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Adjusting to natural disasters

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Abstract People adjust to the risks presented by natural disasters in a number of ways; they can move out of harms way, they can self protect, or they can insure. This paper uses Hurricane Andrew, the largest U.S. natural disaster prior to Katrina, to evaluate how people and housing markets respond to a large disaster. Our analysis combines a unique *ex post* database on the storm's damage along with information from the 1990 and 2000 Censuses in Dade County, Florida where the storm hit. The results suggest that the economic capacity of households to adjust explains most of the differences in demographic groups' patterns of adjustment to the hurricane damage. Low income households respond primarily by moving

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into low-rent housing in areas that experienced heavy damage. Middle income households move away to avoid risk, and the wealthy, for whom insurance and self-protection are most affordable, appear to remain. This pattern of adjustment with respect to income is roughly mean neutral, so an analysis based on measures of central tendency such as median income would miss these important adjustments.

Keywords Natural hazards · Economic adjustment · Hurricanes

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Adjusting to natural disasters

Natural disasters force adjustment. The Indian Ocean tsunami in late 2004 and Katrina's devastation in New Orleans and throughout the Gulf Coast in August 2005 renewed our collective awareness of disasters. Natural disasters can also provide opportunities for quasi-random experiments to learn how households adjust to these events. For example, Kahn's (2005) recent analysis of the death toll from natural disasters suggests that the level and distribution of income, along with presence of "higher-quality" institutions, can influence the severity of the outcomes from disasters. Nonetheless, there are limits to our ability to use a detailed reduced form model to parse the factors in many different countries that contribute to social and economic outcomes. Ideally, one would like to be able to hold political institutions and the cultural context constant.[1] However, this strategy forfeits the cross-country variation providing detailed information of the spatial differences in disasters. As a rule, detailed spatial information of this type is unavailable for a single location. Our analysis is unique in that we have a spatially delineated record of *ex post* damage of a large-scale disaster from Hurricane Andrew as well as maps designating risk zones that proxy for *ex ante* hazard information for our study area.

Our analysis is also related to the literature in economic geography spawned by analyses summarized in Krugman (1998). Most empirical tests of this framework focus on the importance of increasing returns for the degree of spatial differentiation. Recently, for example, Davis and Weinstein (2002) considered allied bombing of Japanese cities in World War II as a shock to relative city sizes and find that the location of densely settled areas is preserved even in the presence of significant temporary shocks of a large scale. Comparable conclusions were drawn by Miguel and Roland (2006) for the bombing's effect on local poverty, consumption levels and population density in Vietnam 25 years after the War. However in this case there was significant effort at reconstruction of bombed facilities. These analyses are primarily relevant for the size and density of population not the mix by demographic group or the distribution of income and housing values.

Hurricane Andrew made landfall in August 1992 and was the largest U.S. natural disaster on record prior to Katrina.[2] With the 1990 and 2000 Censuses, we consider how people

[1] See Cohen and Werker (2005) for an interesting conceptual analysis describing how political and cultural factors can influence the character of efficient public action.

[2] Robert Hartwig, Senior Vice President and Chief Economist of the Insurance Information Institute, used this characterization in describing the impact of hurricanes on economic activity in hurricane prone counties. He observed that:

> "Hurricane Andrew, until September 11, 2001, was the global insurance industry's event of record. For nearly a decade it was the disaster against which all other disasters worldwide were compared.... Andrew struck Florida in August 1992 with 140 mile-per-hour winds and produced insured losses of $15.5 billion—about $20 billion in current (2001) dollars....Although Andrew has now been eclipsed as

adjusted to the damage caused by the storm. This can happen in a number of ways: people can move out of harms way; they can self-protect, building structures less vulnerable to damage; or they can insure. In the first part of our results, we provide a description of how Andrew reshaped Dade County, Florida after the hurricane made landfall and destroyed a large portion of the private housing and commercial facilities. The second part of the analysis uses Census data on the value of homes in areas likely to be perceived as subject to higher risk after the disaster. This component focuses on the market consequences of these adjustments. Both parts provide insight for designing policies that facilitate people's ability to return to their everyday activities after disasters.

Our empirical models exploit a unique *ex post* evaluation of Andrew's damage conducted by the National Oceanic and Atmospheric Administration (NOAA). The findings were published in the Miami Herald on December 20, 1992 (referred to later as the NOAA/Miami Herald data). They include information on 420 subdivisions and condominium developments in the area affected by Andrew. We also acquired the FEMA flood maps providing a record of the differing nature of the *ex ante* flood risk of damage throughout the country. By matching these two data sources with demographic and economic measures for Dade County census block groups, a spatial picture can be developed for both the adjustments that took place and the context for those changes.

Our findings confirm some prior beliefs about this hurricane and overturn others. In contrast to the popular views of the storm's impact, white, middle-income households experienced more significant damage than poor, minority households. Financial capacity, as reflected by home ownership and education, are key factors in who adjusted to the damage. In the eight years after Andrew the population in areas with 50 percent or more of the homes damaged so seriously as to be rated uninhabitable grew faster than areas with less damage. There does not appear to be a significant pattern of adjustment for white and black homeowners in relation to the damaged areas. White renters moved away from damaged areas. Hispanic households, both owners and renters, moved into the areas with hurricane damage. Lower income households tended to move into damaged areas while middle income moved out. In general, the storm's damage did not appear to affect higher income households. In 2000, households with annual incomes over 150,000 were the only group likely to be attracted to areas with a comparable "type" of household—i.e. to areas where the same income level households lived in 1990. Thus, the analysis highlights the potential importance of household heterogeneity for measuring the effects of spatially-delineated environmental impacts. Indeed we suggest that studies based on summary measures, such as the median income, miss much of the story.[3]

The second half of the analysis—the evaluation of the economic consequences of these adjustments—evaluates the changes in the distributions of rents and homeowners' beliefs about their homes' values between the 1990 and 2000 Censuses in response to average damage and the fraction of a block group in a FEMA risk zone. The coefficients for the areas with differing risks of coastal flooding in models using changes in the median measures

the largest insurance event in world history (by September 11). ... It remains the largest natural disaster on record in terms of insured losses, not only in the United States but world-wide..." (Hartwig, 2002 pp.1–2, parenthetical phrase added).

