One Million Dollars a Mile?

The Opportunity Costs of Hurricane Evacuation*

John C. Whitehead**

Department of Economics

East Carolina University

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** Associate Professor, Department of Economics, East Carolina University, Greenville, NC 27858; phone: (252) 328-6821, fax: (252) 328-6821, e-mail: WhiteheadJ@mail.ecu.edu.

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Abstract

The best estimate of hurricane evacuation costs is the often-stated "one million dollars a mile" of evacuated coastline. The purpose of this paper is to pursue better measures of the opportunity costs of hurricane evacuations that depend on storm intensity, behavior, and population. We model the hurricane evacuation decision of households using revealed and stated preference data methods. In a sample of North Carolina residents who experienced 1998's Hurricane Bonnie, evacuation behavior is according to predictions from economic theory. We use the predictions of evacuation and estimates of household evacuation costs to estimate the aggregate opportunity costs of hurricane evacuations. We find that hurricane evacuation costs for ocean counties in North Carolina range from about $1 to $50 million depending on storm intensity and emergency management policy. These costs are much less than "one million dollars a mile" of evacuated coastline.

Introduction

Shortly after the National Hurricane Center issued a hurricane watch for Hurricane Bonnie covering North Carolina on Monday, August 24, state emergency managers recommended mandatory evacuations for more than a quarter million coastal North Carolina residents and vacationers. At 6:00 p.m., on Tuesday, August 25, the hurricane warning was extended to cover North Carolina. On 2:00 p.m. Wednesday, August 26 Hurricane Bonnie made landfall on the coast of North Carolina at Cape Fear, 20 miles south of Wilmington. As Bonnie landed in southeastern North Carolina it had wind speeds of 115 miles per hour. Over the next few hours Bonnie lost wind speed, became a tropical storm, and traveled northeast covering the entire North Carolina coast (Avila, 1998). One out of every four North Carolina residents and thousands of vacationers evacuated the coast as a result.

When issuing hurricane evacuation orders, as during Hurricane Bonnie, the primary concern of emergency managers is the benefits of the evacuation - the health and safety of those in the path of the storm. The cost of an evacuation - travel expenditures, lost wages, and missed vacations - is of secondary importance, if it is considered at all. One reason for this focus is the visibility of the benefits of evacuation (i.e., lives saved). Conversely, hurricane evacuation costs are difficult to measure. To our knowledge, the best estimate of hurricane evacuation costs is the often-stated “one million dollars a mile” of evacuated coastline.[1] This measure is clearly not an opportunity cost as it is tied to a physical variable. “One million dollars a mile” ignores storm intensity, behavior, and the population of evacuated areas. Better measures of the opportunity costs of hurricane evacuations are needed for informed emergency management decisions.

The primary purpose of this paper is to estimate the opportunity costs of hurricane evacuations. We examine the likelihood of household evacuation using data from a survey of

North Carolina coastal residents who were affected by Hurricane Bonnie. The decision to evacuate during Hurricane Bonnie is revealed preference data. Revealed preference data is limited in that it can only be used to predict evacuation rates during similar hurricanes. Hypothetical questions can be used to obtain stated preference data that can be used to assess behavior beyond the range of historical experience. However, stated preference data may be prone to hypothetical bias. In these situations, stated preference data can be “calibrated” by being combined with revealed behavior data and results adjusted accordingly (Louviere, 1996).

While most hurricane evacuation research has used revealed preference data, some researchers have experimented with stated preference data to simulate the response to different hurricane situations (Baker, 1991). Recently, Dow and Cutter (1997) survey residents of Hilton Head and Myrtle Beach, S.C. and Wilmington, N.C. after Hurricanes Bertha and Fran. Of the respondents 39% evacuated for both hurricanes, 37% stayed home for both, and 21% did not evacuate for Bertha but evacuated for Fran. Respondents were queried about their evacuation behavior in the case of a future hurricane. The largest portion reported that whether they would evacuate or not "would depend" on the severity of the storm.

Peacock, Morrow, and Gladwin (1997) conducted a survey of households throughout Dade County, Florida, three to four months after Hurricane Andrew. One part of the survey was a stated preference question about household behavior in the case of a future hurricane. Respondents were asked if they would evacuate and given the following response categories: "stay home," "go to safer building," "leave the area entirely," and "depends on the strength of the storm." Almost half reported that it would depend on the strength of the storm. The remaining respondents were split between "stay home" and "leave the area entirely."

Past hurricane evacuation research using stated preference data is limited because the survey questions did not explicitly identify the severity of the hypothetical hurricane. In this paper we use stated preference data from survey questions concerning all categories of storm intensity in the Saffir-Simpson Hurricane Scale (National Hurricane Center, 1999). We combine revealed and stated preference data to predict evacuation rates and costs at each level of storm intensity. We use household evacuation costs and various measures of hurricane risks to test the validity of the revealed and stated preference data.

