Do Migration Systems Predict Post-Disaster Migration Patterns?: The Case of the Gulf of Mexico Coastal Counties Before and After Hurricanes Katrina and Rita

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Only recently has research on the effects of climate change on human migration shifted from highly speculative estimates of the number of "climate refugees" to more theoretically-informed and empirically-based estimates of the numbers of environmental migrants and their likely destinations (Findlay 2011; Gemenne 2011). Findlay (2011: S51-S52) extracts several general principles for how environmentally-driven migration occurs based on a small but growing empirical literature on this subject. The first principle is that most potential migrants prefer not to move. However, once a decision to move has been made, the second principle states that migrants will move relatively short distances. Finally, to summarize the third through sixth principles, migrants prefer to go to places where they already have ties that allow them to more easily and profitably exchange their human, social and cultural capital. For most migrants, these places lie within their own nations' boundaries, although a few more advantaged migrants follow their historical, cultural or economic ties to foreign countries. These general principles dampen alarmist concerns that climate change will produce large numbers of poor migrants from the global South to the global North, while also providing a set of testable hypotheses to guide empirical research. However, these principles do not extend beyond the initial migratory reaction to an environmental change.

Most models of environmental and climate-driven migration focus on how macro-level drivers of migration affect households' migration decisions (e.g., Black, Adger, Arnell, Dercon, Geddes, and Thomas 2011; Perch-Nielsen, Bättig, Imboden 2008). To assess how climate change affects human settlements over time, the unit of analysis must shift from the household to the affected place and the time frame must extend to years after the event. McLeman and Smit (2006) do this by drawing from the case of the 1930s Dustbowl Migration out of Oklahoma to describe several types of migration that affected the population size of Oklahoma counties in subsequent years. In this case, the out-migration of the Dustbowl refugees to rural California, mostly displaced tenant farmers, is best known. Less noted is the in-migration of return migrants and rural migrants to nearby cities and towns in Oklahoma. Thus, in McLeman and Smit's (2006) conceptual model the final outcome is the size and composition of the climate-change affected counties, which is modified by not only selective out-migration, but also return migration of previously departed residents and new in-migration.

Working from a model that incorporates post-event return migration and new in-migration, the principles of environmental migration outlined above can be applied to changes in the flows of migrants within the migration system after an environmental shock. Culling evidence from four cases of "climate migration", McLeman and Hunter (2010) conclude that such migration usually occurs within a region or locality, agreeing with the second principle of environmental migration. In accord with the third through sixth principles, they also emphasize the push and pull factors and social networks that channel migrants to specific destinations. They expand on those principles by generalizing that such migration is rarely permanent; barring a permanent environmental change that destroys housing and livelihoods, few places are completely abandoned (see also McLeman 2011).

This conceptual model also corresponds with the accumulating empirical evidence on migratory flows in the Gulf of Mexico counties affected by the 2005 hurricane season. The majority of residents in the most threatened coastal counties evacuated in anticipation of Hurricane Katrina's landfall (Groen and Polivka 2010). Return migration certainly explains how several of the most devastated counties which lost more than half their population became some of the fastest growing counties in the United States from 2006 through 2010 (U.S. Census 2008; Census 2011). Return migration was selective, depending on damage to homes and communities, as well as displaced residents' capital endowments (Fussell, Sastry, and VanLandingham 2010; Groen and Polivka 2010; Myers, Slack, and Singelmann 2008). Migratory in-flows included newcomers as well, such as "hurricane chasers" seeking construction employment, young professionals pursuing education, housing, health care, urban development, and entrepreneurial opportunities in the recovering region, and energy sector workers repairing the damaged industrial infrastructure (Ehrenfrucht and Nelson 2013; Fussell 2009).

In our study, we take these migrant flows between places as the unit of analysis to understand how the migration systems of the Hurricane Katrina and Rita-affected coastline counties in the Gulf of Mexico changed. We test several hypotheses which, if supported, would extend the principles of environmental migration and contribute to our knowledge of how extreme coastal weather events, which are expected to be more frequent with climate change (IPCC 2007), will affect coastal populations.

A MIGRATION SYSTEMS PERSPECTIVE

Scholars concerned with global climate change have looked at studies of the effect of Hurricane Katrina on New Orleans as an example of what could happen to coastal cities struck by hurricanes and coastal flooding (e.g., Adamo 2010). Most research on the demographic effects of Hurricane Katrina on New Orleans has focused on the unequal vulnerability of residents to displacement by race, income, and other socio-demographic and place-based characteristics (Cutter and Emrich 2006; Elliott, Haney, and Sams-Abiodun 2010; Fussell, VanLandingham and Sastry 2010; Groen and Polivka 2010; Myers, Slack, and Singelmann 2008). But none, to our knowledge, has considered how the disaster impacted the broader migration system of the disaster-affected coastline counties over the more prolonged recovery period. Considering such effects is important to understand large-scale and possibly long-run impacts of environmental events on human populations, most vitally whether environmental events affect existing patterns of migration.

We bring a systems perspective to this question, a perspective that, while not unfamiliar to demographers, is not the dominant approach to migration research. Within this perspective, dating to Ravenstein's study of migrant streams and counter-streams in the 19th century United Kingdom, the entire migration system is the object of study as opposed to the individual migrants, or their places of origin or destination (Ravenstein 1885; Lee 1966; Fawcett 1989). The central proposition is that when one place within the system experiences a change, such as an environmental event, the effects of that change are felt throughout the entire system (Mabogunje 1970; Andrienko and Guriev 2004). A key element of the migration system is the ties connecting places, which are the basis for measuring the magnitude and attributes of the flows of migrants between them. Theses ties, or flows, and their attributes and relationships, interact to perpetuate and reinforce the system by encouraging migration along certain pathways and discouraging it along others (Mabougunje 1970:12; see also McHugh 1987; Kritz et al. 1992). Although stability in the system over time and across space is emphasized in work adopting a systems perspective (DeWaard et al. 2012; Massey et al. 1998), some scholars focus at least conceptually on factors operating to alter the system elements and, it follows, the migration system (Bakewell 2012; de Haas 2010; Fawcett 1989).