[3] Recently, quasi-experiments (such as the one performed here) have raised questions about the the viability of earlier hedonic studies on the value of air quality improvements and superfund clean up (see Chay and Greenstone, 2005; Greenstone and Gallagher, 2005). The current paper bears on this discussion as well. To the extent that changes in these other environmental amenities result in large distributional changes like those found here, quasi-experiments based on summary data may be biased.

for housing values indicate slower appreciation in both the high and the medium risk areas (based on the FEMA flood ratings). The difference in the coefficients for the areas is not statistically significant. However, when we weight each coefficient by the average land area in each Census block group in the risk category, the differences are significant and the relative magnitudes of the effects are consistent with the ordering of the risks. Using the average share of the block groups in the high risk zones, this information would imply about a three percent reduction in the median value, while for the medium risk areas it would be about one percent due to the information we hypothesize was acquired from the storm.

Section two develops the hypotheses motivating our expectations for differences in households' adjustments. The third section describes the spatially delineated data required to undertake the analysis. Our results are developed in section four in two parts. First we describe the changing features of neighborhoods based on the 1990 and 2000 Censuses for the county. After that we discuss the changes in the distribution of housing values and rents with the location of the block groups in relation to FEMA flood risk zones and the NOAA measures for Andrew's damage.[4] The last section discusses the implications of the analysis for what we might expect for the pattern of adjustment in the Gulf Coast area after Katrina.

1 Non-market and market responses

1.1 Background

When a large share of the private and public capital supporting daily activities is significantly damaged, some private responses are inevitable. Kahn (2005) argues that great political accountability will induce democracies to take pro-active actions and adapt to hazards in a way that reduces their overall impact. We know very little about who is adjusting and what factors induce those who do to act. Most of the available economic models of household adjustment to exogenous changes in community attributes are intended to describe responses to relatively small changes in features of a home or a neighborhood. In the empirical tests of these models the attributes of interest are assumed to be conveyed to homeowners through their locational choices. Households are assumed to be heterogeneous, with different preferences for location specific amenities. As a rule, they assume there is one or more endogenous (to the adjustment process) attributes of neighborhoods that can reinforce or retard responses to an exogenous change in the location specific attribute. For example, in the externality/filtering models (Coulson and Bond, 1990) average neighborhood income is hypothesized to be a factor that influences household preferences for a neighborhood. It also changes as people alter their choices for neighborhoods. As a result, changes in mean income can enhance or reduce the effects of an exogenous change in a neighborhood attribute. The overall effect this process has on composition of an area depends on the size and direction of the effect of neighborhood mean income on the marginal willingness to pay for the attribute that changes.

A comparable set of influences can be found in the sorting models that would have consistent predictions for large changes in neighborhood attributes and indeterminant implications for small (see Banzhaf and Walsh, 2004). The externality/filtering and sorting models rely

[4] For some variables, our analysis will use mean values for the relevant variables. In other cases we use medians. These decisions are largely mandated by the summary statistic available at the block group level for both census years. We also investigated the possibility of estimating means from reported frequency distributions with an assumed distribution for the response variable of interest (e.g. household income), but do not report these findings here because the changes in the frequency distributions for these variables provide a more complete description without the need to make a specific distributional assumption.

on a common formal structure. The first identifies two types of households who must select among locations with continuous variation in an exogenous attribute. Sorting models assume a finite set of communities and continuous variation in household tastes. Banzhaf and Walsh illustrate their analysis with two communities varying in an exogenous attribute and describe sorting among communities. In both structures an equilibrium is defined. In the externality filtering models, the equilibrium definition stems from the law of one price whereas in sorting models it is boundary indifference. Comparative statics with each relationship, given the constraints linking household heterogeneity to endogenous outcomes, yields the implications for how heterogeneity in preferences or constraints affects the impact of a change in the exogenous attribute. Both models require some version of the single crossing condition and a large change to derive unambiguous hypotheses about outcomes. This requirement for a large change is a key advantage for analysis of outcomes after natural disasters.

The filtering and sorting frameworks have two implications for our research. First, the larger the damage in a neighborhood, the greater the prospects for a change in measures of its demographic and economic composition. Such changes offer the opportunity, given individuals have the resources to pay for adjustment, to observe whether the exogenous change offsets any endogenous retarding (or enhancing) effects of the changes in the existing composition of a neighborhood. Second, the models imply that uncovering the effects of damage adjustment requires comparing changes in the distributions of the household types with the 1990 and 2000 Censuses rather than changes in measures of the central tendencies for these distributions.

1.2 Models

Our strategy for tracking who adjusts uses a simple regression format. We estimate how $(y_{j(t+10)} - y_{jt})$ varies with the average proportion of homes that are judged uninhabitable. y_{jt} is the proportion of households (or individuals depending on the measure being summarized) in category j for $t = 1990$. For example this could be the proportion in a racial group or it could be the proportion born in Florida. This relationship is estimated with a variety of control variables, including the baseline (i.e. 1990) proportion of households (or individuals) in each group, the location of block groups in relation to FEMA flood zones, and the potential effects of a neighborhood bordering Homestead Air Force Base.[5]

An expanded specification for the basic model is given in Eq. (1) with d_j designating the Miami Herald damage measure and z_{jk} a set of variables that correspond to the different controls investigated as part of evaluating the robustness of our conclusions. To test the logic of Brock and Durlauf's (2001) social interactions models, we consider some models with z_j corresponding to the y_{jt}. The argument is simply that demographic groups seek to stay within areas that share common interests and social networks. For other models, z_{jk} corresponds to measures of the extent of a block group in areas with higher risks of coastal flooding as measured by the FEMA flood maps.

$$(y_{j(t+10)} - y_{jt}) = \alpha_0 + \alpha_1 d_j + \sum_k \tau_k z_{jk} + \varepsilon_j \tag{1}$$

ε_j is a random error assumed to be classically well behaved, α_0, α_1, and τ_k are parameters to be estimated.

