the form shown in Equations 1 through 4, where r is the parameter for constant relative risk aversion that represents the risk attitude of an evacuee. When the parameter $r = 0$, risk neutral behavior is indicated; $r > 0$ denotes risk aversion, and $r < 0$ denotes risk seeking. When $r = 1$, $U(x) = \ln(x)$, where x is the item over which utility is defined and can be money.

In addition, t is the time interval, and therefore the time elapsed. T is the time of the hurricane's landfall. Therefore, $T - t$ is the time remaining before landfall; k is the additional time required to prepare the residence to brave the storm and m is the time needed to prepare to leave (mobilization time). There are no inherent assumptions on k and m for the purpose of the proposed model.

The utility of staying under the case that the storm would hit ($U_{\text{hit}}^{\text{stay}}$) is defined as the sum of the time already spent staying (t) and the additional time to prepare the residence to brave the storm (k). The time already spent staying (t) needs to be considered as part of the utility because an individual would have used the time to gather information about the hurricane to determine what type of preparation needs to be undertaken. This time represents the value of staying until time t given the storm would hit.

$$U_{\text{hit}}^{\text{stay}} = \frac{(t+k)^{1-r}}{1-r} \tag{1}$$

The loss associated with staying if the storm did not hit would be the time spent in preparation to stay (k). The utility associated with staying and the hurricane missing ($U_{\text{miss}}^{\text{stay}}$) is defined as

$$U_{\text{miss}}^{\text{stay}} = -\frac{(k)^{1-r}}{1-r} \tag{2}$$

The mobilization time m is the time to prepare the household to evacuate, and k is the time required to prepare the structure for hurricane impact.

The utility associated with leaving if the hurricane hit is defined over the mobilization time (m), the time required for a household to prepare for an evacuation. If the hurricane hits, the evacuee would perceive the time spent preparing for the evacuation as useful. The time already spent staying (t) would have been of no value in the preparation to evacuate because they could very well have evacuated earlier, and the additional time spent would have provided no value. Therefore the utility of leaving given a storm hits ($U_{\text{hit}}^{\text{leave}}$) is written as

$$U_{\text{hit}}^{\text{leave}} = \frac{(m)^{1-r}}{1-r} \tag{3}$$

However, if the hurricane does not hit, the time spent preparing (m) and the time that was not spent at home, that is, the time difference between the expected landfall (T) and the time at which the household evacuated (t), would be lost. This difference is the period during which the household would have gathered information about the storm if they had stayed. Therefore the disutility associated with leaving given that the hurricane misses ($U_{\text{miss}}^{\text{leave}}$) is

$$U_{\text{miss}}^{\text{leave}}(T-t) = -\frac{(T-t)^{1-r}}{1-r} \tag{4}$$

Therefore the expected utility associated with the two abstracted lotteries, one lottery for staying and the other for leaving, is shown in Equations 5 and 6:

$$\text{EU}_{\text{stay}} = P_{\text{hit}} U_{\text{hit}}^{\text{stay}} + (1 - P_{\text{hit}}) U_{\text{miss}}^{\text{stay}} \tag{5}$$

$$\text{EU}_{\text{leave}} = P_{\text{hit}} U_{\text{hit}}^{\text{leave}} + (1 - P_{\text{hit}}) U_{\text{miss}}^{\text{leave}} \tag{6}$$

where P_{hit} is the probability of the hurricane making landfall.

An evacuee makes a choice between leaving and staying at a time interval t. Let t index the time interval, and define $t \in \{1, 2, \ldots, T\}$ (it is assumed that $t = 0$ is the time that the evacuation process begins, which usually coincides with the implementation of the evacuation plans). So the specification used for the lottery choices over objective probabilities must be a binary sequential specification because an individual chooses to stay at every time interval before evacuating. For the sake of convenience the following definitions are presented:

$$\text{eu}_{\text{stay}}^{t} = \exp\left(\left(\text{EU}_{\text{stay}}^{t}\right)\right) \tag{7}$$

$$\text{eu}_{\text{leave}}^{t} = \exp\left(\left(\text{EU}_{\text{leave}}^{t}\right)\right) \tag{8}$$

A superscript associated with the time dimension t is added to the expected utility associated with staying and leaving in Equations 7 and 8.