We investigate three elements of the migration system of the disaster-affected coastline counties to assess three corresponding hypotheses. First, the central focus of the current study is whether the migration system remains stable or changes in the face of an external, environmental event. Stability in the system would result if members of the disaster-affected populations relocated to places with existing connections, perhaps relatives and friends who had moved in the pre-disaster period, most of whom would return to their pre-disaster counties in the recovery period. However, we might also expect some change in the system given the large-scale and involuntary nature of population displacement from the disaster-affected coastline counties. Some members of the disaster-affected populations might have relocated to counties that were not part of the pre-disaster migration system, thereby introducing new ties to the recovery migration system. New ties may also be introduced if people from counties outside the pre-disaster migration system relocate to the disaster-affected coastline counties in search of work or other recovery-led opportunities. We examine the extent of stability and change in the migration system through an analysis of ties between specific county pairs that are unique to the pre-disaster and recovery periods: the smaller the number of unique ties, the more similar the migration system between the two periods.

Second, we further examine stability and change in the migration system by analyzing the magnitude of in-flows among all ties within the pre-disaster and recovery periods. Both environmental and disaster-driven migrations are shaped by the nature of the environmental change in the origin community. Since hurricanes are rapid on-set, short-duration events and, in this case, resources were available for recovery, we expect that displaced residents will return as the recovery progresses and new in-migrants will arrive to pursue emerging opportunities. If the recovery is promising, then we would expect to see larger migration flows to the disaster-affected coastline counties in the recovery period than in the pre-disaster period. However, if the recovery is faltering, there would be smaller flows of displaced residents and opportunity seekers into these counties.

Third, extending the analysis of the magnitude of in-flows, we examine change in the size of the in-migration flows to the disaster-affected coastline counties from nearby and urban counties between the pre-disaster and recovery periods. The principles of environmental migration propose that disaster-affected migrants' destinations will mostly be nearby counties and urban counties since these are the kinds of places where migrants will be best able to use their existing human, social, and cultural capital. As displaced residents of the disaster-affected coastline counties return from these places in the recovery period, we expect the size of these flows to be larger than they were in the pre-disaster period.

DATA

We define three geographic regions radiating out from the disaster-affected coastline counties. The first region is comprised of the (1) disaster-affected coastline counties, followed by (2) all other Gulf of Mexico coastal counties, and finally (3) all other counties in the continental U.S. We also identify urban counties within each of these regions, since our third hypothesis relates to urban counties. In differentiating coastline and coastal counties we are following the model of the U.S. Census report on coastline population trends between 1960 and 2008 (Wilson and Fischetti 2010). In this report counties adjacent to coastal waters or territorial seas are labeled coastline counties and are a subset of all coastal counties. Coastal counties are defined by the National Oceanic and Atmospheric Administration (NOAA n.d.) as counties with at least 15% of its land within the nation's coastal watershed or a coastal cataloging unit. In the remainder of the paper we refer to these three types of places as disaster-affected coastline counties, Gulf of Mexico coastal counties, and other counties.

We focus on coastline counties because hurricanes are most destructive when they make landfall. Hurricanes destroy human settlements through strong winds and rain as well as the storm surge that pushes large amounts of water onto land and up rivers. There are 36 coastline counties that were declared federal disaster areas by the Federal Emergency Management Agency (FEMA) after Hurricane Katrina (August 29, 2005) and Hurricane Rita (September 24, 2005). There are 124 other Gulf of Mexico coastal counties and 2,951 other counties. Slightly less than half (1,297) of the other counties are urban.

Our study concerns the connections between places rather than the places themselves. Consequently, we examine the ties between counties and the size of migrant flows across these ties. Following Rogers' (1990) call, we focus on in-flows and out-flows, rather than net flows, because the meaning of the flow depends on its directionality. In our case, in-flows to all types of counties from the disaster-affected coastline counties describe the out-migration dimension of the system and identify where disaster-affected residents had social networks or other forms of support that might have helped them to evacuate and possibly relocate. In contrast, the in-migration dimension of the system is described by in-flows to the disaster-affected coastline counties from all types of counties. Based on existing research (Fussell, Sastry, and Vanlandingham 2010; Sastry and Gregory 2012), we assume that most migrants are returning to their pre-disaster homes and counties, although we cannot confirm this with our annual migration data. Other migrants may be attracted to the disaster-affected coastline counties because of new opportunities related to the recovery (Fussell 2009). If our assumption that these flows are largely composed of return migrants is sound, the out-migration flows from other counties to the disaster-affected coastline counties allow us to test our hypotheses about environmental migration by investigating the size of flows and number of ties.

We measure migration flows and their attributes with the Internal Revenue Service (IRS) Statistics of Income Division (SOI) County-to-County Migration Data files. The data is prepared by the Bureau of the Census in cooperation with the IRS to assess county-to-county migration flows, although it lacks any information about the movers other than their household income and crude age. The data includes all U.S. federal income tax-payers. Therefore, it underrepresents the poor and the elderly, who are less likely to file income tax or be included as dependents on others' tax returns, as well as the small percentage of tax returns filed after late September of the filing year (Gross n.d.). The lack of socio-demographic information and biases in representation make the data inappropriate for research on the causes or correlates of individual migration, however, they are useful for estimating inter-county migration flows (e.g., Manson and Groop 2000). These data are ideal for our study because they capture annual migration flows that pre-date and follow the 2005 hurricane season.

After Hurricanes Katrina and Rita struck in 2005, many taxpayers filed elsewhere, filed late, or failed to file at all. Johnson, Bland, and Coleman (2008) found a general decline in match rates between the tax filing years 2004-2005 and 2005-2006. The decline was greatest in the areas affected by Hurricane Katrina and Hurricane Rita. Given data problems in those years, we focus on the recovery period and use tax filing years 1999-2004 to model our pre-2005 hurricane season migration system and tax filing years 2007-09 to model our post-2005 recovery migration system.