In the remainder of this paper we begin with a theory of hurricane evacuation decisions. Then we discuss the Hurricane Bonnie case study including survey design and data. In the empirical section we treat the combined revealed and stated preference data as a panel and make predictions about evacuation behavior beyond the range of recent experience. With this model, we estimate the costs of hurricane evacuations under different storm intensity and evacuation order scenarios. We also speculate on the efficiency of mandatory evacuation orders.

A Theory of Evacuation Behavior

We assume that households consider health and income when making evacuation decisions under uncertainty. Individuals possess the utility function

[1] $$U = U(H, y)$$

where utility (U) is a function of exogenous health status (H) and income (y). Households have two alternative actions given the risk of a hurricane strike, evacuate to someplace safer or stay at home. If utility is additively separable in health and income individuals have utility with good health

[2] $$U(H=1, y) = h(1) + m(y)$$

where H=1 is the case of good health. Good health is enjoyed in the absence of a hurricane or by avoiding a hurricane through evacuation. Utility with bad health is

[3] $U(H=0, y) = h(0) + m(y)$

where H=0 is the case of bad health.

Even in the absence of a threatening hurricane, health status is uncertain. Households have a perceived probability of good health (g) and bad health (1-g) in the absence of a hurricane. When confronted with a potential hurricane, households have a perceived probability of good health (p) and bad health (1-p). The probability of good health is higher in the absence of a hurricane threat, $g > p$. The change in the probability of good health with a hurricane threat is the hurricane health risk, $r = g - p$. With uncertainty about health status, expected household utility during a hurricane threat is

[4] $EU_p = m(y) + ph(1) + (1-p)h(0)$

and the expected household utility when avoiding a hurricane threat with evacuation is

[5] $EU_g = m(y-c) + gh(1) + (1-g)h(0)$

where c is the cost of evacuation.

The expected utility gain from avoiding a hurricane threat by evacuation is the difference between [5] and [4]

[6] $\Delta EU = m(y-c) – m(y) + r[h(1) – h(0)]$

where ΔEU is the change in expected utility. The first part of equation [6], $m(y-c) – m(y)$, is the decrease in utility resulting from evacuation costs. The second part, $r[h(1) – h(0)]$, is the increase in utility resulting from the change in the probability of good health. If the increase in utility from the change in the probability of good health exceeds the decrease in utility from evacuation costs, the household will evacuate. As ΔEU increases the probability of evacuation will increase.[2]

The cost of a hurricane evacuation depends on a number of factors. Households typically leave their homes by private automobile and drive to shelters, motels or hotels, or to the homes of friends and family. The direct evacuation costs are the transportation costs plus food, lodging, and other miscellaneous expenses. Transportation costs include gas and oil and the time costs of driving. The transportation costs are increasing in distance. Time costs are increasing in the wage rate and distance. We expect that lodging costs are a function of income with households who do not go to the homes of friends or family sorting themselves in shelters and hotels/motels based on income.[3] Therefore, evacuation costs are a function of distance (d) and income

[7] $$c = c(d, y)$$

where $c_d > 0$ and $1 > c_y > 0$.

The perceived health risk from a hurricane depends on storm intensity (s) and household characteristics such as housing type (e.g., mobile home) and location (e.g., a beach house)

[8] $$r = r(s, z)$$

where z is a vector of household characteristics increasing in the risk of the residence, $r_s > 0$, $r_z > 0$. Substitution of [7] and [8] into [6] yields

[9] $$\Delta EU = m[y - c(d, y)] - m(y) + r(s, z)[h(1) - h(0)]$$

where the change in expected utility is a function of income, distance, storm intensity, and residence characteristics.

Comparative static analysis enables us to determine the effects of exogenous variables on evacuation behavior. The effect of the distance traveled during an evacuation is

[10] $$\Delta EU_d = m_c c_d < 0$$

since $m_c < 0$. The probability of evacuation is expected to decrease with the distance that must be traveled. To varying extent, household distance traveled is endogenous. When households choose among evacuation destinations they may consider a visit to a far off friend or relative or a short trip across an island bridge. Households that must go to a shelter due to income or other constraints have fewer alternatives. Distance traveled also depends on when the hotel and public shelter-seeking households choose to evacuate. Households that leave earlier will drive shorter distances due to the lack of vacancies as hurricane landfall approaches.

The effect of storm intensity on the change in expected utility is

[11] $\Delta EU_s = r_s[h(1) - h(0)] > 0$

As storm intensity increases, hurricane risk increases and evacuations are expected to increase. The effect of individual risk characteristics is also positive

[12] $\Delta EU_z = r_z[h(1) - h(0)] > 0$

As individual risk characteristics increase, hurricane risk increases and evacuations are expected to increase.