The cell definitions of some of the economic variables, such as the distributions of incomes, rents, and housing values, changed between the two Censuses. These changes in the 2000

[5] This facility was closed after the hurricane due to extensive damage.

Census expand the resolution in the middle categories and change the upper censoring point. We redefined the 2000 categories for rents, housing values, and income so they matched the 1990 categories.

For property values and rents these models generalize the logic proposed by Chay and Greenstone (2005) to use quasi-random experiments to estimate the incremental value of changes in site specific amenities. That is, a hedonic model's ability to recover an estimate on the incremental willingness to pay for amenities conveyed through residential location relies on sorting behavior. People select the best locations they can afford. Nonetheless, there may be unobserved differences in the households that select locations with low amenity levels in comparison to those choosing the ones with high levels. Use of an exogenous instrument and a difference-in-difference framework allows the effect of interest and the influence of unobserved heterogeneity to be distinguished.

Applications of this logic for environmental effects have generally relied on county (or Census tract) level mean or median housing values across Censuses and we report the results for these summary measures as well.[6] However, we add to them another approach—examining the changes in the distributions of housing values and rents. To the extent there is a change in the composition of the housing available as a result of the amenity differences, the "average" may not be distinguishing a marginal value for the change in the amenity. By using changes in the distributions of housing values or rents, we have greater control over the "types" of housing through the value and rent brackets. As a result, it is possible to consider how amenity changes influence the composition of housing.

2 Data

In December 1992 the Miami Herald published a special report analyzing the factors responsible for areas with significant damage that were far from the storm's strongest winds. As part of the report, the newspaper included the full documentation for the NOAA damage assessment by local housing subdivisions. Using the map included with the Miami Herald's feature article it was possible to align the roadways with an Arcview map of the primary roads within the county. A set of 306 grids was defined to match the subdivision records to Census block groups. Each block group was assigned the average (area weighted if a subdivision crossed Census boundaries) damage measure for the subdivisions falling within its boundary.

These damage estimates are proxies for the extent to which neighborhoods offer opportunities for nearly complete replacement of residential structures. When one hundred percent of the homes in a neighborhood are judged to be uninhabitable, then it seems clear the damage measure offers a clear-cut index of the opportunities to transform the composition of the area. The impact of smaller amounts of damage on changes in the composition of a block group depends on several factors. Partial damage may well signal the quality of the remaining housing stock. In fact, an important motivation for the Miami Herald's special report was the heterogeneity in damage by subdivision. The damage to residential structures, as estimated based on this survey, were not completely consistent with the areas experiencing the highest wind levels from the hurricane. To develop this comparison, we obtained Wakimoto and Black's (1994) maps describing the wind patterns for Andrew. A cross tabular analysis of the Miami Herald damage survey data with an approximate wind based qualitative variable for the damage suggests using a fairly coarse grid to distinguish higher wind areas, these zones were

[6] As noted earlier, the level of spatial disaggregation (county, census track, or census spatial block group) and the variable involved can limit the summary measure (mean or median) that is available in public use data.

Table 1 Average proportion of households in each demographic category for block groups classified by damage class from andrew for the 1990 and 2000 Censuses in Dade County[a]

	Damage is greater than 50% uninhabitable		Damage is less than 50% uninhabitable		Average proportion overall block groups	
	1990	2000	1990	2000	1990	2000
I. Demographic composition						
Owner occupied						
White	0.780	0.705	0.716	0.663	0.718	0.664
Black	0.140	0.175	0.236	0.258	0.234	0.256
Hispanic	0.200	0.439	0.444	0.520	0.437	0.518
Renters						
White	0.714	0.549	0.638	0.605	0.640	0.604
Black	0.201	0.308	0.291	0.290	0.289	0.291
Hispanic	0.261	0.428	0.507	0.541	0.501	0.538
II. Income distribution						
Less than 15,000	0.189	0.175	0.317	0.247	0.313	0.245
15,000–25,000	0.138	0.167	0.178	0.148	0.177	0.149
25,000–40,000	0.229	0.198	0.196	0.177	0.197	0.178
40,000–60,000	0.284	0.174	0.151	0.159	0.155	0.159
60,000–150,000	0.149	0.256	0.131	0.216	0.132	0.217
over 150,000	0.011	0.031	0.026	0.052	0.026	0.052

[a]Damage measure is based on the NOAA/Miami Herald Survey of subdivisions in Dade County

more likely to experience damage. Nonetheless, as the Miami Herald story "Less Winds, Lots of Damage," December 20, 1992, documents there are a number of exceptions. Moreover, the Miami Herald feature also identified problems in the county's building inspections, noting that "Unsupervised and understaffed, with civil service rules that give them job protection, Dade's building inspectors were no match for the development of the 1980s."[7]

Actual implementation of a spatial analysis requires a number of judgments. For example, between the 1990 and 2000 Censuses, the definition of block groups for the county changed, expanding from 1048 in 1990 to 1222 in 2000. This change reflects the increase in population in the county and the need to re-align Census summaries to the population growth. To avoid mixing the potential for endogeneity in the neighborhood definition with the event being studied (i.e. Andrew's damage) we map the 2000 records into the 1990 definition of block groups.

We construct area weighted averages of Census statistics from the 2000 block groups so that each record can be matched to its 1990 counterpart. Table 1 reports an overall summary of the demographic and economic patterns in 1990 and 2000. The average proportion of each demographic and economic category across block groups is reported for three samples. The last two columns labeled "overall" provide these average proportions for all the block groups between 1990 and 2000. The first two sets of columns decompose this set into block groups experiencing 50% or greater of their homes as uninhabitable based on the NOAA-Miami Herald survey. The number of block groups in this category is 27. The second group includes those with less than 50% uninhabitable. The number of observations in this category ranges from 968 to 997 depending on the variable selected.

