GeoHazards

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Determinants of Displacement and Displacement Duration Following Hurricanes Katrina and Rita: A Hurdle Model Approach

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Abstract: In 2005, Hurricanes Katrina and Rita caused widespread destruction and displacement in parts of Louisiana, Alabama, and Mississippi. This research evaluates determinants of displacement and, conditional on being displaced, the duration of displacement for households living in areas affected by these hurricanes. Hurdle Models, which assume that different processes govern zero outcomes (i.e., no displacement) and positive outcomes (i.e., amount of time displaced), are used to model the likelihood of household displacement and its duration as a function of socioeconomic characteristics, hurricane-caused property and neighborhood damage, social support, and financial assistance. Results show that mobile home residence, marital status, educational attainment, the presence of children, and property and neighborhood damage affect the likelihood and expected length of displacement among sample respondents. Financial assistance and social support are also correlated with displacement and its duration, but endogeneity concerns complicate the interpretation of these results. The findings highlight the diversity of factors that slow households' return following displacement and underscore the need for additional research on the role of social capital in determining hazard-related outcomes.

Keywords: natural hazard; displacement; displacement duration; hurdle model

Citation: Price, J.I.; Bohara, A.K.; Hansen, W.L. Determinants of Displacement and Displacement Duration Following Hurricanes Katrina and Rita: A Hurdle Model Approach. *GeoHazards* **2022**, *3*, 412–427. https://doi.org/10.3390/geohazards3030021

Academic Editor: Tiago Miguel Ferreira

Received: 7 June 2022
Accepted: 9 August 2022
Published: 11 August 2022

1. Introduction

Tropical cyclones, like all hazard events, have profound consequences for affected populations, including adverse health outcomes, property damage, reduced income, and the disruption of services from community and environmental amenities. According to the Emergency Event Database, 1190 cyclone-related hazard events occurred globally between 2000 and 2021. Of these events, 176 were due to North Atlantic hurricanes, defined as cyclones with maximum sustained winds of at least 119 km per hour. These hurricanes affected, either directly or indirectly from ensuing storm surge or flooding, an estimated 41 million people and caused $524 billion (2021 USD) in damage.

Hurricanes often trigger temporary household displacement, which can result from mandatory evacuations, voluntary pre-hurricane relocation due to safety and health concerns, and forced relocation due to unsuitable post-hurricane living conditions. A household's decision to return following displacement depends on, among other factors, the condition of their home and neighborhood and their ability to leverage formal and informal support networks. Households displaced for longer periods have typically been more affected by the hazard event and are, subsequently, less able to rebound than households displaced for shorter periods [1]. Moreover, prolonged displacement can amplify household losses via, for instance, protracted joblessness and disruptions to education. Identifying systematic differences in the likelihood and duration of displacement can thus offer insight into the vulnerability of population sub-groups.

Numerous studies have evaluated household decisions to evacuate in response to hurricane events [2–8]. In a meta-analysis of 38 such studies, Huang et al. [9] find that official warnings, mobile home residence, perceived risks, and social cues consistently have significant effects on evacuation decisions. Demographic characteristics have weaker, sometimes inconsistent, effects on the likelihood of evacuation. Similar findings are reported by Karaye et al. [10] and Tanim et al. [11] in their respective meta-analyses. Several studies have evaluated departure timing following the decision to evacuate [7,12–16]. Results suggest that households most frequently depart in the morning a few days prior to hurricane landfall, with factors such as the number of household members, homeownership, and perceived risk affecting the time taken to prepare before departure.

Several extant studies have evaluated the determinants of returning to the same home, community, or region after hurricane-caused displacement. Landry et al. [17] consider decisions to return to the Gulf region in the months following Hurricane Katrina. Results indicate that the likelihood of return is affected by socioeconomic characteristics like household income, age, educational attainment, marital status, and home ownership. It also depends on the wage differential between the respondent's original and displaced locales. Similarly, Kim and Oh [18], Groen and Polivka [19], and Paxson and Rouse [20] evaluated return decisions following Hurricane Katrina. They found that black respondents and those that experienced greater property damage to their home and community are less likely to return. Household income, home ownership, age, and the presence of children are significant predictors in some, but not all, of these studies. Reinhardt [21] extends this literature by showing political trust to be a possible mechanism explaining different rates of return between black and non-black individuals. Xio and Van Zandt [22] investigated linkages between household and business returns following Hurricane Ike. They found that households and businesses are mutually dependent, where households' return decisions are influenced by businesses reopening and vice versa.

Fussell et al. [23], to our knowledge, is the only study to model displacement duration following a hazard event. They evaluated the factors that affect how quickly displaced residents returned after Hurricane Katrina using data from the Displaced New Orleans Residents Pilot Study. Results from a piecewise exponential hazard model showed housing damage to be the main factor slowing return. The hazard rate was not significantly correlated with most socioeconomic characteristics, including the respondent's race, education, marital status, employment status, and housing tenure. Merdjanoff et al. [24], using a related modeling approach, evaluated factors that affect how quickly displaced respondents found stable housing following Hurricane Katrina. Socioeconomic characteristics, like marital status, income, home ownership status, and social support affected the amount of time until stable housing was acquired.

In-depth interviews with people affected by natural hazards highlight the importance of social support and networks in making evacuation and return decisions [25–27]. Few studies, however, have evaluated the statistical relationship between social support and hurricane-related displacement or return decisions. Paxson and Rouse [20] and Thiede and Brown [6] included measures of social support and local social ties in their respective analyses. Thiede and Brown [6] found that people with stronger social ties were less likely to evacuate prior to hurricane landfall. In contrast, Paxson and Rouse [20] did not find a significant relationship between social support and the likelihood of return following Hurricane Katrina.