The effect of income on evacuation behavior is

[13] $\Delta EU_y = (m_y^* - m_y) - m_y^* c_y$

where m* = m(y-c). The effect of income on the change in utility is either positive or negative. This derivative can only be signed under special cases. If the effect of income on evacuation costs is zero, $c_y = 0$, then the effect of income on the change in utility is positive if the marginal utility of income is diminishing over the range of evacuation costs ($m_y^* - m_y > 0$). Households with higher incomes will be more likely to evacuate. If the marginal utility of income is constant over the range of evacuation costs, $m_y^* = m_y$, and the effect of income on evacuation cost is positive, $c_y > 0$, the effect of income on evacuation is negative, $-m_y^* c_y < 0$. Households with higher opportunity costs of time will be less likely to evacuate.[4]

Survey Design and Data

The data for this analysis comes from a January 1999 telephone survey of North Carolina residents who were affected by Hurricane Bonnie in the summer of 1998 (Maiola et al., 1999). The survey used a random digit dial sample of households in the eight North Carolina ocean counties: Brunswick, Carteret, Currituck, Dare, Hyde, New Hanover, Onslow, and Pender. Of the households contacted, 76% completed the interview. The original sample has 1029 cases. Cases with missing values were deleted from the sample leaving 895 cases.

Respondents are asked if they left their home for someplace safer during Hurricane Bonnie, how far they drove, and whether they went to a motel/hotel, public shelter, the home of friends or family or somewhere else. Respondents are then told that Bonnie was a category 3 hurricane and asked stated preference questions concerning a future hurricane with a randomly assigned hurricane storm intensity based on the Saffir-Simpson Hurricane Scale.[5] Given a hurricane watch and randomly assigned storm intensity, respondents are asked if they would evacuate their home. If they say no, the second stated preference question asks if they would evacuate if they were issued a voluntary evacuation order. If they say no, the third question asks if they would evacuate given a mandatory evacuation order. Finally, if they still say no, the fourth question asks if they would evacuate given a hurricane warning. If the household would evacuate they are then asked the number of miles they would drive and whether they would go to a motel/hotel, public shelter, the homes of friends or family or somewhere else.

Measurement of distance traveled is problematic for two reasons. The first problem, as discussed previously, is that distance traveled is endogenous. The second is that there is considerable missing distance data. Since only 26% of the sample evacuated during Bonnie we only know the revealed preference distance traveled for this group (n = 244). The average round trip distance traveled is 178 miles. For respondents who state that they would evacuate during the hypothetical storm (n = 645) the average stated round trip distance traveled is 262 miles.

Combining these data would leave 275 cases with a missing distance variable.

In order to address these two problems we use a predicted distance variable from a regression model with stated round trip distance as the dependent variable and revealed round trip distance and hurricane category, measured by the Saffir-Simpson Hurricane Scale, as independent variables. For respondents who did not evacuate during Bonnie, we use the mean distance traveled for respondents in the county conditional on whether the household lives on an island. Since trips of great distance are most likely multi-purpose trips, we top-code the round trip distance at 565 miles. This is the highest mean county round-trip distance and between the 90^{th} and 95^{th} percentile of the revealed preference distance distribution.

In the stated preference distance regression model, the independent variables explain 20% of the variation in the dependent variable. The coefficient on revealed round trip distance is significantly different from zero at the .01 level with a coefficient estimate of .85 indicating a close correspondence between stated and revealed distance. Stated distance increases almost 24 miles with each increment in storm intensity. This coefficient is significantly different from zero at the .01 level. Stated distance traveled is higher if the respondent lived on an island and/or in a mobile home. Distance is increasing for respondents with pets and if the respondent is white.

Distance traveled is predicted for each respondent and truncated at .5 miles and 565 miles. Predicted distance traveled is used to calculate travel and time costs for all respondents. Travel cost is valued at $.32 per mile. Descriptive statistics are shown in Table 1. The average round trip travel cost is $85 (TRAVCOST). Time cost is valued at 50% of the wage rate and assuming an average speed of 45 miles per hour. The average time cost is $63 (TIMECOST).

Objective hurricane risk variables include whether the respondent received a voluntary (VEO) or mandatory evacuation order (MEO) and whether they lived in a mobile home

(MOBLHOME).[6] Evacuation orders measure information received by households that suggest they are in a high risk area. Sixteen percent of the sample received a voluntary evacuation order during Bonnie. Fourteen percent of the sample received a mandatory evacuation order. Residents of mobile homes face greater risk because of the instability of the structure when faced with strong winds. Fifteen percent of the sample lives in mobile homes. In addition to these objective risk measures we include two variables that measure perceived risk from hurricane force winds (WINDRISK) and storm surge flooding (FLODRISK). These variables are equal to one if the perceived risk is "medium" or "high" and equal to zero if perceived risk is "low." Eighty one percent perceive their wind risk to be medium or high while 42% perceive their flood risk to be so.

Average annual household income is $42 thousand.[7] Two-thirds of the sample has at least one pet (PETS). Since pets are not allowed in most shelters or motels, pet ownership acts as a constraint on evacuation behavior and we expect its effect on evacuations to be negative. We also control for other demographics while not anticipating any effect of these variables on evacuation behavior. WHITE indicates whether the respondent is white or nonwhite. FEMALE indicates whether the respondent is female or male. The number of years of education is EDUC.