Comparing the attributes of the populations in the damaged areas in 1990 to summary measures of these attributes for the County as a whole in 1990 suggests the hurricane's damage

[7] Lisa Getter, "Inspections: A Breakdown in the System," Miami Herald, December 20, 1992.

was *not* disproportionately experienced by minority or poor households. In 1990 block groups with 50% or over damage were largely white (both owner and rental households) in the income range from 25,000 to 60,000. When we consider the proportions in 2000, white households appear to have moved out (both owners[8] and renters). Hispanic households moved in. These changes partially reflect the overall growth in the share of Hispanic households in the county. To the extent they are moving from outside the U.S., it may also reflect differences in the information they have about the risks in these areas.

Based on these averages it appears middle income households moved out and the lower (15,000–25,000) and high income groups moved in. They would change somewhat if we modify the threshold used to isolate the high damage block groups. Our separation at 50% leads to a relatively small sample of block groups that underlies the means used to characterize who is adjusting to extensive damage. Below, we use regression models to evaluate how the differences in damages in block groups affect changes in their composition.

3 Results

3.1 Who adjusts

Our analysis of the changes in the composition of the Census blocks in Dade County between 1990 and 2000 considers three types of models and reports for some of these, our more comprehensive evaluation of the effects of the area definition (e.g. 1990 versus 2000 block groups). The first set of models evaluate whether the proportionate change in a demographic or economic variable describing population changes are related to the NOAA/Miami Herald damage measure assigned to each block group. These analyses include such dependent variables as the counts of white, black, and Hispanic homeowners or the households in the 40,000 to 60,000 dollar income bracket, each relative to the relevant total number of households. As noted, these models are estimated with two samples. The first uses the 1990 block definitions and the full sample of block groups. Different area weights are used for count and continuous variables.[9]

The second sample is intended to evaluate the effect of the area weights used to reconstruct the 1990 equivalents. For these analyses, we use a sample with only the block groups that did not change between 1990 and 2000. The second group of models evaluates whether the relationships between the proportionate changes in the variables measuring demographic attributes and the NOAA/Miami Herald damage measure depend on the initial (i.e. in 1990) fraction of each group in each 1990 block group. This strategy offers a simple gauge of whether the social interactions logic influences the relationship we observe between damage and the change in each type of group. Finally the third set of analyses considers whether the FEMA flood zones influence the locational choices of different groups.

Table 2 reports the simple model, considering whether the fraction of households reporting that they stayed in the same house, was influenced by the NOAA/Miami Herald damage measure assigned to each block group. Damage did not affect the propensity to leave one's house or county. It does appear to influence the relocation patterns of those households

[8] Statistical models for changes in the proportion of white homeowners to not support a significant positive relationship with damages.

[9] When the variable being summarized is a count we apply the fraction of the 2000 block group that is from the original 1990 definition. Assuming uniform density of the relevant population in each 2000 block group this process assigns the correct weight to each component. For continuous measures, such as the median income or the median value for homeowners' reports for their home's sale price, the appropriate weight is the fraction of the 1990 block group that is in the 2000 block group. These weights sum to unity when we collapse the 2000 summary statistics to the 1990 map for block groups.

Table 2 Proportionate change in households as a function of percentage uninhabitable due to Andrew's damage: comparing 2000 and 1990 block groups[a]

Model	Same block group	Area weighted 2000 to 1990
A. Staying put		
Proportion—same house	−0.04	0.00
	(−0.88)	(0.03)
Proportion—same county	0.04	0.04
	(1.00)	(1.37)
B. Changes in composition based on birth area		
Midwest	−0.03	−0.04
	(−2.54)	(−4.75)
Northeast	−0.02	−0.03
	(−1.16)	(−1.61)
South	−0.10	−0.08
	(−4.97)	(−4.37)
West	−0.01	−0.00
	(−0.79)	(−0.30)
Florida	0.06	0.06
	(1.84)	(2.36)

[a]The numbers in the table are the slope coefficients for the damage measure in a model with the change in the proportion of households in each category between 1990 and 2000 as the dependent variable. The numbers in parentheses are t-ratios for the null hypothesis of no association.

born outside Florida. These groups avoid areas with damage. Native Floridians are then a disproportionately higher share of the population. None of these results is affected by which sample was used for the tests.

Table 3 reports the simple models for demographic variables, income, rents, and housing values. Each entry in the table corresponds to the coefficient for the damage measure from a different model where the dependent variable is the proportionate change between the 1990 and 2000 Censuses and the independent variable is the NOAA/Miami Herald damage measure (d_j in Eq. (1)) or this measure along with the 1990 proportion of the relevant group in each block group (WI for 'with initial conditions'). We do not report estimates for the parameters associated with this baseline proportion. The table entries indicate its sign (N or P) and significance (S or I) of these lag terms, included to gauge the robustness of the estimates for the damage measure.

White renters appear to avoid damaged areas. It appears that black households with home equity adopt the same adjustments in qualitative terms as the white owners—moving away from damaged areas—but neither model has these negative effects statistically significant. Black renters and Hispanic households, both owners and renters, increase in the damaged areas. While some of the Hispanic increase reflects an overall increase in this demographic group, as suggested in the average proportionate growth measures by demographic groups for the county as a whole (in Table 1), there is also a disproportionate growth in the damaged areas. Considering the results for groups based on the various educational levels achieved, the proportions with less than high school along with those who have graduate degrees are consistently significant and negatively related to the damage measure.[10]

[10] In interpreting estimates it might seem implausible to have all negative estimates. However, both the numerator and the denominator in each ratio for each educational category are changing between census years. Moreover we are not including all educational categories in the decomposition.