In this analysis, we investigated household displacement and return behavior in the two and a half years following Hurricanes Katrina and Rita. The study objectives were threefold: (1) to identify determinants of displacement and displacement duration, (2) to evaluate whether the factors that have the greatest effect on the likelihood of displacement differ from those that affect displacement duration, and (3) to explore possible associations between social support and displacement. To this end, we developed a Hurdle Model—a modified survival (or count) model that assumes different processes govern zero outcomes (i.e., no displacement) and positive outcomes (i.e., amount of time displaced)—to evaluate how socioeconomic characteristics, property and neighborhood damage, housing type, financial assistance, and perceived social support affect the likelihood of displacement and, conditional on being displaced, the duration of displacement. To the best of our knowledge, this study is the first to use a Hurdle Model within the context of hazard-related displacement; it is also one of the few studies to model displacement duration. The results thus contribute to the limited knowledge about how key predictors affect the rate at which people return after being displaced. An improved grasp of these relationships is crucial to understanding population dynamics and heterogeneity in recovery among population sub-groups following hazard events.

2. Case Study Background

In 2005, Hurricanes Katrina and Rita devastated parts of Mississippi, Alabama, and Louisiana. The most severe damage occurred in New Orleans, where storm surge from Hurricane Katrina breached multiple levees, flooded 80% of the city, and rendered many neighborhoods uninhabitable [28]. Other Gulf-coast communities were damaged due to intense winds and heavy rainfall. Ultimately, Hurricane Katrina, often cited as one of the worst natural disasters in recent U.S. history, was responsible for 1800 deaths, mass displacement, and an estimated $108 billion in property damage [28]. Hurricane Rita, while less destructive, was responsible for $12 billion in damage [29]. Figure 1 depicts areas where Hurricanes Katrina and Rita damaged commercial, residential, industrial, and governmental buildings.

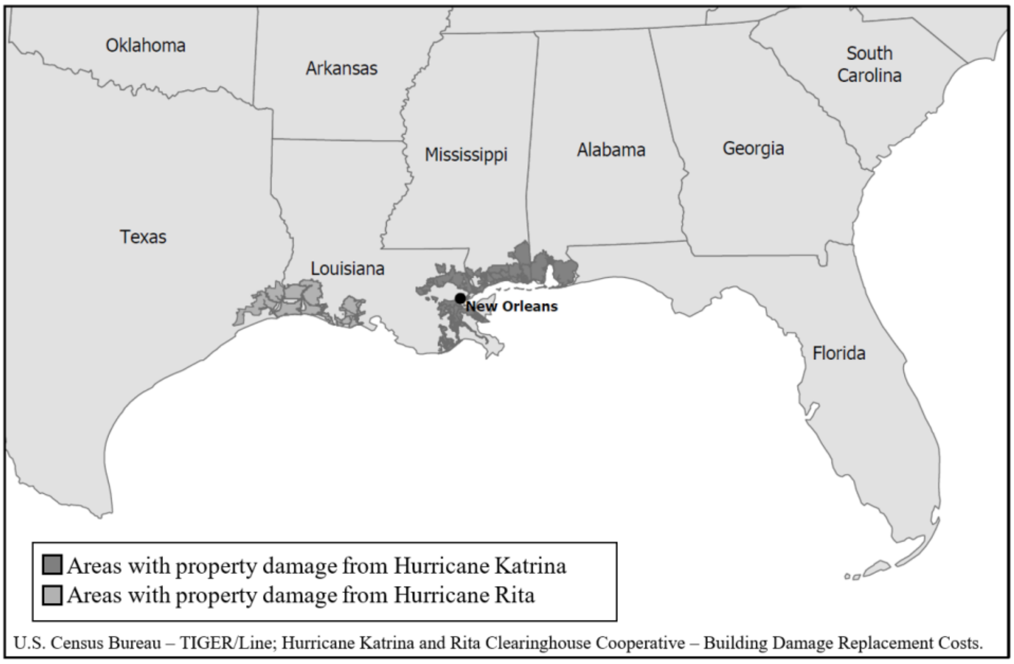

Figure 1. Areas damaged by Hurricanes Katrina and Rita.

Thousands of people were evacuated or displaced because of Hurricanes Katrina and Rita. As with the loss of life and property damage, evacuation and displacement were most pronounced in New Orleans where the city's population fell to only a few thousand residents [23]. Following the hazard event, the city's population gradually increased from 230,000 in mid-2006 to 384,000 in mid-2014 [30]. The latter value is approximately 78% of the pre-Katrina population. People who were unable to return home largely remained in the Southern U.S., residing mostly in Texas, Georgia, or elsewhere in Louisiana [31].

3. Materials and Methods

We investigated determinants of displacement and their duration for a sample of households affected by Hurricanes Katrina and Rita. Previous literature either modeled the likelihood of displacement or the length of displacement, but here we used a Hurdle Model approach to evaluate the two processes simultaneously. Households affected by Hurricanes Katrina and Rita were analyzed together.

3.1. Data Sources

Data for this analysis were obtained from the 2005 and 2007 Panel Survey of Income Dynamics (PSID)—an ongoing longitudinal survey of U.S. individuals and family units administered by the Institute for Social Research at the University of Michigan. Survey respondents are interviewed every two years (1997 to present) on a wide range of household characteristics and behaviors, including employment status, income, health, wealth, education, housing, expenditures, marital and fertility behavior, and philanthropy. The 2005 PSID included approximately 500 families residing in Louisiana, Alabama, or Mississippi who may have been affected by Hurricanes Katrina and Rita. In 2007, a supplemental questionnaire was administered to these families regarding the physical, psychological, and economic impacts of the hurricanes. These questions were used to construct measures of displacement, displacement duration, property damage, and perceived social support for this analysis. The final dataset, after removing respondents with missing data, contains 398 observations.