METHODS

Researchers have used several data sources to measure the mobility of the hurricane-affected population in the subsequent year. The American Community Survey Gulf Coast Area Special Products includes households in the 117 counties and parishes in Alabama, Louisiana, Mississippi, and Texas designated by FEMA as receiving individual and public assistance as of October 7, 2005 for Hurricane Katrina and October 20, 2005 for Hurricane Rita. It does not include people living in group quarters or temporary housing. Using this data, Koerber (2006: Table 3) found that mobility in the hardest hit urban areas was high: 45.9%, 33.9% and 23.7% of residents had changed residences in the urban areas of New Orleans, Gulfport-Biloxi, and Beaumont-Port Arthur in the September-December 2005 period, whereas in the January to August 2005 period the comparable figures were 14.5%, 16.4%, and 16.7%. Using flow data from the IRS, Johnson, Bland, and Coleman (2008) identified the metropolitan statistical areas of Houston, Dallas, and Atlanta, Baton Rouge and New Orleans itself as the areas concentrating movers originating in the New Orleans metropolitan statistical area. These studies capture the short-term mobility of household residents after Hurricane Katrina and reveal the destinations of the displaced. But these descriptive, short-term analyses do not show how the migration system was affected by the hurricanes.

Our methodological approach improves on these analyses by examining county-to-county flows for two periods, the pre-disaster period (1999-2004) and the recovery period (2007-2009), to move beyond description and to test hypotheses concerning migration patterns in a natural experiment framework. As such, we address two current problems in research on population-environment interactions. First, we are able to examine change over time instead of inferring it from cross-sectional data. Second, we use smaller geographic units than many studies examining local-level responses to environmental change (e.g., Grübler et al 2007; Lutz et al 2007). By using all counties in the 48 contiguous U.S. we more completely represent the migration system.[1] Our analysis builds on Curtis and Schneider's (2011) approach that spatially and temporally links environmental projections and small-area population projections to provide more sensitive estimates of local migratory responses to hurricanes and coastal flooding.

Modeling Migration Systems

We use the IRS data to develop a series of maps of changes in the Gulf of Mexico migration system which took place between the pre-disaster (1999-2004) and recovery (2007-2009) periods. Like any demographic process, characterizing these changes requires modeling migration systems in such a way so as to simultaneously consider the population of persons "at risk" of migrating in each and every sending county. It also requires developing these portraits from the vantage points of both sending and receiving counties.

We begin by summarizing migration patterns from disaster-affected coastline counties to each county in the contiguous U.S. using a multiregional transition model (Rogers 1975, 1995; see also DeWaard in press). For each receiving county *j*, we assemble a diagonal matrix, $\mathrm{l}(0)$, composed of a hypothetical population of persons at risk of migrating to *j*.

$$\mathrm{l}(0) = \begin{bmatrix} \mathrm{l}_1 & 0 & \dots & 0 & 0 \\ 0 & \mathrm{l}_2 & \dots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & \mathrm{l}_k & 0 \\ 0 & 0 & \dots & 0 & \mathrm{l}_j \end{bmatrix} \qquad \text{Eq. (1)}$$

[1] A consideration in any study of spatial units over time is the consistency or stability of the unit itself. However, there have been no changes in boundary lines for the focal counties in this analysis.

where l_i (i=1,2,…,k) represents the size of the population in each sending county at risk of migrating to receiving county j. Per demographic convention, the starting population size in each disaster affected coastal sending county is arbitrarily set to 1,000 (Palloni 2001), and zero for all other counties. Since we are ultimately interested in migration to receiving county j, we then fix l_j in (1) such that l_j=0.

Using the information on county-to-county flows in the IRS data for the pre-disaster and post-disaster periods, we then assemble two matrices of county-to-county migration probabilities, Q.

$$\mathbf{Q} = \begin{bmatrix} q_{1,1} & q_{1,2} & \cdots & q_{1,k} & q_{1,j} \\ q_{2,1} & q_{2,2} & \cdots & q_{2,k} & q_{2,j} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ q_{k,1} & q_{k,2} & \cdots & q_{k,k} & q_{k,j} \\ q_{j,1} & q_{j,2} & \cdots & q_{j,k} & q_{j,j} \end{bmatrix} \qquad \text{Eq. (2)}$$

The dimensions of these matrices are 3,111 by 3,111, totaling 9,678,321 potential migration flows among each and every county in the contiguous U.S., including where i=j (i.e., non-migrants). Each row is a probability vector whose elements sum to 1.0. Accordingly, the population dynamics governing migration between each pair of counties can be written as:

$$\mathbf{l}(\mathbf{1}) = \mathbf{l}(\mathbf{0})\mathbf{Q} \qquad \text{Eq. (3)}$$

The sum of the last column vector in (3) is a count of the number of persons from our starting hypothetical population in (1) who, in fact, migrated to receiving county j. When this quantity is divided through by the size of the hypothetical population at risk of migrating to j, i.e., the trace of the matrix in (1), this gives the proportion of persons at-risk of migrating to j who actually did so, i.e., as governed by the probabilities in (2). Subtracting this quantity for the pre-disaster period from that for the recovery period, we arrive at an estimate of how the system of migration flows to from disaster-affected coastline counties to receiving county *j* changed over time. We then repeat these steps for each receiving county *j*, one at a time, and map the combined results.