Use of the proportionate changes in the groups in the income cells allows more direct consideration of the heterogeneity arguments associated with the filtering/sorting models used to describe how the composition of a community changes in response to an exogenous shock. The proportion of households in the lowest two income categories (less than 15 K and 15 K to 25 K) grows while the middle income group (40 K to 60 K) declines. Upper income

Table 3 Estimated parameters for proportionate change in households in demographic and economic adjustments between 1990 and 2000 in response to Andrew's damage[a]

	Same block group		Area weighted 2000 to 1990	
Model	S	WI[b]	S	WI
A. Demographic				
1. Owner Occupied				
Proportion—White	−0.09	−0.01 N	−0.41	−0.04 N
	(−0.21)	(−0.25) S	(−1.16)	(−1.15) S
Proportion—Black	−0.05	−0.47 N	0.01	0.01 N
	(−1.42)	(−1.42) S	(0.34)	(0.20) S
Proportion—Hispanic	0.24	0.18 N	0.23	0.16 N
	(6.19)	(4.76) S	(6.72)	(4.94) S
2. Renters				
Proportion—White	−0.95	−0.11 N	−0.13	−0.12 N
	(−1.79)	(−2.14) S	(−2.91)	(−3.07) S
Proportion—Black	0.12	0.12 N	0.13	0.12 N
	(2.86)	(2.98) S	(3.64)	(3.66) S
Proportion—Hispanic	0.18	0.07 N	0.22	0.12 N
	(2.93)	(1.29) S	(4.55)	(2.62) S
B. Education				
Proportion less than H.S.	−0.21	−0.21 P	−0.21	−0.20 P
	(−2.99)	(−2.98) S	(−3.63)	(−3.57) I
Proportion with H.S.	−0.05	−0.06 N	−0.04	−0.03 N
	(−1.49)	(−1.91) S	(−1.73)	(−1.40) S
Proportion with some college	−0.00	−0.03 N	−0.01	−0.02 N
	(−0.18)	(−1.30) S	(−0.63)	(−1.17) S
Proportion with college	−0.04	−0.04 P	−0.03	−0.03 P
	(−2.00)	(−1.87) I	(−1.72)	(−1.57) S
Proportion with graduate school	−0.06	−0.07 N	−0.05	−0.06 N
	(−2.10)	(−2.30) S	(−2.44)	(−2.66) S
C. Income				
Proportion Income <15 k	0.09	0.09 N	0.11	0.10 N
	(2.63)	(2.54) S	(3.47)	(3.24) S
Proportion 15 K < Income < 25 K	0.06	0.06 N	0.05	0.05 N
	(1.85)	(1.99) S	(1.91)	(1.90) S
Proportion 25 K < Income < 40 K	0.02	0.04 N	−0.02	−0.02 N
	(0.64)	(1.04) S	(−0.66)	(−0.57) S
Proportion 40 K < Income < 60 K	−0.16	−0.14 N	−0.17	−0.16 N
	(−5.39)	(−4.48) S	(−6.79)	(−6.51) S
Proportion 60 K < Income < 150 K	−0.04	−0.03 N	0.03	0.03 N
	(−1.03)	(−0.81) S	(1.02)	(1.10) S
Proportion Income > 150 K	0.03	0.03 P	0.01	0.01 P
	(1.38)	(1.56) S	(0.52)	(0.77) S

(Continued on next page)

Table 3 *(Continued)*

Model	Same block group S	WI[b]	Area weighted 2000 to 1990 S	WI
D. Rents				
Proportion Rent < 250	−0.05	−0.03 N	−0.06	−0.04 N
	(−1.10)	(−0.81) S	(−1.61)	(−1.31) S
Proportion 250 < Rent < 500	0.26	0.23 N	0.31	0.26 N
	(3.29)	(3.06) S	(4.70)	(4.18) S
Proportion 500 < Rent < 750	−0.20	−0.21 N	−0.22	−0.23 N
	(−2.19)	(−2.20) S	(−2.76)	(−2.93) S
Proportion 750 < Rent < 1000	−0.02	−0.02 N	−0.12	−0.12 N
	(−0.23)	(−0.20) I	(−1.87)	(−1.88) I
Proportion Rent > 1000	0.01	−0.00 N	0.09	0.09 P
	(0.13)	(−0.03) S	(1.55)	(1.59) I
E. Housing values (HV)				
Proportion HV < 40 K	−0.04	0.06 N	−0.03	0.04 N
	(−0.63)	(1.16) S	(−0.59)	(0.83) S
Proportion 40 K < HV < 100 K	0.36	0.47 N	0.19	0.27 N
	(2.96)	(4.30) S	(2.02)	(3.01) S
Proportion 100 K < HV < 250 K	−0.35	−0.33 N	−0.16	−0.16 N
	(−3.16)	(−3.13) S	(−1.95)	(−1.96) S
Proportion 250 K < HV < 400 K	0.02	0.02 N	0.00	0.00 N
	(0.46)	(0.47) I	(0.06)	(0.07) I
Proportion 400 K < HV < 500 K	0.01	0.01 N	0.00	0.00 N
	(0.75)	(0.73) I	(0.23)	(0.22) I
Proportion HV > 500 K	−0.00	−0.00 P	−0.00	0.00 P
	(−0.07)	(−0.01) S	(−0.14)	(0.02) S

[a]The numbers in the table are the slope coefficients for the damage measure in a model with the change in the proportion of households in each category between 1990 and 2000 as the dependent variable. The numbers in parentheses are t-ratios for the null hypothesis of no association.
[b]This column corresponds to models that include the damage measure for Andrew along with the initial count of the group being modeled in each block group in 1990. The letters refer to the sign and significance of a term included to reflect the count of households in the relevant group in 1990. *N* = negative, *P* = positive, *S* = significant, *I* = insignificant.

groups do not significantly change in response to the damage areas. This pattern is broadly consistent with the expectations of sorting models. In a Tiebout (1956) model households adjust to local public goods (and bads) based on their ability to pay. The middle income group may have the ability to pay for adjustment. Moving to avoid risk is the way they appear to adjust. Lower income groups may be taking advantage of the lower rents in these areas. They do not have the ability to pay for moving out to another lower risk area as an adjustment. The damage and re-construction creates an opportunity when the replacement of residential structures is with lower cost units.