Twenty-six percent of the sample evacuated during Hurricane Bonnie (Table 2). WATCH indicates whether the household would evacuate if a hurricane watch is announced for the hypothetical hurricane. Combining all storm scenarios, thirty-five percent of households state that they would evacuate. Sixteen percent of those respondents hypothetically remaining in their homes state they would evacuate if a voluntary evacuation order were given (VEO). Fifty-three percent of those respondents hypothetically remaining in their homes after the voluntary order would evacuate if a mandatory evacuation order were given (MEO). Only a small percentage of the remaining respondents would evacuate during a hurricane warning. We do not consider this response in the remainder of the paper.

When asked the stated preference questions, individuals responded in the expected way with respect to storm intensity (Table 3). Those who faced a stronger hypothetical storm, as measured by the Saffir-Simpson Hurricane Scale, were more likely to evacuate. For those faced with a Category 1 hurricane, 19% stated that they would evacuate under a hurricane watch. Evacuations increase slightly, to 20%, with a category 2 storm, and more substantially with category 3 (30%), 4 (47%) and 5 (65%) storms. An additional 14% - 27% of those remaining would evacuate given a voluntary evacuation order. An additional 47% - 68% would evacuate given a mandatory evacuation order.

Most households that evacuated during Hurricane Bonnie went to stay with friends or family (Table 4). Sixteen percent went to a motel/hotel, 5% went to shelters and 8.5% went somewhere else.[8] The stated preference evacuation destinations are similar. Most respondents state that they would go to stay with friends or family. The percentage going to friends or family is about 10% less than in the revealed evacuations. Almost one-fourth state that they would go to a hotel/motel while only 12% would go to a shelter. Four percent would go someplace else. The stated preference destinations exhibit a similar pattern even while considering increasing storm intensity (Table 5).

An Empirical Model of Evacuation Behavior

We pool the revealed and stated preference evacuation data and treat it as an unbalanced panel. Each of the 895 cases has at least two and no more than four observations (Table 2). We estimate a model of evacuation behavior using the random effects probit model (Greene, 1997)

[14] $$y_{it} = \beta' X + e_{it}$$

where y_{it} = 1 if household i, i = 1, … , 895, chooses to evacuate and 0 otherwise in time t = 1, … , 4, β is a vector of parameters, and X is a vector of independent variables. The error term, e_{it}, is distributed normally and is composed of two parts, $v_{it} + u_i$, where v_{it} is random error, u_i is the error common to each individual and $\sigma_e^2 = \sigma_v^2 + \sigma_u^2$. The correlation in error terms, $\rho = \sigma_u^2/\sigma_e^2$, is increasing in the contribution of the individual error to the total error and is a measure of the appropriateness of the random effects specification.[9]

In the vector of independent variables we include a dummy variable for the stated preference scenarios (SP=1), dummy variables for hypothetical storm intensity (with Bonnie coded as category 3 and the hypothetical category 3 storm omitted), and all variables from Table 1. In all of the random effects probit models estimated the variance of the error term related to the group effects is significantly different from zero indicating that there is common variation across respondents (Table 6). The common variance across groups accounts for 54% of the total variance.

Survey respondents are more likely to state they would evacuate in a future hurricane relative to their actual evacuations during Hurricane Bonnie, holding storm intensity constant. The marginal effect of this overstatement is .13 suggesting that stated evacuations are about 13% higher than revealed evacuations. If Bonnie was perceived as a category 3 hurricane by all respondents then this result is evidence of hypothetical bias in the stated preference data.[10] A simple correction for the bias is to set the SP variable equal to zero when estimating the probability of evacuation under different storm intensity scenarios. However, it is unlikely that all respondents perceived Bonnie as a category 3 hurricane since initially it was a weak, slow moving “borderline category 2/3” storm which quickly became a tropical storm as it threatened the northeastern North Carolina coast.[11] Therefore, setting the SP variable equal to zero for evacuation cost estimation is the most conservative approach.

Respondents state that they will behave as expected when faced with hurricanes of varying strength. Relative to a category 3 hurricane respondents are less likely to evacuate when faced with category 1 and 2 storms and more likely to evacuate when faced with category 4 and 5 storms. The marginal effects of the coefficient estimates indicate that the probability of hurricane evacuation changes by -.16, -.12, .09, and .30 with hurricane categories 1, 2, 4, and 5. There is no statistically significant difference in behavior between category 1 and 2 hurricanes.

We first include all variables in Table 1 in the X vector in the probit model (Model 1). The coefficient on the time cost variable is unexpectedly positive and statistically significant and the coefficient on income is negative and marginally significant. Since the correlation between time cost and income is .85 we drop income as an independent variable in Model 2. In this model the time cost coefficient is not significantly different from zero. Dropping the time cost (Model 3) or travel cost (Model 4) variables turns the income coefficient positive but it is not significantly different from zero. The effect of travel cost on evacuation is negative in all models, as predicted. The effects of time cost and income are not significantly different from zero in any model. These results suggest that the most important economic factor in the evacuation decision is the monetary cost of travel.

Several of the variables that measure hurricane risk affect evacuation behavior in the expected way. The coefficient on the mandatory evacuation order variable is positive and significantly different from zero. The marginal effect of a mandatory order is .40, suggesting that the probability of evacuation is .40 higher with a mandatory order. Respondents who perceive their wind risk to be medium or high do not evacuate more than others but respondents who perceived their flood risk to be medium or high do. The coefficient on the pet ownership variable is negative and significantly different from zero. This indicates that pet ownership acts as a constraint on evacuation behavior. Females are more likely to evacuate. Race and education have no statistically significant effect on evacuations.