Data were not obtained from a random sampling procedure nor are relevant sampling weights available. A comparison of respondent characteristics to the 2010 census data suggests that the sample diverges from the population along several key dimensions. Specifically, a higher proportion of the sample identified as black (80% compared to 50%), a higher proportion had children in the home (55% compared to 37%), and a smaller proportion owned their home (56% compared to 67%) relative to the overall population in the respondents' census tracts. Sample respondents were also slightly younger than the adult population (median age of 41 compared to 46). These differences pose a problem for statistical inference; thus, although standard errors are reported in regression output, we interpreted the results in terms of sample respondents and avoided generalizing the population.

This analysis also employed data from the Federal Emergency Management Agency (FEMA), National Oceanic and Atmospheric Administration (NOAA), and Hurricane Katrina and Rita Clearinghouse Cooperative. These data were used to index the severity of hurricane damage in each respondent's area of residence. Geospatial data obtained from FEMA's Hurricane Flood Recovery Maps, based on aerial photographs, depict the maximum extent of coastal floodwater from Hurricanes Katrina and Rita. The maps provide information on areas inundated by coastal storm surge and areas classified as damaged due to flooding, heavy rainfall, or high winds. Geospatial data obtained from NOAA's National Hurricane Center depicts the paths of the two hurricanes. Finally, from the Hurricane Katrina and Rita Clearinghouse Cooperative, we obtained building replacement cost estimates within each zip code. These estimates, which are derived from the HAZUS software, indicate the total cost of repairing hurricane-related damage to commercial, residential, industrial, and governmental buildings. The Hurricane Katrina and Rita Clearinghouse Cooperative no longer exists; it was maintained by Louisiana State University and was comprised of several hurricane-related databases. Documentation for the cost estimates used in this analysis is available upon request.

3.2. Empirical Model

A Hurdle Model was used to evaluate household displacement and displacement duration. Hurdle Models are modified survival (or count) models that assume that different processes govern zero outcomes (i.e., no displacement) and positive outcomes (i.e., amount of time displaced). It is assumed that a binary process determines whether an outcome is zero or positive while a truncated-at-zero process determines the value of positive outcomes. In this analysis, the former process models the probability of displacement while the latter process, which is truncated at zero because it only concerns positive values pertaining to the amount of time displaced, models the duration of displacement. Hurdle Models have been used within a variety of contexts, including migration frequency [32], demand for recreational fishing [33,34], and repeat instances of self-harm [35,36]. The Hurdle Model, for this analysis, is made operational using the probit distribution for the binary component (i.e., displacement) and the Weibull distribution for the survival component (i.e., displacement duration). The Weibull distribution is a two-parameter distribution commonly employed in parametric survival analysis; it encompasses, in special cases, the exponential and Rayleigh distributions [37]. The validity of the regression results depends on the proper selection of the survival distribution. The Weibull distribution is selected from among several possible distributions through visual examination of the survival function, via the Kaplan–Meier curve, and comparison of Akaike Information Criterion (AIC) values. Statistical analysis is performed with Stata 15.

We employed an accelerated failure time (AFT) metric for the survival function. This metric offers an alternative to the more widely used proportional hazard approach. Whereas covariates in the proportional hazard model act multiplicatively on the hazard, in the AFT model the effect of a covariate is to multiply the predicted event time by some constant [37]. The joint log-likelihood function for the Hurdle Model, comprised of probit and Weibull distributions, is given by:

$$\begin{aligned}\ln L = \sum_{j=1}^{N} \Big[y_1 \ln\big(\Phi(-x_{1j}\beta_1)\big) + (1-y_{1j}) \ln\big(\Phi(1-x_{1j}\beta_1)\big) - \left(\tfrac{y_{2j}}{\lambda}\right)^{\kappa} \\ + y_{3j}\big(\ln(\kappa) - \ln(\lambda) + (\kappa-1)\ln(y_{2j}) - (\kappa-1)\ln(\lambda)\big)\Big].\end{aligned} \quad (1)$$

In Equation (1), y_1, y_2, and y_3 are dependent variables that, respectively, indicate whether household j was displaced, its duration of displacement, and whether the household is right-censored (i.e., has yet to return after being displaced). These variables are derived from responses to two questions in the supplemental questionnaire: Were you displaced from the place you were living because of Katrina or Rita? How long were you displaced from your home? We assumed that responses reflected conditions for the respondent's entire household. The displacement variable is therefore a binary indicator for whether or not the household was displaced. The displacement duration variable is a continuous measure of the number of days the household respondent was displaced.

The term Φ denotes the cumulative normal distribution function, κ the shape parameter of the Weibull distribution, λ the scale parameter of the Weibull distribution, x_1 the vector of explanatory variables that determine the binary process, and β_1 the corresponding vector of estimated parameters. Determinants of displacement duration are incorporated into the model through the scale parameter, which, along with the shape parameter, is positively restricted using the log-link function. The functions are given in Equations (2) and (3):

$$\kappa = exp(\gamma) \quad (2)$$

$$\lambda = exp\big(x_{2j}\beta_j\big); \quad (3)$$

where, x_2 is the vector of explanatory variables that determine the survival process and β_2 is the corresponding vector of estimated parameters. Maximum likelihood estimates are obtained using a modified Newton–Raphson algorithm.

The probability of displacement and displacement duration are modeled as a function of several socioeconomic and hazard-related characteristics. In general notation, these functions are:

$$x_{1j} = f\big(Q_j, H_j, DSI_j,\ SS_j\big) \quad (4)$$

$$x_{2j} = f\big(Q_j, H_j, DSI_j,\ SS_j, P_j\big). \quad (5)$$

In Equations (4) and (5), Q is a vector of socioeconomic characteristics of household j prior to the hazard event, H a vector of property damage indicators, DSI an index of damage severity within a household's community, SS a vector of social support indicators, and P a vector of variables—only pertaining to the survival function—reflecting financial and housing assistance received following the hazard event. Table 1 summarizes the sources and methods used to construct these variables.

Table 1. Source and Method of Construction for Explanatory Variables.