In addition to modeling migration from disaster-affected coastline counties, we likewise consider migration to disaster-affected coastline counties from the vantage points of both sending and receiving counties. To model migration to disaster-affected coastline counties from the vantage point of each sending county in the contiguous U.S., for each row in (2), we sum those elements where receiving county *j* is a disaster affected coastline county. We then subtract this quantity for the pre-disaster period from that for the recovery period, and subsequently map these results to show how migration to disaster-affected coastline counties changed over time. To model migration to disaster-affected coastline counties from the viewpoint of receiving counties requires estimating the model in (1)-(3) for each disaster-affected coastline receiving county *j*, one at a time, with matrix in (1) re-specified so that the starting population in each U.S. county is set to 1,000, excluding l_j (i.e., $l_j = 0$). For each disaster-affected coastline receiving county *j*, the sum of the last column vector in (3) gives an estimate of the number of persons from our hypothetical population in (1) who, in fact, migrated to disaster-affected coastline receiving county *j*. We then compare the resulting figure for the pre-disaster period to the corresponding figure for the recovery period. As before, we then repeat the above steps for each disaster-affected coastline receiving county *j*, one at a time, and map the combined results.

Formal Hypothesis Tests

An advantage of our data is that they offer a unique natural experiment. We seek to determine if the change in the number of ties and the size of migration flows in the disaster-affected coastline counties' migration system between the pre-disaster and recovery periods is in the predicted direction and if the change is statistically significant. Natural experiments offer counterfactuals that can be used to distinguish a secular time trend from changes due to the treatment of interest (e.g., exposure to

Hurricanes Katrina and Rita). This requires simultaneously examining the experiences of a control group. In our study, we define the control group as the Gulf of Mexico coastal counties other than the disaster-affected coastline counties and the experimental group as the disaster-affected coastline counties.

For our hypothesis concerning change in ties, we assess whether the number of all ties and the number of unique ties differ between the pre-disaster and recovery periods. We compare the number and the unique composition of ties by testing if the change in the proportion of all possible ties observed in the pre-disaster period is significantly different from the proportion of all possible ties observed in the post-disaster period, where the number of all possible ties corresponds with the number of sending counties multiplied by the number of receiving counties in the specific group (less one since a county cannot be “tied” to itself). For example, for flows between disaster-affected coastline counties, there are 1,260 (36 x 35) possible ties; whereas for flows to disaster-affected coastline counties from Gulf of Mexico coastal counties, there are 4,464 (36 x 124) possible ties. We conduct this analysis for ties specific to in-flows and out-flows using a two-sample difference in proportion test.

For each hypothesis relating to the size of migration flows, our outcome of interest is the percent change in the size of migration flows to disaster-affected coastline counties (experimental group) or to Gulf of Mexico coastal counties (control group) between the pre-disaster and recovery periods. We test whether the mean of the experimental group is greater than the mean of the control group in a first difference regression framework, which controls for time-invariant factors known to shape the size of migration flows, e.g., geographic distance between the sending and receiving counties (Greenwood 1997; Zipf 1946). We also introduce controls for the population sizes of sending and receiving counties. The model (excluding population size controls) takes the following form:

$$\%\Delta Flow_{ijk} = \beta_0 + \beta_1 K + \varepsilon_{ijk} \qquad \text{Eq. (4)}$$

where $\%\Delta\mathrm{Flow}_{\mathrm{ijk}}$ is the percent change in the size of the migration flow from sending county *i* to receiving county *j* for receiving counties of type *k* ($k \in$ disaster-affected coastline county or Gulf of Mexico coastal county). Therefore, the coefficient, β_0, can be interpreted as the mean percent change for the control group, in our case the Gulf of Mexico coastal counties. The coefficient, β_1, plus the coefficient, β_0, can be interpreted as the mean percent change for the experimental group, the disaster-affected coastline counties. We examine growth in in-flows to these two destinations from different types of origin counties by varying the observations according to the type of source county.

RESULTS

Changes in the migration system of the disaster-affected coastline counties

Our first task is to identify which counties were connected to the disaster-affected coastline counties before Hurricanes Katrina and Rita so that we can describe the migration system and its changes in the recovery period. We define the migration system from the perspective of the disaster-affected counties as the ties through which migrants flow to or from those counties and the attributes of those ties, specifically their magnitude, the types of places they connect, and the aggregate characteristics of the migrants flowing through the tie. We measure stability and change in the ties and their attributes by comparing them in the pre-disaster period and the recovery period.

To determine whether there is stability in the migration system, our first hypothesis, we compare the number of unique ties of the disaster-affected coastline counties in the pre-disaster (1999-2004) and recovery (2007-2009) periods. If the system is perfectly stable, the number of common ties will be identical and, it follows, there will be no unique ties in either period. If the system is expanding there will be more unique ties in the recovery period than the pre-disaster period, and if it is contracting, there will be fewer. We find that the total number of out-flowing ties decreased by -13.6%, a significant drop between the two periods, although there was no significant change in the number of in-flowing ties (Table 1, Panel B). This change is due to the 57.8% decrease in unique out-flowing ties (Table 1, Panel A). Overall, this indicates that in the recovery period the migration system of the disaster-affected coastline counties contracted with respect to out-ties, whereas the number of in-ties remained the same.

[Insert Table 1 about here]

The spatial concentration of the migration system is better understood by distinguishing the ties by the types of counties they connect. The number of unique out-ties decreased for all types of counties, but this change was largest and statistically significant for other counties (-64.2%), followed by Gulf of Mexico coastal counties (-46.8%) (Table 1, Panel A, out-ties). The decrease in out-ties to other disaster-affected coastline counties was also large (-35.6%) but statistically insignificant. Although the in-migration side was also concentrating by eliminating in-ties among disaster-affected coastline counties (-34.8%) and, to a lesser extent, in-ties from other counties (-6.8%), these changes were not statistically significant (Table 1, Panel A, in-ties). The only growth of the migration system of the disaster-affected coastline counties was due to the 33.3% increase in in-ties from Gulf of Mexico coastal counties to the disaster-affected coastline counties. Although this change was not significant overall, when we narrow the sample to only urban origin counties, which make up the majority of ties in the migration system, the 41.8% growth in in-ties to urban Gulf of Mexico coastal counties is statistically significant. This pattern is consistent with the second principle of the environmental migration thesis — migrants move relatively short distances (Findlay 2011) — and the third principle of the environmental migration thesis – migrants prefer to go to places, often cities, where they already have ties (Findlay 2011). Therefore, the in-ties in the recovery period are more likely to originate in nearby and urban counties.