Estimating the Costs of Evacuation

The household-level expected cost of a hurricane evacuation depends on the probability of evacuation, the probability of reaching a particular destination (hotel/motel, shelter, etc.) and the cost of each destination. The probability of evacuation given storm severity (s) and evacuation order (k) is estimated as

$$\Pr(\text{evacuation} \mid s, k) = \Phi(\hat{\beta}' \bar{X} \mid s, k)$$

where Φ(.) is the normal cumulative density function evaluated with the vector of estimated parameters and the means of the vector of independent variables. The probability of destination is

$$\Pr(q \mid s, k) = \Pr(q \mid \text{evacuation} = 1) \times \Pr(\text{evacuation} \mid s, k)$$

where q is the destination mode, q = 1, …, 4. The expected household cost is

$$E(\text{cost}) = \Pr(q \mid s, k) \times c(d, y \mid s, q)$$

The household cost includes direct expenditures, travel, and time costs and is conditioned on hurricane severity and destination mode. Expected household cost is multiplied by the resident population in order to estimate the aggregate cost.

Model 2 from Table 6 is used to predict the probability of hurricane evacuation under various scenarios (Table 7).[12] The stated preference coefficient is set equal to zero to adjust for the potential hypothetical bias. The probability of evacuation is conditioned on storm intensity, s = 1, … , 5, and evacuation order, k = 1, 2, 3 (no order, voluntary order, mandatory order). The predicted probability of household evacuation during a hurricane watch for a category 1 storm is

3%. The probability of evacuation increases as evacuation orders are given and as storm intensity increases. The probability of evacuation during a category 5 storm under a mandatory order is 94%. The differences in probabilities between a hurricane watch and a voluntary evacuation order are not significantly different, holding storm intensity constant. The differences in probabilities between voluntary and mandatory evacuation orders are significantly different.

The household costs of evacuation are separated into two categories: direct costs and travel and time costs. Direct costs of evacuation are those expenditures incurred during the time households are away from home (e.g., lodging costs, restaurant meals). The 37 survey respondents who evacuated during Hurricane Bonnie and went to a motel/hotel spent an average of $163 on lodging, $94 on food and beverages, $13 on entertainment, and $5 on miscellaneous items (Table 8). The total direct cost for these households is $275. Other respondents spent considerably less. Of the 13 respondents who went to a shelter the average direct cost is $86. The 165 households who went to the home of friends or family spent $53. The "other" households spent $20.

Travel and time costs vary across destination. The travel cost for households who travel to a motel/hotel is $106. These households have time costs of $89. Again, other respondents incurred lower costs. Of the 13 respondents who went to a shelter the average travel cost is $35 and the time cost is $23. The 165 households who went to the home of friends or family spent $70 on travel costs and $51 in terms of their time. The "other" households spent $64 in travel costs and $54 in time. The total evacuation costs are $470 for respondents who went to a motel/hotel, $144 for those who went to the homes of friends or family, $174 for those who went to shelters, and $139 for the other households.

We calculate the average travel and time costs conditioned on storm intensity and destination probability. These costs are then weighted by the probability of destination mode to estimate the expected evacuation cost at each storm intensity level. Since storm category does not affect the stated evacuation destination we use the unconditional probabilities as the estimate of the probability of evacuation destination (Table 5). Travel and time costs are then added to the average destination mode costs to determine the full cost of evacuation. The full costs are $211, $233, $273, $256, and $292 for storm categories 1 through 5.

The household evacuation costs potentially overestimate the opportunity costs of an evacuation if the cost would be incurred in the absence of an evacuation. For example, people eat food whether they are at home or away from home. The more appropriate measure of the direct costs of the evacuation is the net direct costs, the difference between costs with an evacuation and without. Since the cost of meals under the constraint of not being in one's own kitchen is higher than the cost of meals without constraint the net costs are positive but less than the full costs of meals. Likewise, net entertainment and other costs may be overestimated.

The household evacuation costs could also potentially be underestimated. Another opportunity cost of a hurricane evacuation that we have not included is lost wages. These indirect costs of an evacuation should only be considered opportunity costs in the event that the workplace is still operating during the hurricane event. This may be the case with false alarms but these income losses are not opportunity costs when an area experiences a hurricane strike and the workplace shuts down. For those who evacuated during Hurricane Bonnie, lost income costs are $137, on average.

Using the predicted evacuation probabilities we estimate the number of evacuees by storm category for the total households from the eight ocean counties. The combined household population of the eight North Carolina ocean counties is 183,058. To find the predicted number of households evacuated for each storm category the probability is multiplied by the total population (Table 9). Multiplying the number of households by the expected household cost produces an estimate of the total costs of hurricane evacuations in North Carolina ocean counties. Total evacuation costs without evacuation orders range from about $1 to $26 million for Category 1-5 storms (Table 9). Total evacuation costs with a voluntary evacuation order covering all households range from about $1 to $27 million for Category 1-5 storms. Total evacuation costs with a mandatory evacuation order covering all households range from about $15 to $50 million for Category 1-5 storms.