The latent index for a household evacuating at time t is then defined as the probability of evacuating at time t. This probability is equivalent to the probability of leaving at time t, given that the individual stayed until time $t - 1$. Say, if $\text{prob}_{\text{leave}}^{t}$ is the probability of leaving at time t and $\text{prob}_{\text{stay}}^{t}$ is the probability of staying at time t, the following is a description:

$$\nabla \text{EU}^{t} = \text{prob}_{\text{leave}}^{t} \prod_{1}^{t-1} \text{prob}_{\text{stay}}^{j}$$

replacing these probabilities by a logit form

$$\nabla \mathrm{EU}^t = \left[\frac{\mathrm{eu}_{\mathrm{leave}}^t}{\left(\mathrm{eu}_{\mathrm{stay}}^t + \mathrm{eu}_{\mathrm{leave}}^t\right)}\right]\prod_{j=1}^{t-1}\left[\frac{\mathrm{eu}_{\mathrm{stay}}^j}{\left(\mathrm{eu}_{\mathrm{stay}}^j + \mathrm{eu}_{\mathrm{leave}}^j\right)}\right] \tag{9}$$

The end result is a log likelihood for the evacuation time choices i defined by

$$\begin{aligned}\mathrm{LL}^{\mathrm{ET}} &= \ln L\left(r, k, m; y, \mathbf{X}\right)\\ &= \sum_t\sum_i\left(\left(\ln\left(\nabla \mathrm{EU}^t\right)\times \mathbf{I}\left(y_i = 1\right)\right) + \left(\ln\left(1-\nabla \mathrm{EU}^t\right)\times \mathbf{I}\left(y_i = 0\right)\right)\right)\end{aligned} \tag{10}$$

where

$\mathbf{I}(\cdot)$ = indicator function and is either 1 or 0,
y_i = 1 denotes choice of staying,
y_i = 0 denotes choice of leaving for evacuee i,
$\mathbf{X}$ = a vector of individual characteristics,
$L(\cdot)$ = likelihood function that needs to be maximized [the maximum likelihood estimation for these sorts of formulations is described at length by Harrison (*18*)], and
r, k, and m = parameters defined as a linear function of the characteristics in vector $\mathbf{X}$.

The method illustrated above is used in the current paper to estimate risk attitudes and evacuation behavior of people that experienced Hurricane Andrew, which hit Louisiana.

DATA DESCRIPTION

The data set used for this study was collected for southwest Louisiana following the arrival of Hurricane Andrew through that region in August 1992. The survey was conducted by the Louisiana Population Data Center at Louisiana State University and sponsored by the Louisiana Office of Emergency Preparedness. The survey asked approximately 100 questions covering a variety of information about a household. Data collected included household sociodemographic information; length of time spent in Louisiana (lngresslr); proximity to a body of water (currswatr); whether a mandatory evacuation order was given (mnevcand1); whether there were children in the household (childr); whether the evacuee had a trailer, boat, motor home, camper, or something similar during the evacuation (ancmpeva) from the hurricane; the time of evacuation (evactime) if the household evacuated; the evacuation destination; and how to get there. Of the 651 households surveyed, 466 were living in an affected parish when Andrew struck. After households with missing information on evacuation time were deleted, the final data set contained data from 429 households, of which 157 evacuated. The time of evacuation for each household was reported in four 6-h time intervals per day (midnight to 6 a.m., 6 a.m. to noon, noon to 6 p.m., and 6 p.m. to midnight). Because time of day has been found to have a significant effect (*5–8*) on decision making, dummy variables were created for time periods between midnight and 6:00 a.m. (b_0), 6:00 a.m. and noon (b_1), and noon and 6:00 p.m. (b_2). These dummy variables were coded as 0 or 1 according to the time of day being evaluated; therefore a decision being made at 9:00 a.m. would have $b_0 = 0$, $b_1 = 1$, and $b_2 = 0$. Their effects were tested on the risk attitudes by including them in the regression model and studying the coefficients. Because evacuation lasted for four time intervals for 3 days and three time intervals for the last day, the total number of time intervals reported in this study was 15.

The hurricane track data were collected for the affected parishes from the NOAA database (*16*). The hurricane track data consisted of the strike probability (P_{hit}, as defined in the previous section) of Hurricane Andrew and its category (ca) in each time interval. On the basis of the time interval, these data were merged with the respondent data set.