Higher income households have the ability to self protect and to insure. As a result, it seems reasonable to expect a wider array of adjustment possibilities. Moving out of an area may be the last alternative for this group. Thus, there is a reasonable explanation for a lack of any changes with this group. The high coastal risk areas also correspond to areas with high coastal amenities. High income households in these zones may have already self protected. When we used the median income, the difference in the log of the median income in the two

Censuses is negatively related to damage, but not significant at the ten percent level (p-value is 0.11). The results in Table 3 help to explain why.

Rents and housing values adapt to support the changing composition of households in the damaged block groups. The proportion of lower rent units increased in damaged areas and the higher rent decreased. The same effects can be traced in the signs and significance of the owner reported housing values. The proportion in the range 40 K to 100 K increased with damage while those in the 100 K to 250 K decreased. There was no change in the proportions in the higher valued categories with respect to damage.

Table 4 considers whether the adjustments are affected by the ability to avoid risky areas. That is, controlling for the average NOAA-Miami damage in a block group we consider whether the fraction in the block group in different FEMA risk categories influenced the proportionate changes in each demographic group and income category. These estimates

Table 4 Estimated parameters for models describing proportionate change in households in each group as a multivariable function of damage, risk zones, and proximity to homestead air force base[a]

	NOAA/Miami Herald damage	FEMA flood zones AE	AH	X500	Homestead air force base
A. Demographic					
1. Owner occupied					
Proportion—White	−0.28	−0.01	0.01	0.05	−0.18
	(−0.78)	(−0.86)	(0.50)	(2.37)	(−1.76)
Proportion—Black	−0.00	0.01	−0.01	−0.03	0.18
	(−0.02)	(1.10)	(−0.65)	(−1.94)	(2.02)
Proportion—Hispanic	0.22	0.04	0.06	0.02	0.01
	(6.29)	(3.29)	(2.65)	(1.02)	(0.08)
2. Renter					
Proportion—Ehite	−0.12	−0.03	0.02	0.02	−0.04
	(−2.81)	(−2.00)	(0.77)	(0.93)	(−0.43)
Proportion—Black	0.13	0.02	0.02	−0.00	−0.04
	(3.47)	(2.09)	(0.88)	(−0.14)	(−0.47)
Proportion—Hispanic	0.20	0.03	0.04	0.01	0.23
	(4.01)	(2.20)	(1.27)	(0.50)	(2.12)
3. Income					
Proportion Income < 15 K	0.10	−0.02	0.06	0.06	−0.03
	(3.39)	(−1.58)	(2.88)	(3.37)	(−0.34)
Proportion 15 K < Income < 25 K	0.05	0.00	−0.03	−0.03	−0.01
	(1.95)	(0.32)	(−1.69)	(−2.19)	(−0.16)
Proportion 25 K < Income < 40 K	−0.02	0.01	−0.02	−0.01	−0.01
	(−0.58)	(0.91)	(−1.01)	(−0.82)	(−0.15)
Proportion 40 K < Income < 60 K	−0.17	−0.00	−0.04	−0.02	0.04
	(−6.52)	(−0.46)	(−2.37)	(−1.32)	(0.55)
Proportion 60 K < Income < 150 K	0.02	−0.00	0.03	0.00	0.05
	(1.71)	(−0.26)	(1.84)	(0.29)	(0.60)
Proportion Income > 150 K	0.01	0.01	−0.00	0.00	−0.03
	(0.64)	(2.21)	(−0.55)	(0.03)	(−0.78)

[a]The numbers in the table are the slope coefficients for the damage measure in a model with the change in the proportion of households in each category between 1990 and 2000 as the dependent variable. The numbers in parentheses are t-ratios for the null hypothesis of no association.

are based on the full sample of block groups. AE is classified the highest risk category for coastal flooding, AH next highest, and X500 minimal risk. Homestead is a dummy variable to indicate whether the block group bordered the Homestead Air Force Base (=1 and 0 otherwise). As we noted earlier, this facility was closed after being completely destroyed by the hurricane. We might expect that there is the potential for two influences to be reflected in this variable. The first is associated with initial land uses around the base and the second with the scale of the effects of damage along with the base closing to depress land values and reduce economic activity.

White renters tend to avoid block groups with the highest risk (AE). Hispanic owners and renters and black renters seem to disproportionately increase in block groups with the highest risk. The results for income groups are not as clear-cut as they are for the demographic categories. Low income groups decrease in the block groups with the largest fraction of their area in the high risk FEMA category (AE) and increase in the AH category. The proportion of middle income groups is for the most part unrelated to risk measures. There is some evidence of a shift toward risky areas with income in that the coefficient for AH shifts from negatively related to the low risk, to positive with increases in income from the 40 to 60 class to the 60 to 150 group. The most intriguing of the estimates is associated with the over 150 K group increasing with the area of the block group in the high risk category. This seemingly counter-intuitive result likely reflects the higher amenity levels associated with these same locations and the ability of this group to self protect and insure against the risks posed in these areas.[11]

Overall, these results confirm the importance of accounting for households' heterogeneity in understanding their adjustments to disasters. As expected, ability to pay appears to be important to understanding why we observe differences in demographic groups' responses to damage caused by natural disasters. Ethnic attachment to neighborhoods, as hypothesized in social interaction models and as proxied in our analysis by the 1990 proportion of each demographic group, does not overturn the results. Hispanic owners respond to damage while white and black homeowners do not. For Hispanic groups, both owners and renters are more likely to move into damaged areas. In their case treating home ownership as a proxy for ability to pay would not allow us to reconcile these findings with what was estimated for other groups.

There appears to be an especially interesting story in the changes in the income distributions. Lower income groups increase in damaged areas and the proportion of middle income groups decreases, suggesting there is adjustment to both damage and potentially the perception of increased risk. The lower income groups may be taking advantage of lower rents. Thus, this finding contrasts with Breen and Gupta's (1997) results suggesting little change in demographics in response to decisions to use new areas for facilities with increased environmental risk.[12]

Our analysis suggests higher income groups do not adjust to the damage caused by disasters and, if anything, tend to move to coastal locations with higher risks of flooding damage. Had we used the change in the median income between the two Censuses, our conclusion would have been much different. It would have suggested the size of the area in high risk zones was negative and significant influence. Equation (2) provides these estimates (with t ratios

[11] Public policy may also subsidize some of this self-protection.