These estimates should be considered rough estimates for several reasons in addition to those mentioned previously. First, North Carolina state government emergency management officials typically recommend mandatory evacuations for all residents of ocean counties, plus those in manufactured housing and storm surge zones of coastal counties. However, evacuation orders from local emergency managers typically cover only a small fraction of these residents, especially for lower intensity storms. Evacuation cost estimates could be adjusted for this reality. For example, in the case of Hurricane Bonnie 14% of households were under a mandatory order and 16% were under a voluntary order. Weighting the estimates in Table 9 by these probabilities yields a $9 million cost estimate for a category 3 storm.

Also, for higher intensity storms, in which more mandatory evacuation orders may be issued by local emergency managers than during Hurricane Bonnie, the increased congestion from the increased number of evacuating households on the roads will increase driving times. This could significantly increase the time cost of evacuation as average miles per hour decreases and driving distance increases as more “no vacancy” signs appear. The predicted evacuation costs for category 4 and 5 storms may be biased downward. Finally, since our survey was conducted during January 1999, our sample does not include tourists. The North Carolina barrier island population swells during the summer. These tourists, seasonal workers, and seasonal dwellers all incur evacuation costs.

This model of hurricane evacuation behavior and costs could be used to analyze the efficiency of emergency management decisions, specifically the mandatory evacuation order. The difference in the cost of voluntary and mandatory evacuation orders is $13 million, $17 million, $26 million, $26 million, and $23 million for category 1-5 storms. The benefit of a mandatory evacuation order is the value of the lives saved. Mrozek and Taylor (1999) perform a meta-analysis of the value of statistical life (VSL) literature. The VSL estimate from their statistical model is roughly $1 million or $4 million depending on the assumptions made (1995$). Using the $1 million VSL, approximately 14 lives saved would justify a mandatory evacuation order, relative to a voluntary evacuation order, for a Category 1 storm. To justify a mandatory evacuation order in Category 2-5 storms 18, 27, 27, and 23 lives must be saved for it to be efficient. Using the $4 million VSL, approximately 4, 5, 7, 7, and 6 lives saved in Categories 1-5 storms would justify a mandatory evacuation order.

Conclusions

In this paper we model the evacuation decision of households during a hurricane threat and predict future household evacuation behavior using revealed and stated preference data methods. These methods allow the assessment of hurricane evacuation behavior beyond the range of historical experience in revealed behavior data. We use household evacuation costs and various measures of hurricane risks and find that respondents respond to risk and other factors according to predictions from economic theory. We find that hurricane evacuation costs for ocean counties in North Carolina range from about $1 million to $50 million depending on storm intensity and evacuation order scenario. Considering that North Carolina has much more than 50 miles of coastline, “one million dollars a mile” is a gross overestimate of the opportunity costs of evacuation.

If emergency managers use the “one million dollars a mile” figure when balancing the benefits and costs of evacuation orders, our results suggest that emergency managers are issuing too few evacuation orders by using an upward biased cost estimate. Popular opinion of emergency management decisions is often the opposite. Emergency managers are perceived as issuing evacuation orders too often and too quickly. Perhaps then evacuation costs of “one million dollars a mile” are not used in emergency managers decision-making. Whatever the case, using evacuation cost estimates based on behavioral models will improve the efficiency of emergency management.

We perform an ex-post breakeven analysis of the number of statistical lives saved that would justify a mandatory evacuation order relative to a voluntary evacuation order. In the event of an extreme or catastrophic hurricane, the mandatory evacuation order appears to be an efficient policy since the breakeven number of lives saved appears low. Of course, this is pure speculation since little data exists to suggest how many lives would be lost without evacuation orders in a modern day storm. Of course, when mandatory evacuation orders are issued and a hurricane does not threaten the area, the “false alarm” evacuation order is an inefficient policy, ex-post.

An ex-ante benefit cost analysis should incorporate the probabilities of a hurricane strike when estimating the expected benefits and costs of evacuation orders. Based on casual observation of the National Hurricane Center’s website during the 1999 Hurricane season, these ex-ante probabilities tend to range from 20% to 33% in the areas most likely to suffer hurricane landfall. This suggests that in an ex-ante benefit cost analysis the breakeven number of lives saved must be 3 to 5 times greater than in the ex-post analysis to justify mandatory evacuation orders. Future research concerning these issues should improve the efficiency of emergency management. This research should be increasingly important in light of the largest peacetime evacuation in United States history during Hurricane Floyd (Pasch, Kimberlain, and Stewart, 2000) and predictions of increases in the number of landfalling major hurricanes (Gray, et al., 2000).