RESULTS

With the modeling framework described in the section on methodology, a model was estimated by using statistical analysis software (Stata). The risk parameter (r), the time required to prepare a house to ride out the storm (k), and the mobilization time (m) were estimated as a linear combination of threat and demographic characteristics. The variables were included in the regression model on the basis of their expected effect on risk and mobilization time and were based on findings in the literature (*5–22*). The actual values of r, k, and m were not available and were assumed to be a linear combination of the dependent variables, whose coefficients were estimated by using maximum likelihood. The equations are shown below (Equations 11 through 13), and the model estimates are shown in Table 1.

$$\begin{aligned} r = 0.7161 &+ 0.0277 * (\text{proximity to a water body})\\ &+ 0.0980 * (\text{mandatory evacuation})\\ &- 0.0018 * (\text{time spent in Louisiana})\\ &- 0.1038 * (\text{time period midnight}-6{:}00\text{ a.m.})\\ &+ 0.0495 * (\text{time period }6{:}00\text{ a.m.}-\text{noon})\\ &+ 0.1051 * (\text{time period noon}-6{:}00\text{ p.m.})\end{aligned} \tag{11}$$

$$\begin{aligned} k = 31.4912 + 4.8450 * \left(\text{child or not}\right) - 4.5005\\ * \left(\text{hurricane category}\right)\end{aligned} \tag{12}$$

$$m = 2.0271 + 3.4200 * \left(\begin{matrix}\text{pull a trailer/boat/motor home/}\\ \text{camper/something similar}\end{matrix}\right) \tag{13}$$

The time-of-day variables b_o, b_1, and b_2, as well as variables mnevcand1 and lngresslr, were found to have a statistically significant effect on the risk attitudes, at a 95% confidence level (p-value <.05). The issuance of a mandatory evacuation (mnevcand1), the time period between 6:00 a.m. and noon (b_1), and the time period between noon and 6:00 p.m. (b_2) were found to have a positive effect on the risk attitude. The indication is that these factors make individuals more risk averse and therefore would result in making people more likely to evacuate. The variable currswatr was not found to be moderately significant at an 85% confidence level.

However, coefficients for the variable representing people living in Louisiana for a longer period of time (lngresslr) and the time between midnight and 6:00 a.m. (b_0) were negative, suggesting that these conditions reduce people's risk aversion, therefore making them less likely to evacuate. The length of time an individual lives in a particular region was found to make the individual less risk averse to hurricanes. That condition has also been identified in earlier studies (*6, 9, 19*).

TABLE 1 Model Estimates for Evacuation Departure Choice

Variable	Coefficient	Standard Error	z	$p > \|z\|$	95% Confidence Interval
r					
currswatr	0.0277	0.0179	1.54	.122	−0.0074 to 0.0628
mnevcand1	0.0980	0.0216	4.54	.000	0.0557 to 0.1403
lngresslr	−0.0018	0.0005	−3.24	.001	−0.0029 to −0.0007
b0	0.1038	0.0340	−3.05	.002	−0.1705 to −0.0371
b1	0.0495	0.0262	1.89	.059	−0.0019 to 0.1009
b2	0.1051	0.0265	3.97	.000	0.0532 to 0.1570
_cons	0.7161	0.0483	14.81	.000	0.6213 to 0.8108
k					
childr	4.8450	1.9515	2.48	.013	1.0201 to 8.6699
ca	−4.5005	2.2094	−2.04	.042	−8.8308 to −0.1701
_cons	31.4912	9.5952	3.28	.001	12.6849 to 50.2976
m					
ancmpeva	3.4200	6.2000	0.55	.581	−8.7319 to 15.5719
_cons	2.0271	2.0122	1.01	.314	−1.9167 to 5.9710

A recent study by Lindell et al. showed that evacuation logistics significantly affect the departure curve (*20, 21*). Robust estimates could have been generated if data had been available on evacuation logistics, such as the time spent preparing for a hurricane if the decision was made to stay (*k*) and the mobilization time (*m*). However, these factors were considered as parameters and estimated, as is shown in Equation 10. In fact, the presence of children in the household was found to affect significantly the amount of time needed to prepare and brave the hurricane. No significant factors were identified for mobilization time.