Variables	Source	Method of Construction
AGE, MARRIED, UNHEALTHY, HIGH SCHOOL, INCOME, MOBILE HOME, CHILDREN IN HOME, LIVE IN ALABAMA, LIVE IN MISSISSIPPI	2005 PSID	Recode directly from PSID data file
MINIMAL DAMAGE, MODERATE DAMAGE, SEVERE DAMAGE, PAYMENTS FROM FAMILY, LIVE WITH FAMILY	2007 PSID Supplemental Questionnaire	Recode directly from PSID data file
LOW SOCIAL SUPPORT, HIGH SOCIAL SUPPORT	2007 PSID Supplemental Questionnaire	Stage 1: Sum inventory items to obtain total CSS scores. Stage 2: Categorize scores by quartile.
DSI	FEMA—Hurricane Flood Inundation Maps, FEMA—Hurricane Flood Damage Maps, U.S. Census Bureau—TIGER/Line (Census Tracts), NOAA—Hurricane Path Maps, Katrina and Rita Clearinghouse Cooperative—Building Replacement by Zip Code	Stage 1: Calculate the proportion of each household's census tract classified as flooded and damaged. Conduct analysis using ArcMap's Intersect tool. Calculate the distance from the center of the household's census tract to the hurricane path. Conduct analysis using ArcMap's Near tool. Stage 2: Match calculated variables and building replacement costs to respondents by census tract and zip code. Stage 3: Construct *DSI* using principal component analysis.

Socioeconomic characteristics pertain to the PSID Reference Person. In the PSID, the Reference Person is defined as the person at least 18 years old with the most financial responsibility for a family unit; however, if this person is female and she has a male spouse or partner in the family unit or a boyfriend with whom she has been living for at least one year, then he is designated as the Reference Person. More information about the Reference Person, and how they are identified, is available from the PSID website [38]. Characteristics include the Reference Person's age (AGE) and indicators for whether or not the Reference Person was married (MARRIED), had below average health (UNHEALTHY), and had completed high school (HIGH SCHOOL). The health status indicator is based on a five-category Likert scale, where respondents self-reporting in the bottom two categories (i.e., fair and poor) are considered to have below average health. In some instances, the supplemental questionnaire was completed by the Reference Person's spouse or partner rather than the Reference Person. We still used the Reference Person's socioeconomic characteristics for these households based on the assumption that the Reference Person has a dominant role in displacement outcomes.

Socioeconomic characteristics also include the household's 2004 income (INCOME) and indicators for mobile home residence (MOBILE HOME), the presence of children (CHILDREN IN HOME), and residence in Alabama (LIVE IN ALABAMA) or Mississippi (LIVE IN MISSISSIPPI). Residence in Louisiana serves as the base category against which the other residence categories are compared [37]. Property damage variables indicate whether the respondent self-reported minimal (MINIMAL DAMAGE), moderate (MODERATE DAMAGE), or severe (SEVERE DAMAGE) property damage. The base category is no hazard-related property damage. Financial and housing assistance variables include the amount of financial assistance received from relatives and friends in 2005 and 2006 (PAYMENTS FROM FAMILY) and an indicator for whether or not the respondent lived with family members while displaced (LIVE WITH FAMILY). We also estimated Hurdle

Models that, in addition to the socioeconomic characteristics mentioned above, included indicators for home ownership, the Reference Person's race, sex, and employment status. These variables had negligible influence on the outcome variables and were excluded from the analysis in the interest of presenting more parsimonious results.

The *DSI* is constructed using principal component analysis; specifically, it is based on the expression given in Equation (6):

$$A_j = \sum_{k=1}^{K} f_k \frac{(a_{kj} - \overline{a}_k)}{s_k}, \quad (6)$$

where A_j is the first principal component for household j, a_k the set of K variables pertaining to damage severity, and $\overline{a}_k$ and s_k the corresponding sample means and standard deviations. The second term in the expression is thus the variables a_{kj} normalized by their mean and standard deviation. The term f_k is a set of weights calculated to extract the greatest possible variance in the data and scaled so that their sum equals unity. A detailed explanation of the principal component method can be found in Jolliffe et al. [39].

The *DSI* is derived from four variables: the portion of a household's census tract classified as flooded, the portion of a household's census tract classified as damaged, the shortest distance between the center of a household's census tract and a hurricane path, and total building replacement costs per capita in a household's zip code. These variables are constructed using ArcMap 10.0 from the geospatial data obtained from FEMA, NOAA, and the Hurricane Katrina and Rita Clearinghouse Cooperative. We assumed that the first principal component, which accounts for 51% of the total variance in the data, reflected the extent of hurricane damage in the respondent households' communities. Across households included in the analysis, the *DSI* ranges in value from −2.11 to 6.02, with a mean of 0 by construction. We hypothesized that the *DSI* is positively correlated with the probability of displacement and displacement duration.

Social support variables are based on the Crisis Support Scale (CSS) which is designed to measure perceived social support following a crisis event [40]. The CSS demonstrates good internal consistency and discriminatory power [41], and it has been used in several natural hazard studies [42–44]. The variant of the CSS incorporated into the 2007 PSID supplementary questionnaire is a 6-item inventory of social interactions that occurred in the weeks following Hurricanes Katrina and Rita. The items concern the: (1) willingness of others to listen, (2) extent of contact with people in similar situations, (3) ability to talk about thoughts and feelings with others, (4) extent of sympathy and support received from others, (5) extent of practical help received from others, and (6) extent of feeling let down by others. As described to respondents, the CSS pertains to all social support and not solely to support connected to Hurricanes Katrina and Rita.