[12] Breen and Gupta (1997) and Banzhaf and Walsh (2004) find comparable results for Hispanic populations' responses to other sources of environmental risks.

in parentheses).[13]

$$\ln(\tilde{m}_{t+10}) - \ln(\tilde{m}_t) = \underset{(13.14)}{0.298} \underset{(-1.60)}{-0.19} \cdot \text{NOAA Damage}$$
$$- \underset{(-2.95)}{0.11}\ \text{AE} \underset{(-0.29)}{-0.02}\ \text{AH}$$
$$- \underset{(-1.58)}{0.10}\ \times 500 \qquad (2)$$

$n = 1022$, $R^2 = 0.01$.

The significant negative coefficient for the proportion of the block group in the AE zone would cause one to overlook the differences in these FEMA zones roles for different income groups. For the highest income groups, the amenity effect dominates the risk effect and the proportion of these households *increased* in areas with higher risk.

3.2 A quasi-experimental analysis of market responses to damage and risk information

Substantial changes in the housing stock or in spatially delineated amenities or disamenities should be signaled through markets. These effects are, after all, the economist's stock and trade. They are the basis for the quasi-experiments referred to earlier. In some respects our research to this point provides motivation for an analysis of housing prices and rents. Our estimates suggest the event—hurricane Andrew—did cause adjustment. Households, whether classified by demographics or income, responded. Now we ask whether Census measures of housing values and rents provide consistent signals of these adjustments.

Tables 5 and 6 report our estimates. In Table 5, we estimate the change in the log of the median housing values for 2000 compared to 1990 and the change in the log of the median rents. In each case we evaluate models with controls for changes in the composition of the "average" units along with the damage measure and proportion of the block group in each FEMA flood risk zone. Because the models consider the proportionate change (i.e. differences in the log of the median values) for the housing values and rents, we hypothesize that these variables capture the change in perceptions of the risk (for the FEMA variables) as a result of Andrew and the net effect of changed quality perceptions and damage related changes to the composition of housing markets for the Miami Herald variable.

The estimated coefficients for the damage measure are insignificant in all models—implying the market effects of the compositional changes we observed from demographic measures are not capable of being recovered with these regressions using proportionate changes in medians. The FEMA flood risk measures are consistent with our hypothesis that they reflect the effects of changed risk perceptions for these areas due to Andrew. The proportions of the Census block group in both the highest risk (AE) and the next highest risk (AH) zones have significant negative effects on the proportionate change in median values of owner occupied housing. While the individual coefficients are not significantly different, if we weight the coefficients by the average share of block groups in each zone (0.30 for AE and 0.05 for AH) there is a significant difference with a *p*-value for the test of 0.057. Moreover, it is consistent with the higher risk area having a larger effect on median property

[13] $\tilde{m}_t$ designates median income in $t = 1990$ and $t + 10 = 2000$; NOAA Damage is the average proportion uninhabitable; AE, AH, and X500 are the proportion of area in each block group in the specific flood zone designation.

Table 5 The log of the change in median housing value and rent: census-based estimates of Andrew's effects on median housing values and rents, 1900–2000[a]

	Home owner values		Rents	
Independent variable	(1)	(2)[b]	(3)	(4)[c]
NOAA/Miami Herald damage	−0.014	−0.014	0.071	0.058
	(−0.12)	(−0.12)	(0.58)	(0.49)
Proportion of block group in AE zone	−0.110	−0.111	−0.085	−0.108
	(−2.61)	(−2.62)	(−2.15)	(−3.21)
Proportion of block group in AH zone	−0.175	−0.178	0.074	0.020
	(−2.22)	(−2.26)	(0.95)	(0.29)
Proportion of block group in X500 zone	0.044	0.052	−0.076	−0.006
	(0.64)	(0.75)	(−1.15)	(−0.10)
Constant	0.349	0.342	0.237	0.260
	(14.43)	(13.78)	(10.30)	(13.07)
Other controls for attributes	No	Yes	No	Yes
No. of observations	945	945	977	803
R^2	0.012	0.017	0.008	0.041

[a]The numbers in parentheses are t-ratios for the null hypothesis of no association.
[b]The controls for the homeowners' equation include the change in the proportion of owner occupied homes with 5 rooms or less, the change in the proportion of one family homes, the change in the proportion of owner occupied mobile homes, the change in the proportion of homes with 2 or more bedrooms, and the change in the proportion of homes with complete kitchens.
[c]The controls for the rental equation include the change in the proportion of rental mobile homes and the change in the proportion of rental units with 2 or more bedrooms.

values. In the case of rents, the information only appears to have an effect in reducing rents for the high risk areas.

Table 6 describes how the effects of damage and areas in risk zones influence changes in the proportion of the homes in each home value interval and in each rent category. These groupings offer another strategy to control for all the housing attributes that could have been included in the models in Table 5 using medians. The distributional approach may well offer a better control because of the likely narrower difference in attributes across the housing units in each cell.

These results isolate the increase in the proportions in the low home value and low rent categories with damage, as we discussed in the case of the simple models presented earlier, though the significance of these effects is somewhat lower. The high risk FEMA zones tend to reduce the number of homes in the middle value group and increase those in the lowest housing value group. Interestingly, as our simpler models and analysis of changes in income distributions seem to imply, there is an increase in the proportion of homes in the 400,000 to 500,000 home value group. The change in the composition of the distribution from middle values to the lowest value category seems to dominate the effect at the highest end of the distribution in yielding our results with an overall negative effect for the risk measures with models based on changes in the medians. When we use the regressions for medians together with the average share of the block groups in each FEMA risk category, the estimates imply about a three percent reduction in median values due to the storm's information for the high risk (AE) areas and about one percent for the medium risk (AH) areas.