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Appendix

Stated Preference Questions

Please consider the following information ... hurricanes are rated on a scale of 1 to 5. Category 1 is a minimal hurricane, 2 is moderate, 3 is extensive, 4 is extreme, and 5 is a catastrophic hurricane. Bonnie was a category 3 (if asked: Fran was a 3, Bertha was a 2, and Hugo was a 4). Suppose a category 1 hurricane is approaching North Carolina. The hurricane has winds between 74 and 95 miles per hour and a storm surge about 4 to 5 feet above normal (If asked: Storm surge is the rise in sea level during a hurricane). If a Hurricane Watch is announced, would you evacuate your home to go someplace safer?

YES (skip to next section)

NO (go to next question)

If you were given a voluntary evacuation order, would you evacuate your home to go someplace safer?

YES (skip to next section)

NO (go to next question)

If you were given a mandatory evacuation order, would you evacuate your home to go someplace safer?

YES (skip to next section)

NO (go to next question)

If a Hurricane Warning is announced would you evacuate your home to go someplace safer?

YES (go to next section)

NO (skip to next section)

Notes

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[1] More recently, The Economist states "… it costs some $450,000 to prepare a kilometre of coastline for a coming storm … ." ("Eye on the Storm," The Economist, pp. 91-93, February 26, 2000).

[2] In the extreme case of bad health, death, the additive separability assumption is unrealistic, suggesting that income increases the utility of the non-living. When allowing for U(H=0, y) = 0, the change in expected utility function in this case does not include the h(0) term and the difference in the marginal utility of incomes is multiplied by the probability of good health.

[3] Households must also consider the indirect costs of evacuation including lost earnings. These indirect costs are an increasing function of the wage rate and the probability of workplace shutdown during a hurricane threat. We abstract from this detail in this model because it would involve an additional uncertainty term, the probability of a hurricane strike.

[4] The signs of these derivatives do not change in the extreme case of death. When allowing for U(H=0, y) = 0 the absolute value of the magnitude of the negative effect of distance on expected utility is smaller by the multiple g. The magnitude of the effects of risk change on expected utility is larger since h(0) drops out of the derivatives. The effect of income on expected utility is unchanged.

[5] See the Appendix for the stated preference questions.

[6] In preliminary models we also include measures of island and storm surge zone residence. Neither of these risk factors are important in explaining evacuation behavior.

[7] The item nonresponse rate for income is 15%. Missing income values were imputed using a regression model with the natural log of income as the dependent variable. Independent variables are education, potential work experience and the square of potential work experience, race,

gender, household size, fulltime work status, and whether the respondent owns their own home. Each of these variables are statistically significant at the .05 level. The model R^2 is .36. The predicted income is used to impute the category of household income that would be answered.

[8] Anecdotal evidence suggests that "somewhere else" includes such places as hospital waiting rooms, for those with special medical needs, and safer ports, for owners of commercial or recreational boats.

[9] The random effects probit model is estimated using the LIMDEP statistical software (Greene, 1995).

[10] If Bonnie was perceived as a category 2 hurricane then the revealed preference data should be coded with Bonnie as a category 2. In these models, the coefficient on the stated preference variable is not statistically different from zero.

[11] It is also possible that the underlying variance of the stated and revealed data is different (Louviere, 1996). Correcting for the variance differences may cause the stated preference effect to disappear. We find that the variance in the revealed and stated preference data is different but the variance function depends on hurricane intensity and not the hypothetical evacuations.

[12] Costs estimates do not substantially change when Models 1, 3 or 4 are used.

Table 1. Data Summary

Variable	Description	Mean	Std.Dev.	Min	Max
TRAVCOST	travel cost	84.83	36.30	0.16	180.80
TIMECOST	time cost	62.86	56.43	0.02	452.72
VEO	1 if voluntary evacuation order, 0 otherwise	0.16	0.37	0	1
MEO	1 if mandatory evacuation order, 0 otherwise	0.14	0.35	0	1
MOBLHOME	1 if lives in mobile home, 0 otherwise	0.15	0.36	0	1
WINDRISK	1 if wind risk is medium/high, 0 otherwise	0.81	0.40	0	1
FLODRISK	1 if flood risk is medium/high, 0 otherwise	0.42	0.49	0	1
INCOME	household income	42.36	30.97	7.5	150
PETS	1 if owns pets, 0 otherwise	0.67	0.47	0	1
WHITE	1 if white, 0 otherwise	0.84	0.37	0	1
FEMALE	1 if female, 0 otherwise	0.62	0.49	0	1
EDUC	education, in years	13.68	2.17	10	18
Cases		895			

Table 2. Revealed and Stated Preference: Evacuations by Scenario

Question	Scenario	Cases	Percent
1	Bonnie	895	26.3
2	WATCH	895	35.1
3	VEO	581	16.4
4	MEO	486	52.7
	Total	2857	31.5

Table 3. Stated Preference: Evacuations by Saffir-Simpson Scale

	WATCH		VEO		MEO	
S-S Scale	Cases	Percent	Cases	Percent	Cases	Percent
1	189	19.0	153	14.4	131	46.6
2	193	20.7	153	14.4	131	49.6
3	185	30.3	129	17.1	107	58.9
4	173	47.4	91	15.4	77	51.9
5	155	64.5	55	27.3	40	67.5
Total	895	35.10	581	16.4	486	52.7