Each item in the inventory is scored by survey respondents on a scale from 1 (never) to 7 (always). Summing responses produce a score—ranging from 6 to 42—that represents a respondent's perceived level of social support. Based on these scores, we categorized households as having low, moderate, or high levels of social support. Households with low (LOW SOCIAL SUPPORT) and high (HIGH SOCIAL SUPPORT) levels of support are defined as being in the lower and upper quartiles of the sample distribution, while households with moderate levels of support are in the inner quartiles. Moderate social support serves as the base category in the Hurdle Model. The literature provides little guidance on how to classify CSS scores; we therefore evaluated the sensitivity of results to alternate specifications of the social support measure. We considered a 2-category specification using the median as a cutoff (i.e., low and high levels of support), a 4-category specification based on quartiles (i.e., low, moderate-low, moderate-high, and high levels of support), the unadjusted CSS score, and an index created using principal component analysis.

The 2007 PSID supplementary questionnaire asked respondents whether or not they were displaced, but it did not distinguish between respondents who left prior to hurricane landfall and those who left in the aftermath. The displacement variable used in this analysis should thus be interpreted as an indicator for households that were compelled to leave their home for any reason, including mandatory evacuation, voluntary pre-hurricane relocation, and forced relocation due to unsuitable post-hurricane living conditions. Consequently, some households observed the damage to their property and community prior to displacement, while others only observed the damage after returning. As discussed below, confounding pre- and post-hurricane displacement has implications for the interpretation of damage coefficients in the probit component of the Hurdle Model.

4. Results

4.1. Descriptive Statistics

Descriptive statistics for both the full sample (n = 398) and subset of displaced households (n = 102) are presented in Table 2. The Reference Person ranged in age from 18 to 85, with a mean age of 42. The Reference Person was typically a high school graduate (72%), neither married nor cohabitating (62%), and in average or above average health (72%) prior to Hurricanes Katrina and Rita. A slight majority of households had children (54%) and owned their home (56%), while a small portion lived in a mobile home (17%). Although not reported in Table 1, most Reference Persons are male (57%), black (80%), and employed (89%). Annual 2004 household income ranged from 10,000 to 237,300 USD, with an average of 37,400 USD. Respondent households primarily resided in Mississippi (57%), with the remaining households located in Alabama (20%) and Louisiana (23%).

Table 2. Variable Definitions Descriptive Statistics.

Variable	Description	All Households		Displaced Households	
		Mean	Std. Dev.	Mean	Std. Dev.
DISPLACED	Household displaced by Hurricane Katrina/Rita (indicator)	0.256	(0.437)	NA	NA
DURATION	Duration of displacement (days)	NA	NA	140.784	(243.804)
AGE	Age of Reference Person (years)	41.573	(14.215)	39.775	(12.976)
MARRIED	Reference Person is married or cohabitating (indicator)	0.384	(0.487)	0.392	(0.491)
UNHEALTHY	Reference Person has below average health (indicator)	0.284	(0.451)	0.324	(0.470)
HIGH SCHOOL	Reference Person completed high school (indicator)	0.721	(0.449)	0.775	(0.420)
INCOME	2004 household income (10,000 USD)	3.742	(3.234)	4.018	(3.798)
MOBILE HOME	Household lives in a mobile home (indicator)	0.166	(0.372)	0.176	(0.383)
CHILDREN IN HOME	Children present in the household (indicator)	0.548	(0.498)	0.569	(0.498)
LIVE IN ALABAMA	Household lives in Alabama (indicator)	0.201	(0.401)	0.108	(0.312)
LIVE IN MISSISSIPPI	Household lives in Mississippi (indicator)	0.570	(0.496)	0.431	(0.498)
MINIMAL DAMAGE	Minimal damage to home (indicator)	0.291	(0.455)	0.284	(0.453)
MODERATE DAMAGE	Moderate damage to home (indicator)	0.161	(0.368)	0.216	(0.413)
SEVERE DAMAGE	Severe damage to home (indicator)	0.113	(0.317)	0.363	(0.483)
DSI	The extent of damage within community (index)	0.000	(1.425)	1.318	(2.056)
PAYMENTS FROM FAMILY	Payments from relatives in 2005 and 2006 (10,000 USD)	NA	NA	0.037	(0.124)
LIVE WITH FAMILY	Household lived with family while displaced (indicator)	NA	NA	0.657	(0.477)
LOW SOCIAL SUPPORT	Household has low social support (indicator)	0.266	(0.443)	0.127	(0.335)
HIGH SOCIAL SUPPORT	Household has high social support (indicator)	0.234	(0.424)	0.373	(0.486)

Notes: Socioeconomic variables reflect household characteristics prior to the hazard events. Descriptive statistics based on the full sample of 398 households (All Households) and the subsample of 102 displaced households (Displaced Households).

Most households report some hazard-related property damage, with 28% reporting minimal damage, 16% moderate damage, and 12% severe damage. The remaining 44% report no property damage. Social support, as measured by the CSS, ranged from the minimum possible value of 6 to the maximum possible value of 42. By design, approximately 25% of households are classified as having low levels of social support and 25% as having high levels of social support, with the remaining households classified as having moderate levels of support. The duration of displacement ranged from 1 to 837 days, where 2% of these households were still displaced at the time of the 2007 PSID. Of displaced households, 66% lived with family members and 3.7% received financial assistance from family. The average total receipt from family was 1900 USD (range 60 to 10,000 USD).

We can assess the extent to which the Hurdle Model is affected by household nonresponse and item nonresponse. For household nonresponse, we compared characteristics of households included in the analysis to those that were eligible but did not respond to the supplemental questionnaire. Fifty-six households from Alabama, Louisiana, and Mississippi declined to participate in the supplemental questionnaire. These households are more likely to own their home and have a Reference Person with a high school education compared to households included in the analysis. On average, nonresponse households also have older Reference Persons. There are, however, no evident differences in household income, presence of children, state residence, or mobile home residence between response and nonresponse households. Moreover, the two groups have similar proportions of households with a Reference Person who is male, black, married or cohabitating, employed, or self-reported below average health.