Changes in the size of in-migration flows to the disaster-affected coastline counties

Our second set of hypotheses concerns the size of the in-flows to the disaster-affected coastline counties in the recovery period. If the recovery is strong, we expect to see that these in-flows are larger in the recovery period than in the pre-disaster period, and that out-flows are smaller than in-flows. On the other hand, if the recovery is weak, we expect to see that the in-flows are smaller or no different in the recovery period than in the pre-disaster period, and that out-flows are larger than in-flows. The descriptive evidence shows that the total flow size into the disaster-affected coastline counties grew by 19.4% overall, and was larger than out-flows from these counties (144,854 versus 137,424) (Table 2). The in-flows from the Gulf of Mexico coastal counties increased the most, by 30.1%, although they were followed closely by in-flows from other counties, which grew by 25.9%. These increases are somewhat larger for in-flows from urban counties, which are 32.7% and 26.4%, respectively (Table 2, in-flows). In contrast, the out-flow size from the disaster-affected coastline counties increased relatively little, by 4.6%, with the largest flows going to other disaster-affected coastline counties (8.2%) or Gulf of Mexico coastal counties (9.2%) and flows to other counties actually diminishing (-1.3%) (Table 2, out-flows). Again, the patterns are similar for urban counties. These results are consistent with the hypothesis that there is higher in-migration to disaster-affected coastline counties in the recovery period than in the pre-disaster period. Furthermore, we see that the spatial concentration of the migration system, evident from the decrease in most types of ties, is accompanied by the intensification of flows, especially in-flows. Such churning of migrants is not indicative of a settlement abandonment process, instead it suggests that the out-migration immediately after the disaster was mostly temporary although these moves may have lasted several years.

[Insert Table 2 about here]

Changes in in-ties and in-flows to the disaster-affected coastline counties are summarized geographically in Figure 1, Panel A, which identifies the tied counties for which the number of migrants changed the most between the pre-disaster and recovery periods. Change estimates are produced by the multiregional migration model and reflect an increase or decrease in the number of migrants between periods. Counties highlighted in the darker shade of grey were among the top 5 percent of counties that increased the number of in-migrants to the disaster-affected coastline counties in the recovery period as compared to the pre-disaster period. Counties shaded in medium grey were the bottom 5 percent, which sent comparatively fewer migrants.[2] Consistent with the analysis of Table 1, which indicates a contraction of the migration system, there are very few dark grey counties outside of the Gulf of Mexico coastal counties. Only a handful of distant counties, largely in Florida, were among the top senders in the recovery period. Instead, the majority of tied counties outside the Gulf of Mexico coastal counties — such as the counties composing the metropolitan areas of Boston, Chicago, Denver, New York, and Washington DC — sent comparatively fewer migrants to disaster-affected coastline counties in the recovery period than in the pre-disaster period. Most of the top sending tied counties were Gulf of Mexico coastal counties or disaster-affected coastline counties. Among the more distant top sending counties, some had relatively small populations and include places with a strong energy industry (e.g., Sweetwater County, Wyoming, and La Plata County, Colorado), suggesting that in-flows from these sending counties might have been new migrants pursuing recovery employment in the Gulf Coast's damaged oil industry. These exceptions aside, the spatial concentration of top-sending counties

[2] Counties highlighted in light grey were in the middle of the range or had no tie to the disaster-affected coastline counties. In either case, there was no substantial change in the estimated migrant flows between the pre-disaster and recovery periods.

is what we would expect if pre-disaster residents of the disaster-affected coastline counties had relocated to nearby counties and were returning in the recovery period.

[Insert Figure 1 about here]

To gain a comprehensive sense of the migration system, the counties receiving the largest increases in out-flows from the disaster-affected coastline counties' migration system between the two periods are identified in Figure 1, Panel B. Counties highlighted in the darker shade of grey were among the top 5% of counties, receiving more in-migrants from the disaster-affected coastline counties in the recovery period as compared to the pre-disaster period. Counties shaded in medium grey received comparatively fewer migrants in the recovery period than before. In the recovery period, migration flows from the disaster-affected coastline counties to nearly all of the tied counties outside of the Gulf of Mexico coastal counties were lower than in the pre-disaster period (nearly all the counties outside the Gulf of Mexico coastal counties are either medium or light grey). Instead, flows from the disaster-affected coastline counties concentrated in the other disaster-affected coastline counties and the Gulf of Mexico coastal counties (most of these tied counties are dark grey). There are a few exceptions, however, with larger recovery period in-migration flows to counties composing the southern metropolitan areas including Miami, Nashville, Oklahoma City, and Shreveport, and a few more distant metropolitan areas such as Boston, Chicago, Denver, Philadelphia, San Diego, and Seattle, which all evidence larger in-flows from disaster-affected coastline counties in the recovery period. For the most part, however, we see the spatial concentration and intensification of the migration system of the disaster-affected coastline counties, as predicted, with only a few distant and mostly urban counties becoming important destinations in the recovery period.

The local spatial concentration is illustrated in Figure 2 which shows changes in the number of in-flows between the disaster-affected coastline counties only. In the recovery period, in-migration to the metropolitan disaster-affected counties grew, specifically to the counties forming the metropolitan areas of Corpus Christi, Houston, New Orleans Gulfport and the more rural Jefferson County, Texas, and Cameron and Vermilion parishes in Louisiana. In contrast, in-migration diminished to the more rural counties along the Texas and Louisiana coastline. Although there are fewer in-ties (Table 1, Panels A and B) and only very small increases in in-flows (Table 2) among disaster-affected coastline counties, this map makes evident that in-flows within the region were directed toward urban areas. This is notable because it suggests that within the region recovering from the disaster, residents concentrated in urban areas.