The model predicted approximately 171 evacuees from the 429 respondents (157 actually evacuated), which is approximately 8% higher than what was observed. The model overpredicted the total evacuation demand by approximately 9%, but as seen in Figure 1, the model was able to predict fairly accurately the temporal distribution of the evacuees. As seen in Figure 2, the regression results have a high R^2 value of .93.

CONCLUSION

This study provides the first step toward explicitly incorporating risk aversion into the modeling framework for estimating time-dependent evacuation demand. The model presented in this paper predicts the total number of evacuees as well as the reasonable accuracy of their departure time. Factors such as time of day, length of time spent in a region, and whether a mandatory evacuation order was issued affected risk attitudes. The presence of children affected the amount of time spent preparing if the family decided to stay.

The value of such a modeling approach is that it can be used to distinguish factors that affect evacuee's risk attitudes from other factors such as mobilization time and time required to prepare to weather the storm. Both significant and practically useful, the ability to distinguish factors affecting the different aspects of evacuation would help emergency managers to develop strategies to affect risk aversion, mobilization time, or time needed to prepare to brave the

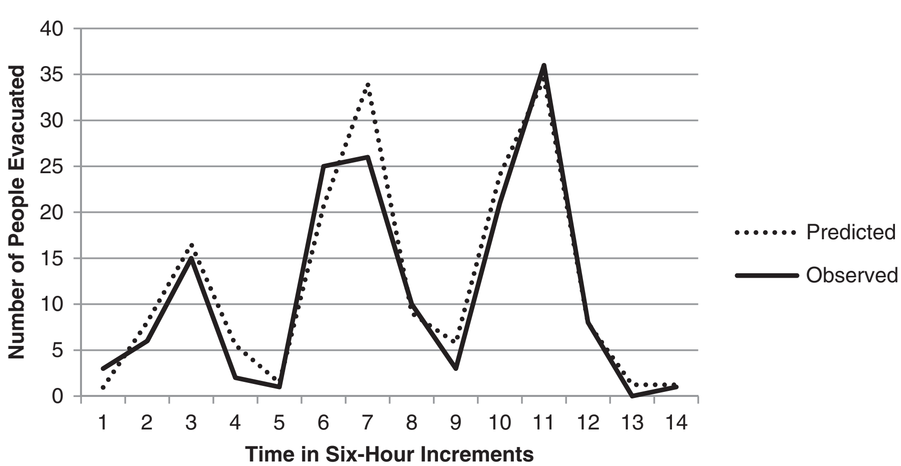

FIGURE 1 Comparison of estimated and observed evacuation response during Hurricane Andrew.

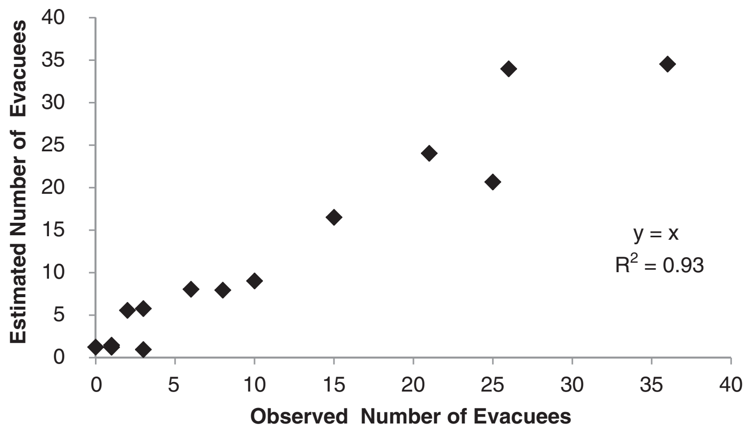

FIGURE 2 Comparison of estimated and observed evacuation response during Hurricane Andrew through regression.

hurricane. For instance, according to the model specified in this study, emergency managers could deliver specific threat information to residents who have stayed in a region for a long period to motivate their departure. The abstraction of this modeling approach as a lottery choice lends itself well to laboratory experiments being conducted, such as the experiments by Gudishala and Wilmot (*22*).

Although this research makes a significant first step, it is recognized that further research will be needed to use actual revealed mobilization time and the time used to prepare to weather the storm, to develop robust estimates. There is also a need to study the transferability of the model parameter for risk aversion.

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