For item nonresponse, we compared the characteristics of households with missing information to households included in the analysis. A higher proportion of households with missing information have a Reference Person with a high school education; they also exhibit a higher average income and a higher average Reference Person age. However, like before, there are no evident differences in home ownership, presence of children, state residence, or mobile home residence. The two groups have similar proportions of households with a Reference Person who is male, black, married or cohabitating, employed, or self-reported below average health. Twenty-one households completed the displacement and property damage questions in the supplemental questionnaire but failed to complete other relevant components of the survey. There are no clear differences in displacement, displacement duration, or property damage between these households and those included in the analysis. Overall, we found little evidence that omitted households differ markedly from included households.

4.2. Kaplan–Meier Curve and Hurdle Model

We visually examined displacement duration using the Kaplan–Meier curve, which is a nonparametric estimate of the survival function that approaches the true function with large samples [45]. Results shown in Figure 2 indicate that more than half of displaced households returned within a few weeks, while most of the remaining households returned in the ensuing two years. The pattern of displacement depicted here suggests that households returned home at a decreasing rate over time, which is indicative of the Weibull, generalized gamma, and log-logistic distributions. The AIC is used to identify a preferred distribution for the Hurdle Model. Although goodness-of-fit is similar across all specifications, models estimated with a Weibull distribution consistently exhibit the lowest AIC.

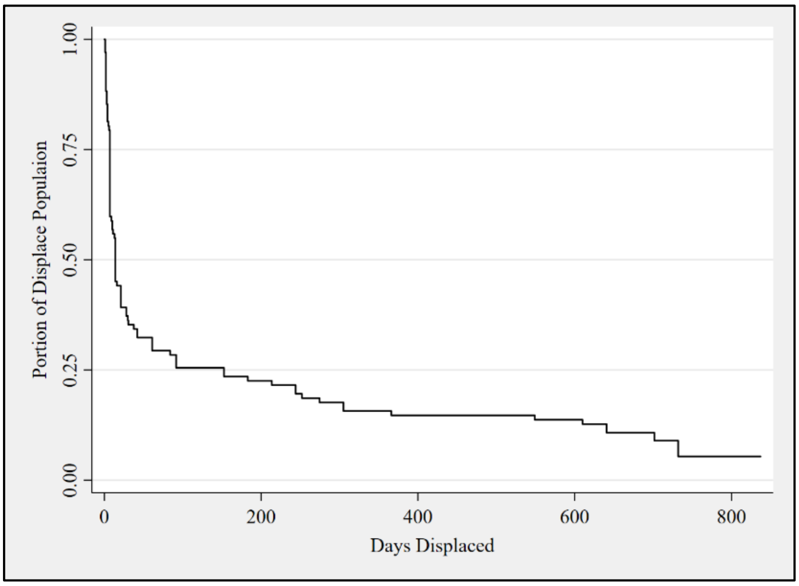

Figure 2. Kaplan–Meier Curve for Displacement Duration.

Tables 3 and 4, respectively, present results for the probit and survival components of the Hurdle Model. Three model specifications are reported. Model 1 evaluates the effects of socioeconomic characteristics on displacement and displacement duration. Model 2 incorporates property damage indicators and the *DSI*. Model 3 additionally incorporates the social support indicators and financial and housing assistance measures. Estimated parameters are largely consistent across model specifications, although the inclusion of damage variables leads to notable changes in the coefficients of some socioeconomic characteristics, such as mobile home residence, the presence of children, whether or not the Response Person is married, and residence in Alabama or Mississippi. Model 3 provides the best fit to the data according to the AIC, but, as discussed below, the interpretation of Model 3 results is complicated by likely endogeneity in the social support and financial and housing assistance variables.

Table 3. The Result from Probit Component of Hurdle Model (Displacement).

	Model 1	**Model 2**	**Model 3**
Constant	0.019 (0.327)	−0.855 (0.364)	−0.831 (0.375)
AGE	−0.009 (0.006)	−0.011 (0.007)	−0.010 (0.007)
MARRIED	−0.085 (0.179)	−0.086 (0.199)	−0.119 (0.207)
UNHEALTHY	0.439 (0.175)	0.456 (0.191)	0.428 (0.191)
HIGH SCHOOL	0.307 (0.178)	0.390 (0.194)	0.359 (0.199)
INCOME	0.024 (0.027)	0.014 (0.034)	0.018 (0.034)
MOBILE HOME	0.294 (0.203)	0.422 (0.212)	0.467 (0.218)
CHILDREN IN HOME	−0.028 (0.154)	−0.096 (0.174)	−0.114 (0.179)
LIVE IN ALABAMA	−1.293 (0.232)	−0.584 (0.295)	−0.592 (0.303)
LIVE IN MISSISSIPPI	−0.947 (0.169)	−0.529 (0.229)	−0.543 (0.230)
MINIMAL DAMAGE		0.678 (0.208)	0.694 (0.210)
MODERATE DAMAGE		0.839 (0.244)	0.789 (0.247)
SEVERE DAMAGE		1.494 (0.333)	1.441 (0.339)
DSI		0.369 (0.118)	0.361 (0.114)
LOW SOCIAL SUPPORT			−0.527 (0.230)
HIGH SOCIAL SUPPORT			0.251 (0.189)

Robust standard errors in parentheses.

Table 4. The Result from Survival Component of Hurdle Model (Displacement Duration).