To the extent our hurricane example is representative, the analysis of changes in medians based on spatial areas would best be interpreted as tests of the effect of changes in an amenity (or disamenity) rather than as estimates of the magnitude of its incremental value. As our

Table 6 Census based estimates of Andrew's effect on distribution of housing values and rents[a]

	NOAA/Miami Herald damage	FEMA flood zones		
		Zone AE	Zone AH	Zone X500
Homeowner Values				
Proportion HV < 40 K	−0.04	0.06	0.04	0.02
	(−0.80)	(3.78)	(1.24)	(0.91)
Proportion 40 K < HV < 100 K	0.18	−0.01	0.00	−0.08
	(1.89)	(−0.40)	(0.06)	(−1.49)
Proportion 100 K < HV < 250 K	−0.13	−0.06	−0.07	0.07
	(−1.59)	(−2.02)	(−1.32)	(1.52)
Proportion 250 K < HV < 400 K	−0.00	−0.01	0.02	−0.01
	(−0.11)	(−0.60)	(0.99)	(−0.90)
Proportion 400 K < HV < 500 K	0.00	0.01	0.01	−0.00
	(0.03)	(2.52)	(0.72)	(−0.54)
Proportion HV > 500 K	−0.00	0.00	0.01	0.00
	(−0.23)	(0.82)	(0.59)	(0.05)
Rents				
Proportion Rent < 250	−0.05	0.00	0.02	0.05
	(−1.54)	(0.29)	(0.80)	(2.71)
Proportion 250 < Rent < 500	0.31	−0.08	0.02	0.00
	(4.74)	(−4.05)	(0.42)	(0.11)
Proportion 500 < Rent < 750	−0.21	0.06	−0.10	−0.04
	(−2.60)	(2.58)	(−2.01)	(−0.94)
Proportion 750 < Rent < 1000	−0.11	0.00	−0.01	0.02
	(−1.79)	(0.19)	(−0.18)	(0.60)
Proportion Rent > 1000	0.06	0.01	0.07	−0.04
	(1.16)	(0.66)	(2.01)	(−1.22)

[a]The numbers in parentheses are *t*-ratios for the null hypothesis of no association.

distributional analysis suggests, there are simply too many changes in the composition of the homes (or rental units) that can be taking place. This is especially true for a large scale event. With a smaller event the discrepancies may be smaller, but the ability to detect them reliably may also be diminished.

4 Implications

This analysis has implications for two areas. The first involves insights into who adjusts to large scale disasters. Most of the differences in adjustment across groups differing in educational and racial background are likely to be due to their economic capacity to undertake changes in their residential locations. The pattern no doubt reflects differences in these groups' available income and wealth. Whites may have access to greater resources to permit their adaptation than Hispanics or black households who don't own their homes.

Several authors' concerns about the confounding effects of household heterogeneity for the composition of communities after exogenous changes in amenities are confirmed with the large scale damage associated with Andrew. Our analysis of the distributions of income, housing values, and rents indicate that the underlying shifts in these distributions can yield ambiguous results for the medians. Nonetheless, the pattern of change in each of these distributions is consistent with the low income groups being least able to adjust to natural disasters. It seems reasonable to conclude that this lack of responsiveness is due largely to economic capacity and not ethnic influences. Indeed, the hypothesis that the social interaction effect associated with attachment to neighborhoods with "like" groups was only supported for the highest income households. All other groups' patterns of adjustment implied movement away from areas with a large fraction of "their group" in 1990.

Second, our analysis of Census based estimates of market capitalization of the signals provided by hurricane Andrew's risk information confirms, in qualitative terms, that Andrew appears to have caused a reconsideration of the risk designation implied by FEMA's flood hazard areas. This finding is also confirmed by a micro level repeat sales analysis of the hurricane's effect that we report in separate research (see Carbone et al., 2006). A comparison of these two efforts suggests what our analysis of the distribution of homes by home value implies. The composition of impacts of large scale exogenous events on housing markets is an important part of "the story." Analysis of medians or means may offer a credible gauge of relative impact of these exogenous events but it is unlikely to be a reliable basis for estimates of the marginal values of response elasticities.

The contrast between the potential interpretations for the variables we used to control for the damage and risk information associated with the storm also highlights the challenges in using summary statistics to implement a quasi-experimental design. Sorting models imply that heterogeneity in preferences and unobservable features of constraints can have large effects on the adjustments households can make in response to large, exogenous shocks. These differences are likely to show up as changes in the distribution of housing values that may not be easily detected with measures of changes in the central tendency.

Our findings of consistent qualitative results between our analyses of the micro-level repeat sales outcomes and the changes between the 1990 and 2000 Census medians may reflect the long term nature of the change in perceptions of the hazards of coastal locations. The changes in the distributions of housing values suggest that the highest income groups appear to be self protecting and insuring. For the other groups the results suggest that their actions depend on whether they have the economic capacity to adjust their locations.

It is difficult to draw transferable lessons from *one* analysis of adjustment to a large scale disaster for other disastrous events, both natural and manmade. It is clear that economic circumstances of households seem to be the most important factor in understanding responses. Perhaps the primary lesson is that there is a great deal that can be recovered from *ex post* studies of asset prices. A better mapping of the spatial effects of the disasters to residential and other sales prices together with more explicit treatment of neighborhood features offers a research strategy with considerable potential. It will require more detailed and immediate record keeping after disasters. Our analysis was possible because there was a controversy after Andrew over the performance of Dade County's building inspectors. This public outrage lead to a special study of the features of damaged areas and the records that permit our study. More systematic record-keeping creates opportunities to learn how to improve the public role in *ex post* adjustment. This lesson is directly relevant to the challenges facing the Gulf Coast recovery from Hurricane Katrina. Ideally, *ex post* palliative spending will be accompanied with record keeping that tracks the temporal and spatial dimensions of public support so it is possible to judge in 2010 what worked and what did not.

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