[Insert Figure 2 about here]

Results from the formal tests of our hypotheses through first difference regression provide more rigorous support for our contention that the migration system of the disaster-affected coastline counties became more geographically concentrated and that movement intensified in the recovery period (Table 3). The positive β_1 coefficients in all five models show the increase in in-flows to disaster-affected coastline counties between the pre-disaster and recovery periods is always statistically significantly greater than for the Gulf of Mexico coastal counties. Model 1 compares the size of growth in the in-flows to these two destinations from all counties, confirming the hypothesis that in-migration to the disaster-affected coastline counties increased in the recovery period. Models 2 through 4 show that the percentage change in in-migration flows to the disaster-affected coastline counties grew more in the recovery period than in-migration to the Gulf of Mexico coastal counties for all three types of origin counties. These models support the hypothesis that in-migration flows will be greater from nearby counties, because the size of the coefficients decrease as distance from the disaster-affected counties increases. Each of these models is duplicated with urban samples (i.e., flows restricted to urban sending counties), thus supporting the hypothesis that in-migration flows will be greater from urban counties (models 5-8). With the exception of the β_1 coefficient in model 6, which is somewhat smaller than its counterpart in model 2, the coefficients are larger in the urban samples than the combined urban and rural samples.

[Insert Table 3 about here]

To facilitate interpretation of our results, we present the percentage change in in-migration flows to the disaster-affected coastline counties and to other Gulf of Mexico coastal counties from each of the nested county groupings (Table 4). The largest percentage increase in in-migration flows to the disaster-affected coastline counties was from other disaster-affected coastline counties (8.3%), followed by Gulf of Mexico coastal counties (5.5%), then by all other counties (0.5%). This is consistent with the hypothesis that in-migration flows are inversely related to distance from the disaster-affected coastline counties. While the same pattern is found for Gulf of Mexico coastal counties, the percentage increases in in-migration flows to those counties are all considerably smaller (2.5%, 0.5%, and -0.6%, respectively). We also observe that in-migration flows to disaster-affected coastline counties from urban counties outside of the Gulf of Mexico coastal counties and the disaster-affected coastline counties were larger than in-migration flows from all other urban counties (1.0% versus 0.5%). Notably, this was not the case for in-migration flows to the Gulf of Mexico coastal counties, which decreased overall but more so for urban source counties (-1.3% versus -0.6%). These results are consistent with our expectations that nearby and urban counties disproportionately attract environmental migrants, and therefore will be the source of out-flows to the disaster-affected coastline counties in the recovery period. Furthermore, the increase in flow sizes in both directions between disaster-affected coastline counties and Gulf of Mexico coastal counties, especially urban counties, suggests that there is heightened mobility in general within these nearby counties.

[Insert Table 4 about here]

Our analysis has shown that the migration system of the disaster-affected coastline counties became more spatially concentrated in the recovery period by subtracting out-ties with all types of counties except other disaster-affected coastline counties. The system mostly added in-ties to Gulf of Mexico coastal counties. At the same time as the migration system contracted spatially, the size of in-flows to the disaster-affected coastline counties from all other types of counties grew. This intensification was particularly evident from nearby and urban counties, thus we also see increasing urbanization of the migration system. While these results were predicted by the principles of environmental migration, what it describes is a churning of migrants within and between the disaster-affected coastline counties and Gulf of Mexico coastal counties. This is evident from the increase in the size of in-flows and out-flows within the disaster-affected coastline counties. This suggests that increased mobility within the migration system may be another principle of environmental migration.

CONCLUSION

Coastal populations are expected to experience more intense and frequent coastal weather events and inundation resulting from climate change. Rooted in a concern for the human impacts of such environmental events, our study investigated the changes in migration systems resulting from Hurricanes Katrina (August 29, 2005) and Rita (September 24, 2005), two severe hurricanes which affected the Gulf of Mexico coast between Texas and Florida within weeks of each other. While hurricanes and other damaging environmental events are not rare for this region, Hurricane Katrina was the sixth most powerful and most costly hurricane thus far recorded (Knabb, Rhome, and Brown 2006) and Hurricane Rita ranked fourth most powerful, although it struck a less populated region of the coast and so damage estimates were not as high (Knabb, Brown, and Rhome 2006). We examine the effects of these events on migration systems to gain unique insights into the migratory consequences of extreme coastal storms.

Before summarizing the contributions of our research we consider its limitations. The IRS flow data only measures the mobility of taxpayers and their dependents, which excludes the very poor and the elderly. This bias may exaggerate mobility rates since these excluded groups tend to be less mobile than the employed and working age populations. Further, because so many taxpayers from the Katrina- and Rita-impacted region failed to file on time in 2005 and 2006, we are also limited to using the years immediately before the hurricanes (1999-2004) and in the recovery period (2007-2009). Since the migration system in the excluded years is likely to have involved higher levels of both in- and out-migration from the disaster-affected coastline counties, our focus on later years misses the immediate post-disaster recovery of population and instead focuses on the medium-term. Finally, although we have amplified the IRS flow data by adding measures of county geography and urbanity, refined geographic measures or measures from additional sources could be added to test these hypotheses. Despite these limitations we feel confident that our analysis describes the dominant changes in the migration system between the pre-disaster and recovery periods.

Starting from the general principles of environmental migration (Findlay 2011) we make methodological, theoretical, and substantive contributions to research on environmental causes of migration. Methodologically, instead of focusing on individual and household out-migration from the area affected by the environmental crisis, as most research on environmental migration does, we use flow data between counties to model the disasters' broad impact on the complete migration system of the most severely disaster-affected coastline counties. Moreover, by leveraging the unique natural experiment quality and the fine temporal and geographic scale offered by the IRS flow data, we are able to test confirmatory hypotheses about the human impacts of environmental events. Our findings inform the emergent literature on environmental migration by lengthening the time-frame and extending the geographic scope of our understanding of this mobility, moving the study of population-environment interactions into a new and fertile domain.