	Model 1	Model 2	Model 3
Constant	4.927 (1.021)	1.533 (0.785)	1.310 (0.737)
AGE	0.017 (0.019)	0.017 (0.010)	0.025 (0.010)
MARRIED	−1.269 (0.505)	−0.630 (0.355)	−0.786 (0.283)
UNHEALTHY	−0.283 (0.512)	−0.331 (0.342)	−0.563 (0.344)
HIGH SCHOOL	−0.577 (0.640)	−0.046 (0.352)	0.426 (0.318)
INCOME	0.022 (0.086)	−0.048 (0.056)	−0.067 (0.040)
MOBILE HOME	−0.787 (0.706)	−0.810 (0.452)	−0.723 (0.419)
CHILDREN IN HOME	0.772 (0.420)	1.231 (0.307)	1.000 (0.266)
LIVE IN ALABAMA	−2.165 (0.779)	0.277 (0.633)	0.312 (0.568)
LIVE IN MISSISSIPPI	−1.135 (0.455)	0.590 (0.407)	0.804 (0.324)
MINIMAL DAMAGE		−0.039 (0.450)	−0.117 (0.397)
MODERATE DAMAGE		1.087 (0.505)	0.801 (0.424)
SEVERE DAMAGE		1.893 (0.588)	2.023 (0.508)
DSI		0.485 (0.138)	0.442 (0.115)
LOW SOCIAL SUPPORT			1.290 (0.475)
HIGH SOCIAL SUPPORT			−0.110 (0.282)
PAYMENTS FROM FAMILY			−4.197 (1.883)
LIVE WITH FAMILY			−0.274 (0.254)
$\ln(\kappa)$	−0.629 (0.069)	−0.265 (0.083)	−0.140 (0.095)

Robust standard errors in parentheses.

Coefficients in the probit component are interpreted as effects on the cumulative normal distribution; they can be used to predict outcome probabilities and marginal effects. All respondents are assumed to follow the same baseline survival curve, where covariates serve to accelerate or decelerate the rate of movement along the curve. Coefficients in the survival component can be exponentiated to facilitate their interpretation. Exponentiated coefficients indicate the factor by which the expected time to return is multiplied due to a marginal change in the covariate [46].

Socioeconomic characteristics exhibit sizable effects on both the probability and duration of displacement. In Model 2, the probability of displacement is positively correlated with residence in a mobile home, household income, and indicators pertaining to the Reference Person, for high school education, and below average health. Thus, the likelihood of displacement was greater for sample households with these characteristics, and households with higher income. The probability of displacement is negatively correlated with residence in Alabama and Mississippi, the presence of children in the home, Reference Person age, and the indicator for marriage. The likelihood of displacement was, therefore, lower for sample households with these characteristics and households with an older Reference Person. Marginal effects indicate there would be a 9.6% increase in displacement among sample households if all households lived in a mobile home (relative to other housing types). Similarly, there would be a 7.8% and 10.1% increase in displacement if the Reference Person in all households had a high school education (relative to not having a high school education) and self-reported below average health (relative to average or above average health), respectively.

Displacement duration is positively correlated with residence in Alabama and Mississippi, the presence of children, and Reference Person age; it is negatively correlated with residence in a mobile home, household income, and indicators for marriage, high school education, and below average health. Households with children were displaced longer than those without children by a factor of 3.42 (i.e., for everyday households without children are displaced those with children are displaced 3.42 days, all else being equal). Residents of Alabama and Mississippi were displaced longer than residents of Louisiana by factors of 1.32 and 1.80. Conversely, households where the Reference Person is married and households living in a mobile home return more quickly by factors of 0.53 and 0.72, respectively. A $10,000 increase in household income is associated with a 0.95-factor decrease in the number of days displaced.

The probability and duration of displacement are also affected by the degree of property damage. Marginal effects indicate there would be a 14.5% increase in displacement among sample households if all households experienced minimal property damage, as opposed to no property damage. The corresponding increases for moderate and severe property damage are 19.0% and 40.3%, respectively. For the survival components, exponentiated coefficients indicate the number of days displaced increases by a factor of 2.97 for households that experienced moderate property damage and by a factor of 6.64 for households with severe property damage, relative to no property damage. The coefficient for the *DSI* is positive in both model components, implying that, on average, greater levels of damage within a household's community increase the probability of displacement and the length of displacement. Because the *DSI* is a unitless index, marginal effects and exponentiated coefficients do not have clear interpretations.

Model 3 incorporates financial assistance, housing assistance, and social support measures. Estimated coefficients for socioeconomic characteristics, property damage indicators, and the *DSI* are similar to those in Model 2. Payments received from family following Hurricanes Katrina or Rita are negatively correlated with displacement duration. The exponentiated coefficient indicates the amount of time-displaced decreases by a factor of 0.02 for every 10,000 USD received. As a point of reference, less than 25% of sample households received payments from family and less than 10% received more than 1000 USD. Similarly, households that lived with family while displaced were displaced for a shorter amount of time than other households by a factor of 0.76.

Finally, the results suggested that households classified as having low social support were less likely to be displaced than households with moderate or high social support. Specifically, we found that there would be a 9.5% decrease in displacement if all sample households had low social support, as opposed to moderate support. There would be a 15.4% decrease if all households had low support, as opposed to high support. If displaced, however, households with low social support were, on average, displaced longer than households with moderate and high support by factors of 3.63 and 4.05, respectively.

We evaluated several alternate specifications of the social support measure, including a 2-category specification, a 4-category specification, the unadjusted CSS score, and an index created using principal component analysis. Results from these model specifications (not reported) are qualitatively like those presented in Tables 3 and 4. They indicate that households with low levels of social support are less likely to be displaced and, conditional on being displaced, take longer to return relative to other households. Thus, findings appear robust to how social support is specified. That said, the inventory used to create the social support indicator is based on all social interactions in the weeks following Hurricanes Katrina and Rita. The amount of support received likely depends, in part, on displacement and the duration of displacement, which implies an endogenous relationship (i.e., explanatory variables pertaining to social support are correlated with the error term, violating model assumptions, and biasing estimated coefficients). Results should be interpreted accordingly. We are unaware of an alternative exogenous measure of social support or an appropriate instrument that could be used to address this issue. A similar argument applies to the financial and housing assistance variables.

5. Discussion

The Hurdle Model results offer three general insights into displacement behavior among sample households. First, the likelihood of displacement and the duration of displacement varied systematically across socioeconomic characteristics, property damage, and neighborhood damage. Second, socioeconomic factors that have the greatest effect on the likelihood of displacement differ from those that have the greatest effect on displacement duration. Third, displacement duration is affected by post-hazard financial assistance and social support.