Table 4. Revealed and Stated Preference: Evacuation Destination

	Revealed		Stated	
	Cases	Percent	Cases	Percent
Hotel/Motel	37	15.7	159	23.6
Shelter	13	5.5	82	12.2
Friends/Family	165	70.2	403	59.9
Other	20	8.5	29	4.3

Table 5. Stated Preference: Evacuation Destination by Saffir-Simpson Scale

	Hotel/Motel		Shelter		Friends/Family		Other	
S-S Scale	Cases	Percent	Cases	Percent	Cases	Percent	Cases	Percent
1	30	24.8	17	14.0	69	57.0	5	4.1
2	23	17.8	14	10.9	84	65.1	8	6.2
3	39	27.5	14	9.9	82	57.7	7	4.9
4	28	20.3	16	11.6	89	64.5	5	3.6
5	39	27.3	21	14.7	79	55.2	4	2.8

Table 6. Revealed and Stated Preference Probit Evacuation Models

	Dependent Variable = Evacuate							
	Model 1		Model 2		Model 3		Model 4	
Variable	Parameter	t-ratio	Parameter	t-ratio	Parameter	t-ratio	Parameter	t-ratio
Constant	-1.334	-3.24	-1.557	-3.85	-1.683	-4.19	-1.822	-4.63
SP	0.536	4.24	0.536	4.24	0.537	4.25	0.533	4.22
S-S Scale = 1	-0.667	-4.23	-0.658	-4.17	-0.659	-4.18	-0.608	-3.86
S-S Scale = 2	-0.490	-3.32	-0.483	-3.26	-0.485	-3.28	-0.463	-3.13
S-S Scale = 4	0.347	2.32	0.347	2.33	0.349	2.34	0.333	2.22
S-S Scale = 5	1.227	7.90	1.223	7.89	1.223	7.89	1.182	7.66
TRAVCOST	-0.007	-3.40	-0.004	-2.60	-0.003	-2.24		
TIMECOST	0.006	2.25	0.001	1.09			0.0003	0.16
INCOME	-0.009	-1.96			0.0004	0.22	0.0002	0.05
VEO	0.073	0.85	0.068	0.80	0.067	0.78	0.069	0.80
MEO	1.627	16.32	1.619	16.33	1.619	16.34	1.622	16.35
MOBLHOME	1.028	6.88	1.090	7.30	1.202	8.23	1.202	8.23
WINDRISK	0.032	0.23	0.026	0.19	0.026	0.19	0.026	0.19
FLODRISK	0.506	4.90	0.510	4.94	0.526	5.09	0.526	5.09
PETS	-0.289	-2.57	-0.316	-2.82	-0.353	-3.15	-0.353	-3.15
WHITE	-0.049	-0.35	-0.097	-0.71	-0.183	-1.33	-0.183	-1.33
FEMALE	0.304	2.95	0.329	3.21	0.316	3.06	0.316	3.06
EDUC	0.023	0.86	0.015	0.59	0.022	0.82	0.022	0.82
ρ	0.536	15.07	0.536	15.10	0.538	15.19	0.538	15.19
Log-L(B)	-1455.85		-1457.83		-1458.5		-1459.953	
Log-L(0)	-1527.74		-1529.68		-1530.7		-1532.753	
Cases	895		895		895		895	
Observations	2857		2857		2857		2857	

Table 7. Evacuations by Saffir-Simpson Scale

	Evacuation Probabilities					
	WATCH		VEO		MEO	
S-S Scale	Probability	SE	Probability	SE	Probability	SE
1	0.03	0.012	0.03	0.013	0.38	0.068
2	0.04	0.016	0.05	0.018	0.45	0.070
3	0.10	0.016	0.11	0.019	0.64	0.036
4	0.18	0.046	0.20	0.051	0.76	0.057
5	0.48	0.072	0.51	0.074	0.94	0.022

Table 8. Direct Evacuation Costs per Household

Costs	Hotel/Motel	Shelter	Friends/Family	Other
Lodging	162.73	0.00	0.00	0.00
Food	94.03	62.54	45.88	17.40
Entertain.	12.70	0.39	2.41	0.30
Other	5.27	23.31	4.81	2.15
Total	274.73	86.23	53.10	19.85
Travel	106.47	35.25	69.70	64.46
Time	88.59	22.75	50.80	54.30
Total	469.79	144.23	173.59	138.61
Cases	37	13	165	20

Table 9. Predicted Evacuees and Costs

	Watch		VEO		MEO	
S-S Scale	Evacuees	Total Costs	Evacuees	Total Costs	Evacuees	Total Costs
1	4,942	$1,045,272	5,775	$1,221,429	69,402	$14,679,118
2	7,290	$1,696,258	8,430	$1,961,627	81,799	$19,033,256
3	18,703	$5,110,912	21,031	$5,747,169	116,564	$31,853,788
4	32,618	$8,353,550	35,983	$9,215,274	138,582	$35,490,907
5	88,148	$25,766,378	93,139	$27,225,118	172,462	$50,411,975