Theoretically, we build on the general principles of environmental migration (Findlay 2011). These principles propose that out-migration from areas experiencing environmental crises tends to be short-distance, intensifying existing connections between places in the migration system, especially in-migration to urban areas. Our contribution is to also consider what occurs after the environmental crisis has subsided and recovery is underway, thereby shifting the focus to in-migration, mostly of former residents but also newcomers. We extend the general principles of environmental migration by proposing that the predicted destinations of out-migrants immediately after the crisis will be the origins of the in-migrants to the crisis-affected areas in the recovery period and that these in-migration streams will be larger in the recovery period. Furthermore, we propose that the disaster-affected migration system will involve more mobility in the recovery period, characterized by larger in- and out-flows within the geographically concentrated system, particularly between urban counties. Furthermore, we add to the general principles of environmental migration an additional generalization: environmental migration tends to be of short duration, as evident from the high rates of migration, presumed to be composed mostly of former residents, to the disaster-affected coastline counties and the heightened mobility within those counties.

Substantively, we contribute to the growing body of research on climate migratory evidence that the pre-disaster migration system channeled the in-migration flows to the disaster-affected coastline counties in predictable ways (Curtis and Schneider 2011). We show that in the recovery period the migration system of the disaster-affected coastline counties became more spatially concentrated, including mostly the Gulf of Mexico coastal counties, especially urban counties, and a few urban counties outside of the Gulf of Mexico. At the same time, the size of in-flows to the disaster-affected coastline counties from these counties grew. Although this spatial concentration and intensification of flows was predicted by the principles of environmental migration, we did not expect to find the increased mobility within and between the disaster-affected coastline counties and the Gulf of Mexico coastal counties. This heightened mobility suggests that migratory churning is part of the recovery as the population adjusts to changed social, economic, political, and environmental structures in disaster-affected regions.

Climate-related environmental migration is inevitable as sea levels rise and weather becomes more variable. Our case study offers principles for predicting how the migration system absorbs migrants from disaster-affected counties that can guide planning for other large-scale population displacements. Applying this knowledge, the nearby and urban counties that are part of the migration system and are most likely to absorb migrants might develop plans for the provision of temporary housing, employment, and social services to minimize migrants' trauma and loss. Such plans should minimize competition between evacuees and receiving county residents for valued resources. From a community perspective, planning should ease the financial burden and diffuse the social costs incurred by receiving short distance, temporary in-migrants. By considering analogues for climate change, such as Hurricane Katrina's impact on the migration system of the most severely affected counties, we can develop more realistic and comprehensive scenarios of how climate change will affect human populations and settlements.

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Table 1. Number of unique and all out-ties and in-ties of disaster-affected coastline counties, IRS county-to-county migration flows data for tax filing years 2000-2005 (pre-disaster) and 2007-2009 (recovery)

Panel A: Number of Unique Ties	Out-Ties				In-Ties			
	Pre-disaster	Recovery	% Change		Pre-disaster	Recovery	% Change	
All counties	612	258	-57.84	*	457	442	-3.28	
Disaster-affected coastline counties	46	30	-34.78		46	30	-34.78	
Gulf of Mexico coastal counties	97	55	-43.30	*	72	96	33.33	
Other counties	469	173	-63.11	*	339	316	-6.78	
All counties (urban)	550	224	-59.27	*	395	402	1.77	
Disaster-affected coastline counties (urban)	45	29	-35.56		45	29	-35.56	
Gulf of Mexico coastal counties (urban)	77	41	-46.75	*	55	78	41.82	*
Other counties (urban)	427	153	-64.17	*	295	295	0.00	
Panel B: Number of All Ties	Out-Ties				In-Ties			
	Pre-disaster	Recovery	% Change		Pre-disaster	Recovery	% Change	
All counties	2,596	2,242	-13.64	*	2,556	2,551	-0.20	
Disaster-affected coastline counties	397	381	-4.03		397	381	-4.03	
Gulf of Mexico coastal counties	512	470	-8.20		500	524	4.80	
Other counties	1,687	1,391	-17.55	*	1,669	1,646	-1.38	
All counties (urban)	2,368	2,042	-13.77	*	2,338	2,345	0.30	
Disaster-affected coastline counties (urban)	383	367	-4.18		383	367	-4.18	
Gulf of Mexico coastal counties (urban)	413	377	-8.72		406	429	5.67	
Other counties (urban)	1,570	1,296	-17.45	*	1,549	1,549	0.00	

Notes: Differences estimated by two-sample difference in proportion test.
* $p < .05$

Table 2. Number of migrant households in out-flows and in-flows to disaster-affected coastline counties, IRS county-to-county migration flows data

Total Flow Size	Out-Flows			In-Flows		
(Number of Migrant Households)	Pre-disaster	Recovery	% Change	Pre-disaster	Recovery	% Change
All counties	131,411	137,424	4.58	121,310	144,854	19.41
Disaster-affected coastline counties	49,959	54,030	8.15	49,959	54,030	8.15
Gulf of Mexico coastal counties	28,711	31,338	9.15	23,727	30,864	30.08
Other counties	52,742	52,056	-1.30	47,624	59,960	25.90
All counties (urban)	126,576	132,684	4.83	116,920	140,062	19.79
Disaster-affected coastline counties (urban)	49,595	53,634	8.14	49,595	53,634	8.14
Gulf of Mexico coastal counties (urban)	26,018	28,587	9.87	21,079	27,969	32.69
Other counties (urban)	50,896	50,400	-0.97	46,247	58,459	26.41

Table 3. First-difference regression analysis of percent change in in-migration flows to disaster-affected coastline counties, IRS county-to-county migration flows data

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
	Total in-migration	Disaster-affected coastline counties	Gulf of Mexico coastal counties	Other counties	Total in-migration (urban)	Disaster-affected coastline counties (urban)	Gulf of Mexico coastal counties (urban)	Other counties (urban)
Treatment effect (β_1)	1.184** (0.057)	5.832** (1.132)	4.959** (0.863)	1.027** (0.051)	2.564** (0.121)	5.534** (1.372)	7.641** (1.114)	2.288** (0.113)
Constant (β_0)	-0.437** (0.027)	2.454** (0.313)	0.523 (0.610)	-0.569** (0.024)	-0.970** (0.057)	3.317** (0.449)	0.616 (0.712)	-1.259** (0.053)
Observations	497,440	16,512	8,928	472,000	224,692	10,468	6,704	207,520