Consistent with the existing literature, we found that the severity of property and neighborhood damage was a key predictor of displacement and displacement duration [9,23]. The greater the degree of damage, the more likely it is that a household was displaced and, conditional on being displaced, the longer the household took to return. An important caveat is that coefficients on damage variables in the probit component have somewhat ambiguous interpretations because we could not distinguish between respondents' displaced pre- and post-hurricane landfall. Households that left their home prior to landfall made their decision based on expected damage and exposure risk, while households that left after landfall made their decision based on actual damage. Nevertheless, results show that damage to homes and neighborhoods, whether expected or actual, are important drivers of displacement.

Among socioeconomic factors, the Reference Person's health status and educational attainment had the most pronounced effect on the likelihood of displacement, where being unhealthy and having completed high school is associated with a greater likelihood of displacement. The Reference Person's marital status and the presence of children in the home had the most pronounced effect on the return decision. Households where the reference person is married are associated with a shorter period of displacement, while households with children are associated with a longer period of displacement. Residing in a mobile home is also an important factor in displacement behavior; it is associated with an increase in the likelihood of displacement and a reduction in the amount of time displaced, all else being equal.

We found evidence, contrary to Paxson and Rouse [20] and Thiede and Brown [6], that households with low social support are less likely to be displaced and, if displaced, take longer to return than other households. If social support is interpreted broadly as a measure of social capital, then findings suggest that households rely on social capital to aid in both displacement and return outcomes. Households with more social capital leverage their connections to avoid exposure risk by evacuating pre-hurricane or to escape unsuitable living conditions post-hurricane. In practical terms, this means, among other possibilities, access to temporary living arrangements, financial assistance, and improved psychological wellbeing. However, more generally, social capital offers the assurance of assistance; it reduces the expected financial, physical, and psychological cost of displacement. Households with more social capital also leverage their connections to facilitate recovery and resettlement. As with displacement, social capital reduces the expected cost of returning by, for instance, mitigating the financial and psychological challenges of rebuilding homes and neighborhoods. For similar reasons, financial aid from and living with family while displaced are associated with a shorter period of displacement.

In addition to the aforementioned issue of interpreting coefficients on damage variables in the probit component, there are two notable limitations to this study. The first limitation is that the data were not obtained from a random sample of households living in areas affected by Hurricanes Katrina and Rita, and evidence suggests that the sample is likely not representative of the population within census tracts where respondents were living. This issue poses problems for statistical inference. Although findings are broadly consistent with expectations and the extant literature, we interpreted results in terms of sample respondents and avoided generalizing the population. The second limitation concerns likely endogeneity in the social support measure. The inventory used to create the social support indicator was based on all social interactions in the weeks following Hurricanes Katrina and Rita, not just those related to the hurricane. However, the amount of support received likely depends, in part, on displacement and the duration of displacement, which implies that estimated coefficients are subject to endogeneity bias. We are unaware of an alternative exogenous measure of social support or an appropriate instrument that could be used to address this issue. Results from Model 2, which do not include social support measures, are not subject to endogeneity bias.

Despite these limitations, this study contributes to the limited knowledge regarding the factors affecting the rate of return following a hazard event. To the best of our knowledge, this study is the first to use a Hurdle Model within the context of hazard-related displacement. Results suggest that the socioeconomic factors most important to the displacement decision are not the same as those most important to the decision about when to return. These differences should be considered when evaluating or predicting population dynamics following hazard events. In addition, and keeping in mind potential endogeneity concerns, results suggest that social capital may be an important mechanism for mitigating exposure risk and facilitating return. This finding highlights the vulnerability of relatively disadvantaged groups, in this case, households with low social capital coping with the multitude of adverse impacts stemming from hazard events. Additional research on the role of social capital in hazard-related outcomes is warranted given its potential effect on population dynamics, recovery processes, and resilience.

6. Conclusions

Hurricanes Katrina and Rita caused widespread destruction and displacement, resulting in unparalleled reliance on emergency assistance, formal social support services, and informal social support networks. This analysis employed a Hurdle Model to evaluate the determinants of displacement and, conditional on being displaced, the duration of displacement. Evaluating systematic differences in the likelihood and duration of displacement can offer insight into population dynamics following hazard events and can help in identifying vulnerable population sub-groups that are less able to rebound. Data for this analysis were primarily obtained from the 2005 PSID and a 2007 PSID supplemental questionnaire administered to families living in Louisiana, Alabama, or Mississippi at the time of Hurricanes Katrina and Rita. The supplemental questionnaire contains information on displacement, displacement duration, property damage, and social interactions in the weeks following the hurricanes. Results show that the degree of property damage, degree of neighborhood damage, and mobile home residence had substantial and positive effects on the likelihood of displacement and its duration. Among socioeconomic factors, health status and educational attainment had the largest marginal effect on the likelihood of displacement, while the Reference Person's marital status and the presence of children in the home had the largest effect on the return decision. Social support is also correlated with displacement and its duration in a manner that suggests it can help households avoid exposure risk and facilitate resettlement, but endogeneity concerns complicate the interpretation of these results.

Author Contributions: Conceptualization, J.I.P., A.K.B. and W.L.H.; Data curation, J.I.P.; Formal analysis, J.I.P.; Methodology, J.I.P., A.K.B. and W.L.H.; Writing—original draft, J.I.P.; Writing—review and editing, J.I.P., A.K.B. and W.L.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was approved by the Institutional Review Board at the University of New Mexico (#08-193; 20 August 2009).

Informed Consent Statement: Not applicable.

Data Availability Statement: Restrictions apply to the availability of these data. Data was obtained from the Institute for Social Research, University of Michigan.

Conflicts of Interest: The authors declare no conflict of interest.

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