Notes: Standard errors in parentheses. Models include controls for mean centered population at origin and destination. Geographic distance is differenced out by this modeling strategy.
Models 1, 5: Experimental group is flows from any/all counties to disaster-affected coastline counties (for i~=j) and the control group is flows from any/all counties to Gulf of Mexico coastal counties (for i~=j).
Models 2, 6: Experimental group is flows from disaster-affected coastline counties to disaster-affected coastline counties (i~=j). Control group is flows from Gulf of Mexico coastal counties to Gulf of Mexico coastal counties (i~=j).
Models 3, 7: Experimental group is flows from Gulf of Mexico coastal counties to disaster-affected coastline counties. Control group is flows from disaster-affected coastline counties to Gulf of Mexico coastal counties.
Models 4, 8: Experimental group is flows from other counties to disaster-affected coastline counties. Control group is flows from other counties to Gulf of Mexico coastal counties.
** $p < .01$

Table 4. Estimated mean percentage change between the pre-disaster and recovery periods in in-migration flows to the disaster-affected coastline counties (treatment group) and other Gulf of Mexico coastal counties (control group), IRS county-to-county migration flows data

	Origin Counties							
Destination Counties	Total in-migration	Disaster-affected coastline counties	Gulf of Mexico coastal counties	Other counties	Total in-migration (urban)	Disaster-affected coastline counties (urban)	Gulf of Mexico coastal counties (urban)	Other counties (urban)
Disaster-affected coastline counties	0.747	8.286	5.482	0.458	1.594	8.851	8.257	1.029
Gulf of Mexico coastal counties	-0.437	2.454	0.523	-0.569	-0.970	3.317	0.616	-1.259

Fig. 1. Change in size of in-flows to and out-flows from disaster-affected coastline counties before and after Hurricanes Katrina and Rita estimated by multiregional migration model

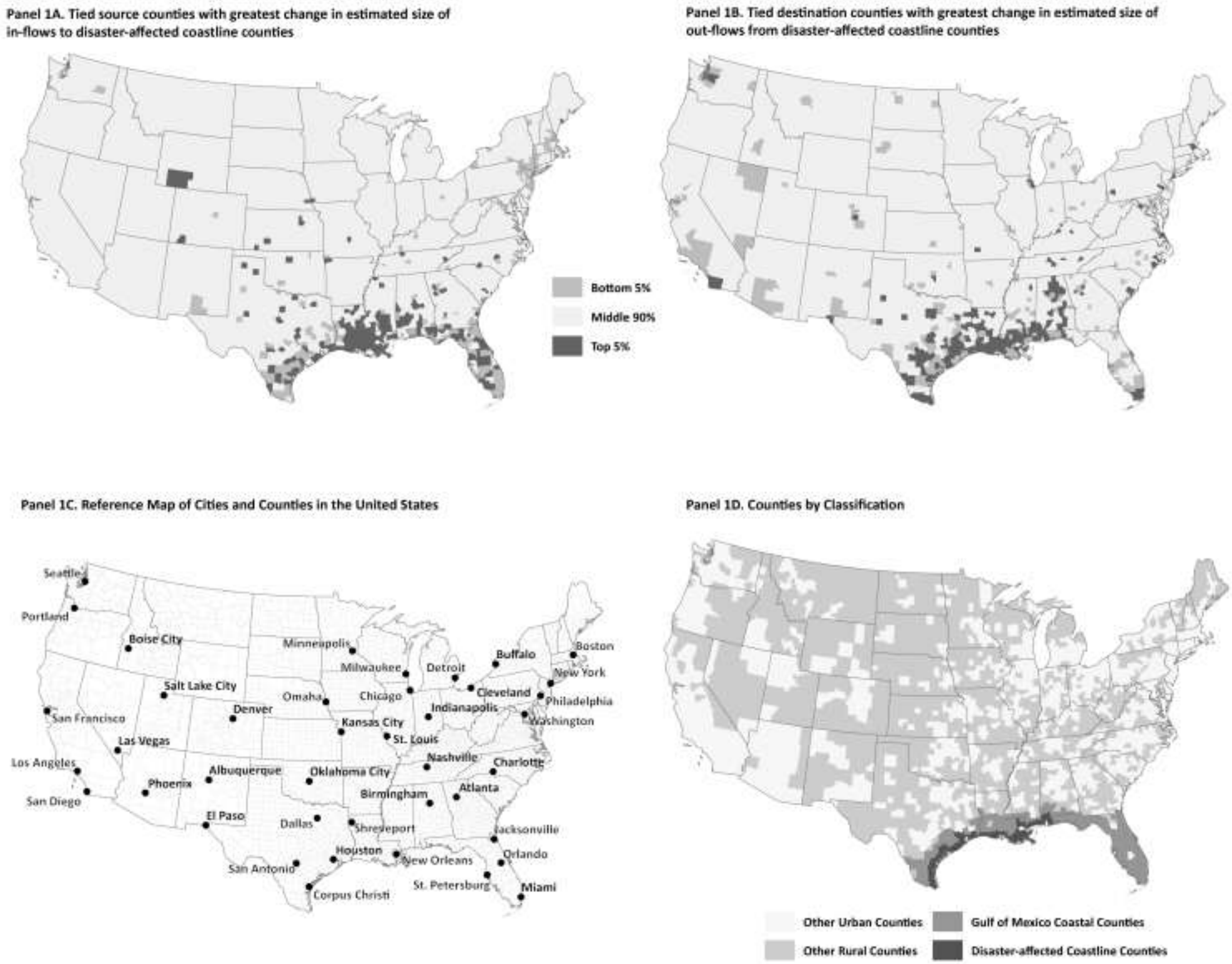

Fig. 2. Change in in-flows to disaster-affected coastal counties before and after Hurricanes Katrina and Rita